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Reserve system design for allocation of scarce medical resources in a pandemic: some perspectives from the field

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Abstract: Reserve systems are a tool to allocate scarce resources when stakeholders do not have a single objective. This paper introduces some basic concepts about reserve systems for pandemic medical resource allocation. At the onset of the Covid-19 pandemic, we proposed that reserve systems can help practitioners arrive at compromises between competing stakeholders. More than a dozen states and local jurisdictions adopted reserve systems in initial phases of vaccine distribution. We highlight several design issues arising in some of these implementations. We also offer suggestions about ways practitioners can take advantage of the flexibility offered by reserve systems.

Keywords: reserve system, categorized priority system, Covid-19, vaccine allocation, equitable allocation, ethical rationing, market design

JEL classification: D45, D47, I14

I. Introduction

In March 2020, at the beginning of the Covid-19 pandemic, Truog *et al.* (2020) wrote that 'never before has the American public been faced with the prospect of having to ration medical goods and services on this scale'. At that point, scholars in public health and medical ethics had written about the importance of recognizing competing goals in resource allocation, but they had rarely confronted the task of operationalizing these abstract principles at scale using a concrete allocation mechanism. The onset of the Covid-19 pandemic, together with renewed attention to concerns about societal inequality and discrimination, ushered in a large-scale reconsideration of rationing guidelines for scarce medical resources in pandemic situations.

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In Pathak *et al.* (2020*c*), we described several existing mechanisms proposed for the allocation of scarce ventilators and vaccines in pandemics. The most common system used for allocating ventilators and intensive care unit (ICU) beds was a priority point system, in which patients are rank-ordered using a priority score, often based on expected harm averted. Importantly, these systems use the same priority ranking of patients to allocate the entire supply of scarce interventions. For allocating vaccines, most existing guidelines also relied on priority mechanisms, but typically based on grouping individuals into several priority tiers. For example, the US Centers for Disease Control and Prevention (CDC)'s 2018 Influenza Vaccine guidelines placed patients into five tiers based on occupation and demographic factors, indicating their risk of contracting or spreading influenza. If there are insufficient vaccines for those in the first tier, that tier is further divided into seven groups, where everyone in the first subgroup precedes everyone in the second, and so forth. For tiers 2–5, all those in the same tier have equal priority. These priority systems require representing every ethically relevant attribute of a potential recipient on a single point or tier scale, irrespective of the distinct nature of different ethical goals.

A priority point or tier system unnecessarily restricts the ability of allocation planners to arrive at compromises because of its reliance on a single priority ranking for all units (Pathak *et al.*, 2020*c*; Sönmez *et al.*, 2021). Even if no compromises are needed, because priority point systems consider each individual candidate without regard to the make-up of the pool of ultimate recipients, they also prevent planners from ensuring that the ultimate recipients adequately represent various groups in the candidate population. As an alternative, we introduced the reserve system, which can also be interpreted as a categorized priority system. In a reserve system, the supply of the scarce medical resource is divided into multiple categories. Within each category, different criteria can be used for allocation. Multiple categories and category-specific allocation criteria allow for more flexibility in designing allocation mechanisms for crisis scenarios.

Our earlier work described how a reserve system can help to resolve debate about priority for essential personnel priority for ventilators. Many ethicists argue that essential personnel should receive priority for certain scarce interventions, based on the principles of instrumental value (their potential to better assist others if helped or promised help) and reciprocity (recognition of the burdens they have undertaken to combat the pandemic). However, prior to the Covid-19 pandemic, states such as New York and Minnesota gave up on essential-personnel priority in part due to concerns about extreme scenarios where health-care workers receive all available resources, leaving none for the rest of society. This concern was articulated in the 2015 New York State Ventilator Allocation Guidelines (Zucker *et al.*, 2015):

> Expanding the category of privilege to include all the workers listed above 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.

The challenge that stymied the Task Force, however, is not unique to essential-personnel priority. It is inevitable when allocators are constrained to rely on a priority system that allocates each and every unit based on identical criteria. In contrast, a reserve system enables allocators to give heightened priority to essential personnel for only some fraction of the total supply of ventilators. The remaining supply can be made available to all patients in need without consideration of occupational status. Limiting priority allocation of ventilators to essential personnel for only a subset of ventilators is a natural compromise.

These ideas apply not only to ventilators, but also for other scarce medical resources such as vaccines. During initial vaccine scarcity, the limitations of priority point and tier systems became apparent in public discussions about operationalizing equitable access for people of colour in vaccine distribution. These surfaced in uproar surrounding Vermont's plan to award Black adults and people from other minority communities priority status for vaccination in April 2021, and similar schemes in Montana and Utah (Economist, 2021). A reserve system offers an alternative when allocation planners wish to be responsive to additional challenges faced by hard-hit communities. For some portion of vaccine doses, heightened priority can be given to specific hard-hit groups. Depending on legal and ethical considerations, these may be defined by race or by other criteria such as social vulnerability (Schmidt *et al.*, 2020). The remaining portion can be allocated without reference to these factors.

Reserve systems have been used in a variety of real-life applications, especially in situations that involve widespread disagreements and extensive community engagement (see Table 1). The construction of reserve categories, the size of these categories, and the allocation criteria to be used within each category can all facilitate compromise between competing objectives. For example, India's affirmative action system adopted a reserve system after more than a decade of community involvement, summarized in the 1979 Mandal Commission Report and formulated in the landmark 1992 Indra Sawhney Supreme Court case (Sönmez and Yenmez, 2022). After Chicago Public Schools eliminated racial quotas in admissions for its selective high schools in response to changes in federal law, the district adopted an affirmative action system, using applicant residence as a factor. In this system, there is a reserve for applicants from each of four socioeconomic groups (Dur *et al.*, 2020). Following debates between pro-neighbourhood and pro-choice factions, Boston's school assignment system established a reserve where half of school seats prioritize applicants from the neighbourhood walk zone (Dur *et al.*, 2018). Reserve systems have also been used in medicine prior to the pandemic. The Organ Procurement and Transplantation Network introduced a reserve system for deceased-donor kidney allocation in 2014 following multiple years of community engagement. The new mechanism increases the role of medical benefit in the system and prioritizes 20 per cent of the highest quality kidneys for patients with the highest expected benefit (Israni *et al.*, 2014).

Even though, time and again, a reserve system has emerged as a tool for compromise, our research demonstrates that its properties are often not well understood by those who adopt or use them (Dur *et al.*, 2018, Pathak *et al.*, 2020*b*). This situation has in turn resulted in unintended policy implications, and even occasional reversal of intended policies in the field (Dur *et al.*, 2018; Pathak *et al.*, 2020*a*; Sönmez and Yenmez, 2022). Our work has therefore analysed the formal properties of reserve systems and extended them to more general environments which may rely on different criteria for allocation of units attached to different reserve categories (Pathak *et al.*, 2020*c*).

Table 1: Reserve systems in the field

Example	Year	Prioritization	Details
Deceased donor kidney allocation	2014-present	Post-transplant survival score	OPTN established 20% reserve for highest quality kidneys for patients with highest post-transplant survival score
H-1B Immigration Visas	2005-present	Lottery	65,000 general category, 20,000 advanced degree
London/Tokyo Marathons		Time+Lottery	Besides certain guaranteed groups, there is qualifying time prioritization. Then sequential lotteries within possibly overlapping group reserves for non-qualifiers are used.
Chicago Public Schools	2009-present	Test score	Four neighborhood reserve groups based on census tracts
Boston School Choice	1999-2014	Lottery	50% of school seats reserved for neighborhood applicants
NYC HS school assignment	2003-present	Lottery+Screened	One third of high schools are Ed-Opt with Low, Middle, and High reserves
NYC Diversity Plan	2018-present	Lottery	90 NYC public high schools and programs use a reserve
Chile Public Schools	2016-present	Screened	Reserve for Financially disadvantaged, Special needs, High-achieving students
Brazil College Admissions	2012-present	Various	Half of seats is reserve for public school graduates, of which half is reserved for low income students.
India Affirmative Action	1902-1950 (pre-constitution) 1950-present (constitutional)	Test score	All public universities and public sector jobs. 50% reserve for historically discriminated against groups.

A reserve system has the following features:

i. flexibility to accommodate multiple ethical goals;
ii. transparency in implementation through easy-to-understand reserve categories;
iii. ability to address group-specific considerations, such as those related to disadvantage or diversity;
iv. ability to give heightened priority to certain patient groups while ensuring that sufficient resources are available to others;
v. ability to accommodate incommensurable ethical values via separate categories;
vi. widespread usage in real-world situations that require a compromise;
vii. ability to easily adjust parameters over time, as evidence accrues about expected effects of different interventions;
viii. ability to allocate across multiple types of scarce interventions by allowing patients and/or their doctors to preference rank treatments. This may be particularly valuable if the relative benefits of treatments differ between groups.

II. Operationalizing ethical goals with a reserve system

In most reserve systems, the focus is on three critical policy levers: (i) the division of the total supply of resources into multiple categories, (ii) the size of each category, and the (iii) priority order within each category (Dur *et al.*, 2018, Dur *et al.*, 2020, Pathak *et al.*, 2020*a*, Pathak *et al.*, 2020*c*). Our earlier work highlights the importance of a fourth lever, which is how the reserve categories are processed. A reserve system must specify what happens when an individual qualifies for a unit through more than one reserve category. Even though individuals only care about whether they receive a unit, and not the category through which they do, the choice of which reserve category provides the unit typically influences the outcome for other individuals. Therefore, careful consideration of this aspect of a reserve system is needed to avoid unintended distributional consequences.

We next describe some principles and ideas about these policy levers and how they relate to several debates during various stages of the Covid-19 pandemic. A reserve category can be based on well-established ethical principles. One example is *priority* for the disadvantaged. Another important principle is *reciprocity* towards persons who accept risk for the common good of saving lives. Reciprocity is also closely related to the principle of *instrumental value*, which gives priority to those who can save others if helped (Emanuel *et al.*, 2020; White and Lo, 2020).

We describe four reserve categories, which we refer to as the *disadvantaged* category, the *instrumental value category,* the *open category*, and the *good Samaritan category*.

Public health emergencies can have differential impact across communities, and there are calls for rationing guidelines to respond to differential incidence. For example, there is strong evidence that specific groups, such as African-Americans, have suffered a disproportionate toll of deaths from Covid-19. These concerns have motivated criticisms of existing rationing guidelines. For example, shortly after Massachusetts released its revised crisis standards of care in April 2020, Manchanda *et al.* (2020) argued that they would exacerbate inequalities in expected health outcomes driven by social inequalities and discrimination in access to health care. Similarly, for vaccine allocation, Schmidt

(2020) argued that rationing guidelines should give priority to groups that have been structurally and historically disadvantaged. To accommodate these types of concerns, a portion of scarce resources could be set aside in the form of a *disadvantaged category* based on legally permissible measures of disadvantage.

An instrumental value category provides some form of priority to essential personnel such as frontline health workers during the pandemic. The priority order of patients typically differs between reserve categories. Therefore, a reserve category emphasizing instrumental value could place more weight on frontline health workers than other categories. In a reserve system, the extent to which policy-makers prioritize instrumental value is flexible. It could be a requirement for eligibility for a specific category, or it could be a secondary factor that plays a tie-breaker rule within a category. One example bases priority on clinical criteria only for a more inclusive *community* category. For the instrumental value category, the priority could use the same clinical criteria as in the community category, but give essential personnel absolute priority for these units. The clinical criteria would be used as a tie-breaker in this category.

Another possibility is to define categories using clinical criteria only, and simply use frontline health-worker status as a tie-breaker. This example is similar to an idea explored in the University of Pittsburgh's system for ventilator rationing (White *et al.*, 2020). Although there is no reserve, the priority score uses Sequential Organ Failure Assessment (SOFA) score and comorbidities. Life-cycle and instrumental considerations shape the tie-breakers:

> In the event that there are 'ties' in priority scores/categories between patients and not enough critical care resources for all patients with the lowest scores, life-cycle considerations should be used as the first tiebreaker, with priority going to younger patients. We recommend the following categories: age 12–40, age 41–60, age 61–75, older than age 75. We also recommend that individuals who are vital to the acute care response be given priority, which could be operationalized in the form of a tiebreaker.

The Pittsburgh system illustrates that preferential treatment for medical personnel can be modest—it is only a tie-breaker—whereas the primary ethical consideration is direct medical benefit. The Pittsburgh system, however, suggests the value of a reserve system, given that its designers hesitated recommending a single tie-breaker. Instead, the guideline suggests utilization of either age or essential-personnel status as a tie-breaker. Apparently, the designers saw direct medical benefit as more important than either indirect benefit (the instrumental value principle) or fairness to people who have not had the same opportunity to live through life's stages (the life-cycle principle). On the other hand, the designers hesitated to make a definitive choice between these two ethical values in the event of tie-breaking. In contrast, a reserve system offers flexibility to use one of these tie-breakers in one of the categories and the other in another category.

The next category we consider is an *open category* which is broadly available to all (or almost all) patients. Fink (2020) cites a British researcher of the 2009 H1N1 flu pandemic cautioning that when a group of patients is excluded, 'at the end you have got a society at war with itself. Some people are going to be told they don't matter enough'. Exclusion criteria are subject to contentious debate in rationing plans. Several state protocols, such as those of Indiana, Kansas, South Carolina, and Tennessee, initially excluded certain groups of patients for rationing of ventilators (Guterl, 2020). White and Lo (2020) have challenged exclusion criteria stating:

> This violates the principle of justice because it applies additional allocation criteria to some patients but not others, without making clear what is ethnically different about the patients that would justify doing so. Categorically excluding patients will make many feel their lives are 'not worth saving,' which may lead to perceptions of discrimination.

They argue that 'morally irrelevant' considerations, such as sex, race, religion, intellectual disability, insurance status, wealth, citizenship, social status, or social connections, should not be used in rationing.

Disability advocates have been particularly active in voicing opposition to allocation plans that are based purely on expected medical benefit. Ne'eman (2020) argues that not treating people differently based on medical differences should be seen as an end in and of itself and can justify saving fewer lives. He also posits that provisions that exclude certain groups can undermine overall trust in the medical system 'based on a well-founded fear of being sacrificed for the greater good'.

A reserve system offers a potential path forward between these different points of view. An open category could allow a portion of scarce units to be available to all patient types, irrespective of expected benefit or expected harm averted.

In contrast to the potential disadvantaged, instrumental value, or open categories, a potential *good Samaritan reciprocity category* may be more controversial with ethicists, though not necessarily with the general public. Emanuel *et al.* (2020) recommend priority for frontline health workers because it provides incentives and recognizes their high-risk responsibilities: 'but giving them priority for ventilators recognizes their assumption of the high-risk work of saving others, and it may also discourage absenteeism.'

Consider a hypothetical good Samaritan reciprocity category that promises a small fraction of scarce resources to those who have saved lives through their past good Samaritan acts. These could be participants for clinical trials of potential vaccines or treatments, altruistic donors who have donated their kidneys to a stranger, or people who have donated large quantities of blood over the years. Good Samaritan status can also be provided for compatible patient/donor pairs who voluntarily participate in kidney exchange even though they do not have to, and save the life of another patient who was incompatible with his/her donor. For example, Sönmez *et al*. (2020) show that 180 additional kidney patients can receive living donor transplants in the US for every 10 per cent of compatible pairs who participate in kidney exchange. A state task force can determine which acts 'deserve' a good Samaritan status. The mere existence of a modest reserve of this nature may mitigate more persistent and ongoing crises in other healthcare domains by creating incentives to help in ameliorating scarcity.

III. Incentive considerations in design of reserve systems

Our hypothetical good Samaritan reciprocity category illustrates that in addition to accommodating various ethical principles, the choice of reserve categories may incentivize good deeds. Indeed, this form of incentivization could even serve as the primary role of some reserve categories. For example, during early phases of the Covid-19 pandemic, when donated convalescent plasma was used as a therapy, Kominers *et al.* (2020) advocated for reserving a fraction of donations for families of the donors, thereby removing potential disincentives for donation.

Use of resource allocation mechanisms to incentivize individuals in a way that mitigates various healthcare crises is not new. For example, Tabarrok (2002) argued for a 'no give, no take' organ transplants system in which people who had signed their organ donor cards would be given priority should they one day need an organ. While this idea is also consistent with the ethical principle of reciprocity, its primary goal is to increase the incentive to sign one's organ donor card. Versions of this policy have been adopted in Singapore in 1987 (Iyer, 1987), in Israel in 2008 (Lavee *et al.*, 2010), in Chile in 2013 (Zuniga-Fajuri, 2015), and in China in 2018 (Kim *et al.*, 2021).

Along similar lines, and also to protect access to medical services during surges of hospitalized unvaccinated Covid-19 patients, some have advocated using vaccination status as a factor for allocation of scarce healthcare resources (Brown, 2021). On the other hand, others disagree with this perspective based on ethical considerations (Schuman *et al.*, 2021). A reserve system that considers vaccination status only for a fraction of the scarce healthcare resources can be used as a compromise between these opposing perspectives. In Persad *et al.* (2022), we make a conceptually related proposal where a fraction of the scarce healthcare resources are reserved for non-Covid-19 patients. A non-Covid-19 reserve is not based on vaccination status, avoiding legal problems in jurisdictions where considering vaccination status is prohibited, and not presenting the ethical problems some have raised regarding the use of vaccination status in triage.

IV. Importance of processing order

We now elaborate on the importance of the last policy lever in a reserve system: how reserve categories are processed. Two modes of implementation are common for reserve systems in the field. In an over-and-above implementation, reserve categories are processed after an open category. Over-and-above implementations are best suited for situations that warrant an extra boost. In a minimum-guarantee implementation, in contrast, reserve categories are processed prior to the general open category. The minimum-guarantee implementation provides a lower ceiling of benefit compared to the over-and-above implementation, and may provide no benefit at all if the target minimum is already reached in the absence of the reserve (i.e. the protected group would receive their fair share even without a reserve category). Minimum-guarantee implementations set a floor on how few resources a group receives, and so are best suited for situations where reserves are seen as providing a protective measure.

To illustrate the significance of the processing order of reserve categories, imagine a simple scenario in which there are 100 units of ICU beds to ration. Suppose a medical ethics committee decides that there are two important principles: maximizing the number of lives saved by ICU beds and prioritizing essential medical personnel. Based on their view, they define a reserve category for essential medical personnel, which reserves 20 per cent of ICUs for them. Within this reservation, allocation is based on a score that measures the expected harm averted. The remaining 80 per cent of ICUs are open to all patients, including essential personnel. These are also allocated via expected harm averted. Suppose that there are 80 essential personnel who need an ICU and 120 other patients from the general community who also do. For simplicity, assume that patient scores for expected harm averted are uniformly distributed in a given interval for both patients from essential personnel and from the general category. We illustrate the ICU supply and the two patient groups in Figure 1.

For a baseline comparison, first consider a scenario where there is no priority for essential personnel, and all ICUs are allocated based on expected harm averted. Since the distribution of patient scores is identical for the two groups of patients, in this scenario 40 units are allocated to essential personnel and 60 units are assigned to other patients from the general community (Figure 2).

As a second baseline comparison, next consider a scenario where there is absolute priority for essential personnel, and within each group units are allocated based on expected harm averted. In this scenario, the first 80 units are assigned to essential personnel as tier 1 patients, and the remaining 20 units are assigned to other patients from the general community (Figure 3).

In our third scenario, ICUs are allocated with an over-and-above version of the reserve system, where 20 per cent of the units are reserved for essential personnel and 80 per cent are open for all patients. Within each category, units are allocated to eligible patients based on expected harm averted. In the first step of this scenario 80 open units are allocated. Since the distribution of patient scores are identical for the two groups of patients, in this step 32 units (i.e. 40 per cent of 80 units) are allocated to essential personnel and 48 units (i.e. 60 per cent of 80 units) are assigned to other patients from the general community. In the second step of this scenario all 20 units in the essential personnel category are allocated to essential personnel. In total, 52 units are allocated

Figure 1: Intensive care units and patients

Figure 2: No priority for essential personnel

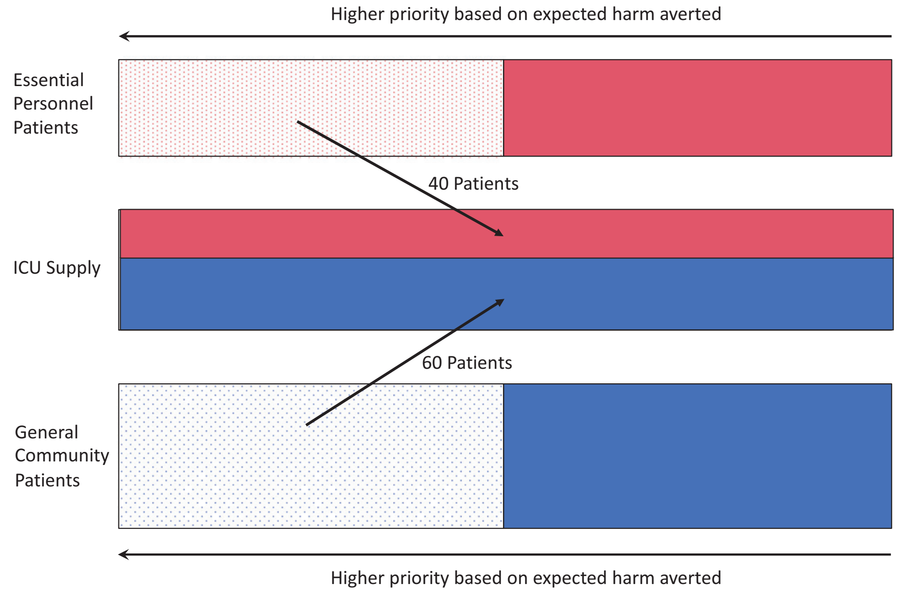


Figure 3: Absolute priority for essential personnel

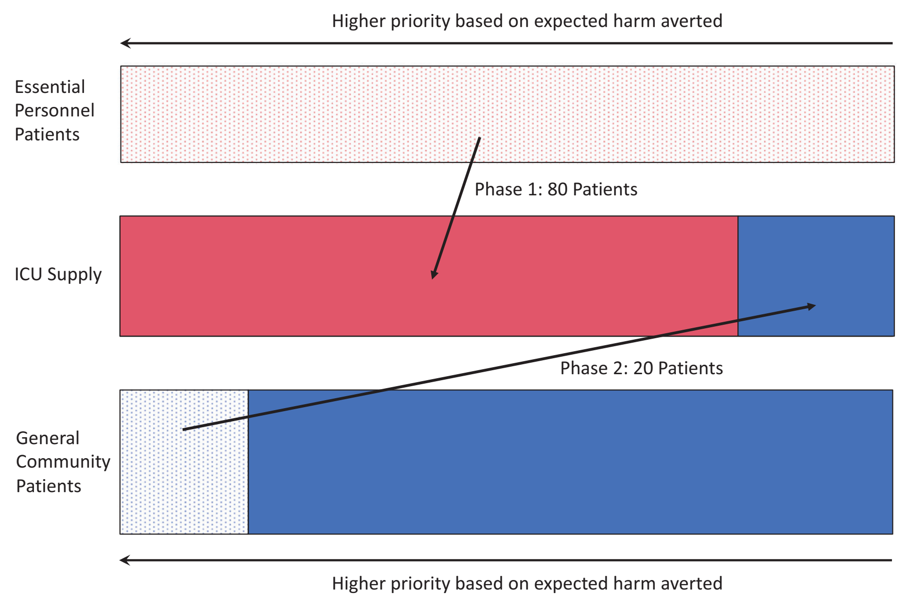
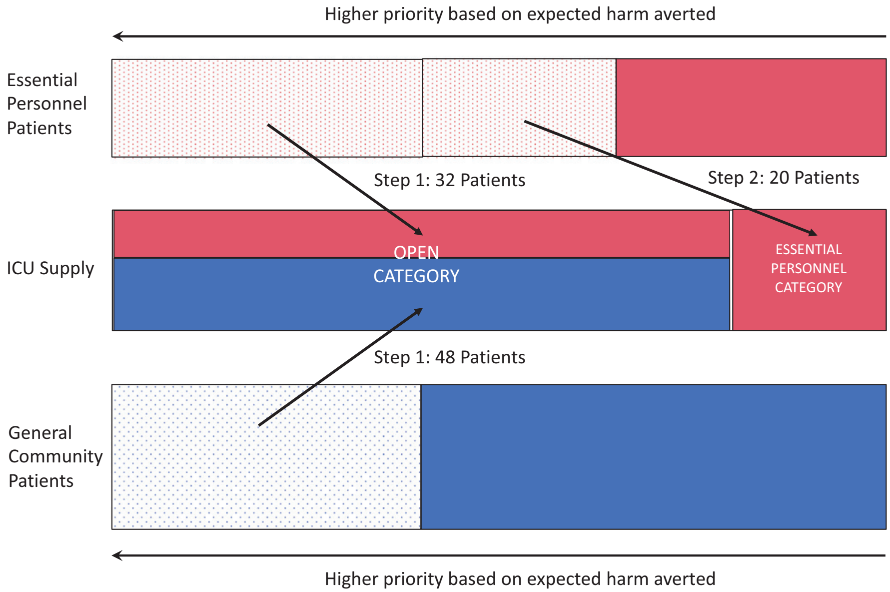


Figure 4: Over-and-above reserve system: 80 open category; 20 essential personnel category

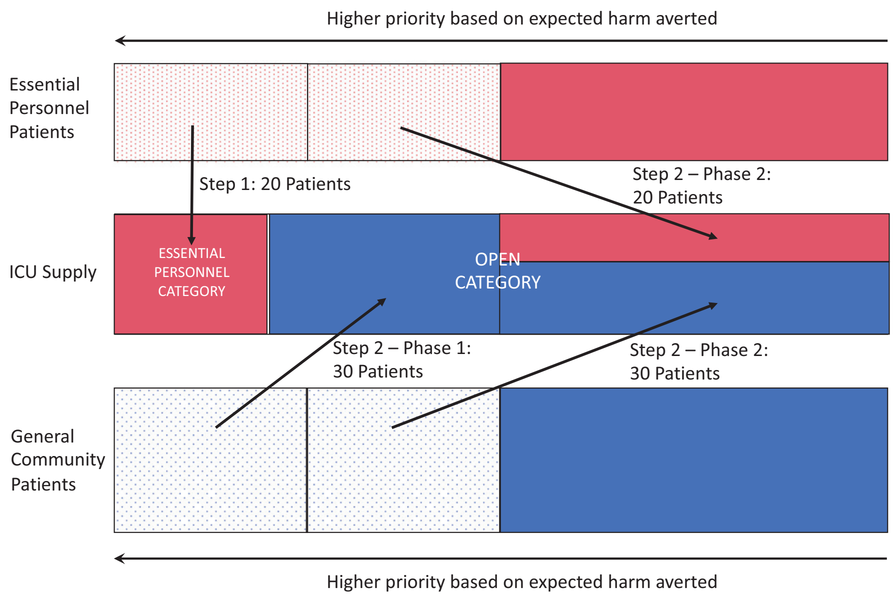


to essential personnel and 48 units are allocated to other patients from the general community (Figure 4).

In our final scenario, ICUs are allocated with a minimum-guarantee version of a reserve system where 20 per cent of the units are reserved for essential personnel and 80 per cent is open for all patients. Within each category, units are allocated to eligible patients based on expected harm averted. In the first step of this scenario, 20 units in the essential personnel category are allocated to 20 essential personnel with the highest scores. Subsequently in step 2 the 80 open units are allocated to all remaining patients with the highest scores. However, since the 20 highest-scoring essential personnel already received units in Step 1, there are 30 patients from the general population in the remaining pool whose scores are higher than the score of any essential personnel. Therefore, the first 30 open units are allocated to these individuals in what can be thought of as Phase 1 of Step 2. At this point the distributions of the scores of remaining patients becomes identical for the two groups again, and hence 20 units (i.e. 40 per cent of the remaining 50 open units) are allocated to essential personnel whereas 30 units (i.e. 60 per cent of the remaining 50 open units) are allocated to other patients from the general community. In total, 40 units are allocated to essential personnel and 60 units are allocated to other patients from the general community (Figure 5).

In this simple example, the choice of the processing sequence of categories is a matter of potential life or death for 12 essential medical personnel and 12 members of the general community. It is also illustrative to note that the outcome in this example under the minimum-guarantee version of the reserve system is identical to the first baseline scenario where there is no reserve for the essential personnel, illustrating that the minimum-guarantee implementation of a reserve system may provide no benefit at all to its intended beneficiary group if the target minimum is already reached in the absence of the reserve.

Figure 5: Minimum guarantee reserve system: 20 essential personnel category; 80 open category



V. From theory to practice

Following our proposal in Pathak *et al.* (2020*c*), we initiated a collaboration with several scholars in public health and introduced the concept of a reserve system to the field for pandemic medical rationing. The fruits of our outreach are reflected in the fact that several other scholars in public health, including Schmidt (2020), Galiatsatos *et al.* (2020), and Persad *et al.* (2020) either endorsed or saw potential in the reserve system idea. Initially, we focused on ventilators, but the attention rapidly turned to therapeutic agents and vaccines.

The most significant effort that led to widespread adoption of the reserve system for vaccine rollout involves the Framework for the Equitable Allocation of Covid-19 Vaccines drafted by a distinguished committee of experts from the National Academies of Sciences, Engineering, and Medicine (NASEM). The reserve system was brought to their attention after inquiries by Professor Harald Schmidt about how the committee intended to recognize the concerns of hard-hit communities following the circulation of their draft proposal in July 2020.

In Pathak *et al.* (2020*d*), we illustrated how a traditional tiered priority system, like the one used in the 2018 CDC guidelines, could be easily modified as a reserve system, by building equity into the system through an index of disadvantage. Our proposal was inspired in part by our earlier study of Chicago Public Schools' reserve system in its place-based affirmative action system (Dur *et al.*, 2020). In that system, six attributes of an applicant's census tract, each of which proxies for disadvantage, are combined into a single index of disadvantage. This index is then used to partition the students into four distinct tiers. At each of the Chicago's 11 selective exam schools, there is an equal-size reserve for applicants from each tier. Likewise, a place-based index, such as the Area

Deprivation Index or the CDC's Social Vulnerability Index (SVI), could be used as the basis for assigning individuals to reserve groups.

NASEM's final framework, issued in October 2020, recommended a reserve for hard-hit areas. The reserve size is 10 per cent. Hard-hit is defined as being in the top (most disadvantaged) quarter of the SVI in the state. The NASEM's guidelines influenced those used by several states and jurisdictions. Pathak *et al.* (2021) describe some reserve systems adopted during the initial phases of the Covid-19 vaccine rollout.

Real-life adoption of reserve systems for vaccine distribution took advantage of the flexibility in choosing between the over-and-above and the minimum-guarantee forms of processing reserve categories (see Table 2). Several state vaccine allocation guidelines emphasized the need to address the disproportionate Covid-19 burden of certain communities. As a result, they employed over-and-above reserve systems for their hard-hit communities. For example, Massachusetts's plan describes a 20 per cent reserve for hard-hit areas, and advocates for allocation within communities based on prioritization guidelines that closely follow the NASEM guidelines. The use of an over-and-above implementation for hard-hit areas is consistent with a solution that warrants an extra boost.

Other states announced systems that used the minimum-guarantee implementation. For example, in February 2021, Connecticut announced a 25 per cent community-level reserve based on measures of high social vulnerability, formulated as a minimum guarantee. Pennsylvania's January 2021 system had a 10 per cent minimum-guarantee reserve for health care personnel unaffiliated with a hospital system. These minimum-guarantee implementations meant that the reserves were designed to ensure that these groups did not receive fewer vaccines than their representation in the population.

Real-life implementations also took advantage of category-specific prioritization. In Pathak *et al.* (2020*c*) we analysed a benchmark environment where there is an open category with an underlying baseline priority order. Any other category provides preferential treatment to a beneficiary group, where the beneficiaries of the category are prioritized over non-beneficiaries and the baseline priority order is used only to break ties within group. Rationing systems in Richmond, Virginia and Washington, DC, however, did not use this canonical structure. In Richmond, 50 per cent of vaccines were reserved for age 65+, 23 per cent for frontline essential personnel, 23 per cent for people in age 16–64 with comorbidities, and the remaining 4 per cent are reserved for people living in congregate care-settings and Phase 1a-eligible but as yet unvaccinated people. Category-specific criteria are used within each of these reserve groups (Richmond City, 2021). In Washington DC's March 2021 vaccine rollout system, an equal one-fifth allotment was reserved for the following four groups: 65+ living in prioritized zip codes, 65+ living in any zip code, age 18–64 with qualifying medical conditions in prioritized zip code, and age 18–64 with qualifying medical conditions in any zip code. The remaining 20 per cent are reserved for eligible workers in age group 18–64 in prioritized zip codes and in any zip code (10 per cent each).

While Covid-19 vaccines are not currently scarce in the United States, possibilities for using reserve systems to more effectively allocate vaccines still exist. Vaccine manufacturers have indicated that the supply of these boosters may initially fall short of demand, and planners will face the question of how to fairly decide who should receive an Omicron-specific vaccine first. Some of the same factors, such as health worker status

Table 2: Some of the officially reported reserve systems for vaccine allocation in the US

Jurisdiction	Date	Reserve Policy
California	March 2021	· 40% of vaccines are reserved for communities in the hardest-hit/most socially vulnerable quartile, 20% are reserved for each remaining quartile.
		· Within each quartile, 70% of vaccines are reserved based on age eligibility, 30% are reserved for sector eligibility.
Chicago, IL	March 2021	· Some appointments are reserved in an over-and-above form for residents of hard-hit/socially vulnerable communities.
Colorado	March 2021	· 15% of vaccines are reserved in an over-and-above form for hard-hit/socially vulnerable communities.
Connecticut	February 2021	· 10% of vaccines are reserved in an over-and-above form for hard-hit/socially vulnerable communities.
	March 2021	· 25% of vaccines are reserved in a minimum guarantee form for communities that have high social vulnerability.
Illinois	March 2021	· 300-500 weekly doses are reserved in an over-and-above form for each of nine sites serving hard-hit communities.
Maryland	March 2021	· Hard-hit/socially vulnerable communities are bundled in five groups and 2,100 weekly doses are reserved in an over-and-above form for each of the five groups.
Massachusetts	December 2020	· 20% of vaccines are reserved in an over-and-above form for hard-hit/socially vulnerable communities.
New Hampshire	January 2021	· 10% of vaccines are reserved in an over-and-above form for hard-hit/socially vulnerable communities
New Mexico	March 2021	· 25% of vaccines are reserved for hard-hit/socially vulnerable communities.
New York City, NY	January 2021	· Some hours and appointments are reserved in an over-and-above form or residents of 33 high-risk communities.
North Carolina	January 2021	· An over-and-above reserve is used for counties to account for larger historically marginalized populations and larger populations over age 65.
	March 2021	· 3% of vaccines are reserved for long-term care settings, state facilities, and community vaccination events.
Pennsylvania	January 2021	· 10% of vaccines received by each health-care provider are reserved in a minimum guarantee form for Phase-1A non-hospital affiliated health care personnel.
Richmond & Henrico, VA	March 2021	· In Phase 1B allocation, 50% of vaccines are reserved for people 65 and older, 23% are reserved for frontline essential personnel, 23% are reserved for people in age-group 16-64 with comorbidities, and the remaining 4% are reserved for people living in congregate-care setting and Phase-1A-eligible but yet unvaccinated people.
		· Within each category, preregistered individuals are prioritized using category-specific criteria.
Tennessee	October 2020	· 5% of vaccines are distributed equitably among all counties.
		· 10% are reserved in an over-and-above form for hard-hit/socially vulnerable counties.
		· The remaining 85% are distributed according to population among all counties.
	December 2020	· The hard-hit/socially vulnerable reserve is decreased to 5%.
Washington, DC	March 2021	· 20% of vaccines are reserved for people 65 and older who living in prioritized zip codes and 20% of the vaccines are reserved for people 65 and older in any zip code.
		· 20% of vaccines are reserved for people in the age-group 18-64 with a qualifying medical condition living in prioritized zip codes and 20% of vaccines are reserved for people in the age-group 18-64 with a qualifying medical condition living in any zip code.
		· 10% of vaccines are reserved for eligible workers in the age-group 18-64 living in prioritized zip codes and the remaining 10% of vaccines are reserved for eligible workers who are in the age-group 18-64 living in any zip code.

Notes: Extended version of the tables in Pathak *et al.* (2020c) and Pathak *et al.* (2021).

or high-risk health conditions, are likely to remain relevant, but new ethical challenges will also arise: for instance, is it fair to prioritize those who remained unvaccinated by choice for access to the 'better' Omicron-specific vaccine over those who followed CDC guidance and became vaccinated and boosted? What about people with conditions that make them more vulnerable to Covid-19, but also make them less likely to respond to vaccines? A reserve system could help operationalize approaches to these challenges.

Globally, many middle-income countries may roll out vaccine boosters with a limited and more varied vaccine supply than the US (which has primarily relied on mRNA vaccines). These boosters may differ in efficacy, with mixing and matching boosters likely to be more effective than boosting with the same vaccine (Jara *et al.*, 2022). A reserve system could help allocators in directing different types of boosters to particular groups.

VI. Conclusion

Our reserve system proposal is most relevant to scenarios where demand far outstrips supply. This is only a small part of the larger task of enabling fair access to and effective uptake of medical interventions. For instance, as vaccine supply expanded, other barriers to increased vaccination uptake became more apparent and required a different set of tools beyond what a reserve system can provide. At the same time, other medical interventions—such as monoclonal antibodies and oral antivirals—have remained scarce and a reserve system could help in fairly and effectively allocating these as well. Rubin *et al.* (2021) describes the use of a reserve system for allocation of monoclonal antibodies in Massachusetts, developed based on our partnership with the medical community.

Determining who should receive a scarce medical resource in pandemic situations is not an enviable task for an individual or a rationing committee. In collaborations between economists and allocation planners, we have found it valuable to understand the goals and objectives of stakeholders without necessarily challenging the underlying motivations for these objectives. The framework we've proposed involves economists taking a supporting position to help implement abstract principles and offering tools that enable compromises when there is no universally endorsed answer. We believe the rapid and widespread adoption of reserve systems for vaccine distribution demonstrates the merits of this approach.

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