Minimalist Market Design: A Framework for Economists with Policy Aspirations

Tayfun Sönmez*

February 2023

This monograph is dedicated to

the loving memory of my soulmate Banu Bedestenci Sönmez,
who left her homeland behind so that I could pursue my policy aspirations as a design economist,
and
William Thomson, who gave me the gift of rigor

*Department of Economics, Boston College, email: sonmezt@bc.edu. This draft is the first version of a manuscript which will evolve into a monograph that describes the philosophy and policy impact of my minimalist approach to market design. This monograph or my approach itself would not exist without the sacrifices of my beloved wife Banu Bedestenci Sönmez, whom we lost to cancer in August 2016. As critical was the guidance of my PhD advisor William Thomson. Banu left our homeland Turkey behind in 2004, sacrificing her career and social life, so that I could pursue my policy aspirations in school choice and kidney exchange in the US. William, on the other hand, is the only reason I was able to achieve any academic feat in the first place. Not only I aspire to achieve his standards of clarity and rigor, but I also inherited his passion for the axiomatic methodology. I had the privilege of collaborating with a large number of brilliant researchers. Naturally my approach to market design benefited from these experiences. Above all, my long-term collaborations with Parag Pathak and Utku Ünver deeply shaped how I think about market design at its most fundamental level. These two amazing people also stuck with me through thick and thin. I am deeply grateful to them for never leaving me alone in my personal and professional quest. Other researchers who had notable contributions to various aspects of either the minimalist approach itself or this manuscript include Tommy Andersson, Philippe van Basshuysen, Eric Budish, Sylvain Chassang, Federico Echenique, Zoë Hitzig, Matthew Jackson, Scott Duke Kominers, Shengwu Li, and Alex Teytelboym. I am grateful to these brilliant researchers. Finally I thank Inácio Bó, Nicolas Brisset, Oğuzhan Çelebi, Andrew Copland, Pietro Dall'Ara, Piotr Dworczak, Aytek Erdil, Joe Quinn, David Levine, Arthur Lewbel, Steven Postrel, Alex Rees-Jones, James Schummer, Ran Shorrer, Joel Sobel, Rakesh Vohra, and Glen Weyl for their detailed comments which significantly improved the content and exposition of the manuscript.

Abstract

Earlier in my career, prevalent approaches for the emerging field of market design largely represented experiences and perspectives of leaders of the field who were *commissioned* to design or reform various institutions. Since I was unlikely to be commissioned for any similar task anytime soon as an *aspiring* design economist, I developed my own minimalist approach to market design. Using the policy objectives of stakeholders, my approach creates a new institution from the existing one through a minimal interference with its elements that compromise the objectives. Minimalist market design initially evolved through my integrated research and policy efforts in school choice from 1997 to 2005, and in kidney exchange from 2003 to 2007. Given its success in school choice and kidney exchange, since then I systematically followed this approach in many other and often unusual real-world settings. In recent years, my efforts through minimalist market design lead to the 2021 reform of the US Army's branching system of its cadets to military specialties, and to the adoption of reserve systems during Covid-19 pandemic for allocation of vaccines in 15 states and therapies in 2 states. The same methodology also predicted the rescission of a 1995 Supreme Court judgment in India which resulted in countless litigations and interruption of public recruitment for 25 years, as well as the mandates of its replacement. In this monograph, I describe the philosophy, evolution, and the successful applications of minimalist market design, and contrast it with the mainstream paradigm for the field. In doing so, I also provide a paradigm for economists who want to influence policy and change institutions with their research.

Contents

1 Introduction **6**

1.1 Mainstream Paradigm for Market Design 7

1.2 An Alternative Paradigm: Minimalist Market Design 11

1.3 Commissioned vs. Aspired Market Design 14

1.4 Roadmap for the Rest of the Manuscript 16

2 Advice for an Aspiring Market Designer **17**

2.1 A Classification of Market Design Applications 18

2.2 A Guide on Execution of Minimalist Market Design 19

3 Evolution of Minimalist Market Design: School Choice **25**

3.1 Research and Policy Efforts on Turkish College Admissions 25

3.1.1 No Justified Envy 26

3.1.2 Multi-Category Serial Dictatorship vs Student-Optimal Stable Mechanism 27

3.1.3 Theoretical Dominance of the Student-Optimal Stable Mechanism . 28

3.1.4 Failed Policy Attempt in Turkey and Lessons Learned 28

3.2 Initial Research on School Choice 30

3.2.1 A Pareto Efficient Alternative to SOSM: Top Trading Cycles Mechanism 31

3.2.2 Boston Mechanism 32

3.3 Policy Impact at Boston Public Schools 35

3.3.1 Boston Globe Story on Abdulkadiroğlu and Sönmez (2003) 35

3.3.2 Collaboration with Officials at Boston Public Schools 36

3.3.3 2005 School Choice Reform at BPS 37

3.4 External Validity for Minimalist Market Design: School Choice Reforms in England and Chicago 39

3.4.1 2007 Ban of the Boston Mechanism in England 40

3.4.2 2009 School Choice Reform at Chicago Public Schools 41

3.5 Contrast with 2003 School Choice Reform at New York City 42

4 Kidney Exchange **43**

4.1 Paired Kidney Exchange and List Exchange 44

4.2 Relation to Abdulkadiroğlu and Sönmez (1999) 45

4.3 First Kidney Exchange Model in Roth, Sönmez and Ünver (2004) 46

4.4 Second Model in Roth, Sönmez and Ünver (2005b) and Establishment of New England Program for Kidney Exchange 48
4.5 Tinkering Phase: Three-Way Exchanges and NDD-Initiated Chains 50
4.6 Contrast with 2005 School Choice Reform in Boston 52

5 US Army's Branching Process 52
5.1 My Introduction to US Army's Branching Process 53
5.2 History of Branching Process and the BRADSO Incentive Program 54
5.3 Alternative Mechanism by Switzer (2011) 57
5.4 Relation to Matching with Contracts and Cadet Optimal Stable Mechanism 58
5.5 Failure of Efforts to Reform the USMA-2006 Mechanism 59
5.6 Talent-Based Branching Program and the Redesign of US Army's Branching System 60

6 Formulation and Implementation of Normative Criteria: Equitable Allocation of Public Positions in India 63
6.1 Affirmative Action in India 63
6.2 Vertical Reservations, Migration and the Over-and-Above Choice Rule . . . 64
6.3 Horizontal Reservations and Adjustments 66
6.4 Failures of the SCI-AKG Choice Rule and Its Minimalist Correction 68
6.5 External Validity for the Minimalist Approach by the Supreme Court of India 70

7 Pandemic Medical Resource Allocation During Covid-19 71
7.1 The Toughest Triage 72
7.2 Advocacy of Pandemic Reserve Systems in Pathak et al. (2020d) 74
7.2.1 A Generalized Reserve System to Balance Various Ethical Principles 75
7.2.2 Maintaining Informed Neutrality Between Reasonable Normative Principles 76
7.3 Teaming Up with Three Leaders in Bioethics 77
7.3.1 Policy Impact on Allocation of Covid-19 Therapies in Pennsylvania . 80
7.4 Policy Impact During the Covid-19 Vaccine Rollout 80
7.4.1 Debates in the US on Priorities for the Covid-19 Vaccine 81
7.4.2 NASEM Framework for Equitable Vaccine Allocation 82
7.4.3 States and Cities which Adopted a Reserve System for Various Phases of the Vaccine Rollout 83
7.5 Policy Impact on Allocation of mAb Therapies in Massachusetts 85

8 Contrasts with Paradigms based on Mechanism Design **87**
8.1 The Role of Private Information and Incentive Compatibility 89
8.1.1 Dominant Strategy Incentive Compatibility vs. Strategy-Proofness . 89
8.1.2 Role of Private Information in Traditional Mechanism Design 90
8.1.3 Role of Private Information in Minimalist Market Design 90
8.2 The Role of Non-Utilitarian Principles 91
8.2.1 Transparency 91
8.2.2 The Role of Normative Economics and Informed Neutrality Between Reasonable Ethical Principles 92
8.2.3 Algorithmic Bias and Normative Gap 93
8.3 Is Design Economics a Form of Social Engineering? 95
8.4 Identity of a Design Economist and the Role of Theory 96

9 Conclusion **98**

1 Introduction

Starting with the first spectrum auction of the Federal Communication Commission (FCC) in 1994,[1] last three decades witnessed the emergence of the field of *market design*; a field where researchers in auction theory and matching theory have been playing increasingly active roles in the design and redesign of economic and social institutions. Over the next decade, other prominent applications of the emerging field included the redesign of the entry-level matching market for medical doctors in the US (Roth and Peranson, 1999), the redesign of the school choice mechanisms in Boston and New York City (Abdulkadiroğlu and Sönmez, 2003; Abdulkadiroğlu et al., 2005a,b), and the design of a kidney exchange clearinghouse in New England (Roth et al., 2004, 2005a,b). Subsequently, the increasing role of market design in mainstream economics was reaffirmed when Alvin Roth shared the 2012 Sveriges Riksbank Prize in Economic Sciences in Memory of Alfred Nobel with Lloyd Shapley for their contributions on "Stable Allocations and the Practice of Market Design," Parag Pathak received the 2018 Clark Medal for his contributions on market design and economics of education, and Paul Milgrom and Robert Wilson shared the 2020 Sveriges Riksbank Prize in Economic Sciences in Memory of Alfred Nobel for their "Improvements to Auction Theory and Inventions of New Auction Formats." According to Jackson (2013), "this is an area where microeconomic theory has had its largest direct impact."

How did market design come to directly affect policy in a wide range of important areas? Which factors and research paradigms contributed to its success? How can its policy relevance and effectiveness can be further increased?

In his 1999 *Fisher-Schultz Lecture*, Nobel laureate Alvin Roth provided his vision on these questions and made the following call:

> "Whether economists will often be in a position to give highly practical advice on design depends in part on whether we report what we learn, and what we do, in sufficient detail to allow scientific knowledge about design to accumulate."
>
> Roth (2002)

In this manuscript I respond to Roth's call, and based on my experiences over the last 25 years, I offer my somewhat unorthodox perspective on some of the factors which contributed to the success of the field. In sharing my experiences and personal perspective on

[1] Key figures in the design of FCC's spectrum auction includes many auction theorists John McMillan as a consultant for the FCC, Paul Milgrom and Robert Wilson as consultants for Pacific Telesis, and Preston McAfee as a consultant for AirTouch Communications (McMillan, 1994; McAfee and McMillan, 1996).

the field, I also formulate a design framework that is complementary to the mainstream paradigm for market design. Before I do so in Section 1.2, I first describe my perception of the main elements of the mainstream paradigm for the field.

1.1 Mainstream Paradigm for Market Design

According to common wisdom, modern market design is thought of as a field that builds on traditional mechanism design (Hurwicz, 1960, 1972, 1973) as its main theoretical methodology, but it puts more emphasis on institutional details, and aims to provide policy-relevant insights. Assuming *self-interested* and *rational* behavior from the participants, mechanism design à la Hurwicz studies how design of institutions affects behavior of participants along with the outcomes chosen by these institutions. In his 2007 *Nobel Prize Lecture*, Eric Maskin identifies mechanism design as the "engineering" side of economic theory (Maskin, 2008).[2]

Consistent with the common wisdom in the field, in a mutual interview, Roth and Wilson (2019) identify non-cooperative game theory, cooperative game theory and mechanism design as antecedents of market design:

> "Designs of auctions and matching markets evolved from the disparate branches of noncooperative and cooperative game theory. Agents' private information is the main consideration in auctions, and designs focus on procedures that elicit demands and yield good outcomes. The goal is to implement Walras and Hayek using Hurwicz's scheme.
>
> [$\cdots$] Auction designs often take the set of bidders as a datum, but as Al describes below, a matching market presents the more formidable challenge of yielding an outcome so good it attracts participants."

Roth and Wilson (2019) further summarize the roles of noncooperative game theory, cooperative game theory, and mechanism design in market design as follows:

> "The big lesson of market design is that marketplaces are small institutions in a big economic environment: participants have bigger strategy

[2]Formally, a mechanism consists of a message space for each participant and a function which selects an outcome for each message profile. Using various solution concepts from noncooperative game theory, there are two main approaches in mechanism design. Under the first approach, the focus is on the design of an *optimal* mechanism, where optimality typically corresponds to the maximization of a given objective function subject to various constraints. Under the second approach, the objective is attaining "desirable" outcomes (represented as a *social choice rule*) at equilibrium. This segment of mechanism design is known as *implementation theory*. See Jackson (2014) and Jackson (2001) respectively for excellent surveys on mechanism design and implementation theory.

> sets than you can see, and there are lots of players, not all of whom may even be active participants in the marketplace, but can influence it. So we needed a way to design mechanisms that had both good equilibrium properties for the rules we knew about, and good stability properties for the strategies we didn't know about.
>
> Thus, the connection between coalitional and strategic models as they can be used in market design is not as models of different kinds of games, but as models of a given game at different levels of detail, used for complementary purposes. For parts of the game that we're designing, we use "noncooperative" strategic models to precisely specify actions available to players. For parts of the game that we don't have complete control over, we use "cooperative" coalitional models to tell us something about the incentives that agents and coalitions of agents may have to circumvent the rules."

Hence, under this perspective, the need for market design emerges mainly in environments where participants hold private information which may present a barrier to implementation of desired policies that rely on this information, and where individuals may hesitate to participate in.

Although they identify game theory and mechanism design as antecedents of market design, Roth and Wilson (2019) emphasize that formal analysis plays a less central role in their vision of market design than these highly rigorous fields:

> "Mathematical models themselves play a less heroic, stand-alone role in market design than in the theoretical mechanism design literature. A lot of other kinds of investigation, communication, and persuasion play a role in crafting a workable design and in helping it to be adopted and implemented, and then maintained and adapted."

Roth (2002) identifies the "other kinds of investigation" that are key to a successful design as *experimental and computational economics*. The role of these methods in institution design "to supplement the traditional analytical toolbox of the theorist" is "dealing with complications" which are not addressed by simple theory.

What about the"communication" and "persuasion" strategies mentioned by Roth and Wilson which are also key for a successful design? What exactly is the role of these types of *soft skills* under this view of market design?

The answer to this question is elaborated in Roth (2002), where he asserts that "adoption of a design is at least partly a *political* process." Thus, the role of these soft skills

is to navigate this "political" process. Indeed, Roth (1986, 2015) uses the metaphor of "whispering into the ears of princes" to describe some of these "communication" and "persuasion" strategies he identifies as an important element of a successful design.[3]

In summary, the main role of theory in market design under the vision of the field articulated in Roth and Wilson (2019) is to provide intuition, a view that is repeatedly emphasized by many leaders in the field who follow the same paradigm:

> "A lesson from this experience of theorists in policy-making is that the real value of the theory is in developing intuition. The role of theory, in any policy application, is to show how people behave in various circumstances, and to identify the tradeoffs involved in altering those circumstances. What the theorists found to be the most useful in designing the auction and advising the bidders was not complicated models that try to capture a lot of reality at the cost of relying on special functional forms. Such theorizing fails to develop intuition, as it confounds the effects of the functional forms with the essential elements of the model. A focused model that isolates a particular effect and assumes few or no special functional forms is more helpful in building understanding."
>
> McAfee and McMillan (1996)

> "Two important lessons that I learned from working on high-stakes auctions are that they operate in an almost infinite variety of contexts, and that this variety is the reason for the paradoxical importance of including unrealistic assumptions in models built to understand and illuminate reality. No single set of assumptions is adequate to describe all the various settings in which auctions are used, and too much specificity in models can blind the analyst to important general insights."
>
> Milgrom (2021)

There is one final aspect of the paradigm described in Roth and Wilson (2019) which played an important role in my pursuit of an alternative approach to market design as a junior design economist. To the best of my knowledge, this paradigm mainly (if not

[3]The use of soft skills in policy under this view has recently been scrutinized by the critics of market design. See, for example, the following quote from Weyl (2020):

> "This community focuses its attention on what Roth described as "whispering in the ears of princes": providing expert quiet advice to technocratic government officials on the design of market institutions, largely away from the public eye."

exclusively) reflects the experiences of leading design economists who were *commissioned* to design or reform various institutions.

In the rest of the manuscript, I refer to the institution design paradigm discussed so far as the *mainstream paradigm for market design*. Some of the main features of this paradigm for my purposes can be summarized as follows:

- Assuming self-interested agents, the focus is the design of a mechanism that either optimizes an objective function or attains desirable outcomes at equilibrium.
- The need for design arises due to either *private information* or *participation* considerations.
- The main role of theory is to provide *intuition*.
- Details of the design are managed through experimental and computational techniques.
- Policy impact is mostly tied to applications in which reputable experts in design economics are *commissioned* to organize or reform an institution.

In the next section, I present an alternative institution design paradigm I developed over the last 25 years with important contributions from several collaborators, most notably from my friends and co-authors Parag Pathak and Utku Ünver. In an effort to overcome a range of barriers detrimental to my policy aspirations as a junior design economist, earlier in my career, I was motivated to develop this alternative to the mainstream paradigm. The last feature of the mainstream paradigm, i.e., its exclusive representation of the experiences of leading economists from projects they were commissioned to guide an institution design, was critical in my pursuit of an alternative approach. In collaboration with various co-authors and partners in the field, I deployed my approach to inform policy and change institutions in a wide range of real-life settings, and against all odds, succeeded in my goal in many cases.

In its evolution phase, the core elements of this approach evolved through my integrated research and policy efforts in school choice (Balinski and Sönmez, 1999; Abdulkadiroğlu and Sönmez, 2003; Chen and Sönmez, 2006; Ergin and Sönmez, 2006; Pathak and Sönmez, 2008, 2013a), and in kidney exchange (Roth et al., 2004, 2005b, 2006, 2007). Most recently, in various teams, I followed this approach to guide my integrated research and policy efforts on,

1. analysis and reform of the US Army's branching process of its cadets to military occupations (Sönmez and Switzer, 2013; Sönmez, 2013; Greenberg et al., 2023),

2. analysis of Indian court judgments on affirmative action (Sönmez and Yenmez, 2022a,b; Sönmez and Ünver, 2022), and

3. design, analysis, and implementation of pandemic medical resource allocation policies and procedures during Covid-19 (Pathak et al., 2020d, 2022; Rubin et al., 2021; White et al., 2022).

1.2 An Alternative Paradigm: Minimalist Market Design

I have been fortunate to play an active role in this exciting field since late 1990s. While the methodology I adopted in my research and policy efforts in market design has many overlaps with the mainstream paradigm of the field discussed in Section 1.1, it also has some fundamental departures.

My approach to institution design or reform heavily relies on the following two elements of a potential application:

1. Legitimate objectives of policymakers and other stakeholders in establishing the institution.

2. The existing structure of the institution.

In my definition, "legitimate" means any publicly stated or implied objective of democratically elected officials. These objectives may, and indeed they often do, include various *normative* objectives that differ from *preference utilitarianism.* Indeed, many of these objectives may not even be *consequentialist*. For example, when a *strategy-proof* mechanism was enforced throughout England for allocation of public school seats with a reform of the Education Code in 2007, the main justification given by the Education Secretary Alan Johnson was that the old mechanism "forces many parents to play an 'admissions game' with their children's future" (Pathak and Sönmez, 2013a). Thus, *strategy-proofness* was an objective of the policymakers not because of its consequences on the outcomes, but rather because of the values it promoted.[4]

If a goal cannot be articulated in the open, it is not considered "legitimate" under my definition.[5] It is certainly possible that, the existing institution may also be serving some goals which fall outside my definition of legitimacy. My framework does not rule out this possibility. Indeed, due to the manner in which the above two particulars of the

[4]See Section 3.4.1 for the details of the 2007 school choice reform in England.

[5]To be absolutely clear, I do not intend to imply that an objective which cannot be publicly stated is necessarily *illegitimate*, although it certainly can be.

institution are utilized in the design, it may even work better for such applications than the mainstream paradigm.

Assuming that the existing institution fails the legitimate objectives of policymakers, as a first step, the root causes of these failures are determined. Subsequently, only interfering with these sources of failures, the existing institution is reformed in a way that corrects these failures. It is as if a *surgeon* only removes the unwell part of a body in a surgery, but otherwise does not operate on the rest of the body. I refer to this design paradigm as ***minimalist market design***.

My paradigm for institution design or reform is motivated by the following thesis: In a wide variety of economic, social, and political environments, while stakeholders show considerable flexibility in various technical details of procedures devised to reach their decisions, at the same time they also have some strong views on certain objectives. The first and the most critical step of minimalist market design is to identify what these key policy objectives are, and to what extent the current institution satisfies them. Often, the history of an institution provides valuable guidance or clues to determine these objectives. Since these objectives often go beyond *preference utilitarianism*, minimalist market design accommodates a wide range of normative principles. As such, it is also in line with Sen (1987), who advocates for reconnecting the two origins of economics in "ethics" (normative origin) and "engineering" (positive origin) which diverged over time with the rise of neoclassical economics.[6]

From a pragmatic perspective, as unlikely as it is to convince policymakers as an outsider to abandon their current institution, a design economist may perhaps be able to turn the tables and convince them by

1. correctly identifying and formulating what matters for various stakeholders,

2. establishing that the current institution design fails to satisfy some of these key objectives, and

3. providing alternatives that better satisfy the key objectives.

From its inception, a research program guided by minimalist market design is structured with an eventual aim of informing policy. In that sense, it is a paradigm for *integrated* efforts in research and policy. It can also be thought of a paradigm based on *local improvements* from the status quo which may harbor a wide range of considerations as well as compromises between potentially opposing views. Rather than designing a brand new institution, the main objective is *fixing* the existing one. This aspect of minimalist market

[6]Jackson (2019) credits Keynes (1904) for distinguishing positive economics from normative economics.

design is instrumental to determine which elements of the existing institution are taken as given, and which ones are in need of modification. Therefore, from a technical point of view, its methodology helps to formulate the primitives of the analytical model.

Due to the wide range of objectives it accommodates, the formal methodology that plays the lead role in theoretical analysis under minimalist market design is different than those typically adopted under the mainstream paradigm. While techniques from game theory and mechanism design often play key roles in establishing the failures of an existing institution, an analytical framework that is particularly useful for formulating alternatives that escape these failures is the *axiomatic methodology* (Moulin, 1988, 2004; Thomson, 2001, 2011). Hence, another important departure of my minimalist approach from the mainstream paradigm is the primary role the axiomatic methodology plays in formal analysis, while game theory, mechanism design, experimental, computational, and empirical techniques assume supporting roles.

Is minimalist market design a competing paradigm for the mainstream paradigm? In general, I do not think so. I mainly see the two paradigms as *complementary*. In my opinion, while minimalist market design provides more value than the mainstream approach in some settings, in others, it does not. On the one hand, if (i) the goals of policymakers are either vague or they are fully in line with neoclassical approach and (ii) the institution needs to be established from scratch, then there may not be much of a reason to adopt the minimalist approach. On the other hand, when there are well-defined policy objectives and existing tools to implement them, then the reach of the minimalist approach goes beyond the boundaries of mainstream paradigm for market design where the main issues are limited to those which emanate from considerations of private information or voluntary participation. Settings with complex normative desiderata is one such direction where the minimalist approach can be especially valuable. As emphasized in Li (2017),

> "Market design must speak about ethics because policymakers sometimes need help expressing what they want [...]
>
> A policymaker may be familiar with the details of their environment, and yet not know how to state their ethical requirements in precise terms [...]
>
> In addition to studying cause and effect in markets, economists also have a comparative advantage in stating precisely the normatively-relevant properties of complex systems [...]"

Supporting policymakers with formulation and accommodation of their normative desiderata has recently been an especially fruitful avenue for design economists. Along these lines, recent research guided by the minimalist approach generated policy impact

in the context of pandemic medical resource allocation (Pathak et al., 2020d, 2022) and received external validity in the context of Indian court judgments on affirmative action (Sönmez and Yenmez, 2022a), even though private information or participation considerations had little bearing in these applications.

In summary, here is a list of the main features of minimalist market design that differentiate it from the mainstream paradigm:

- Formulating objectives of policymakers and other stakeholders as rigorous axioms, the focus is on the design of an institution that satisfies these objectives through a minimal interference with the existing institution.
- Often it relies on *axiomatic methodology* as its primary technique for formal analysis.
- Formal theory is the main method for analysis and the role of theory goes beyond providing intuition.
- It is especially useful in settings in which the "intended" institution is clear, but finding it requires formalism and technical expertise.[7]
- It may be particularly valuable for *aspiring* design economists in settings where the need for a change is not established.

1.3 Commissioned vs. Aspired Market Design

Why in the world, as a junior design economist, I did not adhere to the mainstream paradigm, and instead adopted a different approach? As unconventional as it may appear at first glance, I had valid reasons for my choice of strategy in my pursuit of policy impact through my research.

As a design economist, policy impact on a cause I believe in has always been a higher priority for me than publishing my findings in the best scholarly outlets. Consequently, departures between my approach to market design and the mainstream paradigm emerged out of necessity, due to a key aspect of my policy efforts as a junior design economist that differs from the earlier contributions in the field.

As I earlier emphasized in Section 1.1, the mainstream paradigm for market design largely reflects experiences and insights of leading experts in design economists who have been *commissioned* to design or reform various institutions. As a result, the paradigm

[7] That is, because, in many such settings, the divergence between the intended institution and the one in place is due to lack of formalism and technical expertise. See, for example, Sönmez and Yenmez (2022a) for a most apparent example of this.

these experts propagated captures an approach that may be more informative for settings in which the need for a change is already established, and input from a design economist is already sought. Often in these cases the commissioned design economist is trusted with a great deal of control over various details of the design. Under normal circumstances, once a design economist is commissioned, policymakers do not expect additional theoretical analysis for various details not covered under simple models. Complications that arise from various details are often managed through experimental and computational methods (Roth, 2002).

In contrast, my perspective reflects that of an *aspiring* design economist who offers unsolicited policy advice as an outsider, and often at the expense of an existing institution. Not only is the need for a change rarely established or acknowledged in such settings, but also a critical view from an eager researcher is often deemed undesirable. The departure of my approach from the mainstream paradigm reflects my pragmatic efforts over the years to bypass this additional barrier as an aspiring market designer. In order to achieve this goal, my design had to reflect the aims of policymakers and other stakeholders themselves, without compromising any of these aims.[8] Essentially, as an aspiring market designer, I had to convince policymakers and other stakeholders that my design is better aligned with their aims than the current institution.

In contrast to an expert who is commissioned to guide a reform, a mere intuition provided by a simplified analysis of an aspiring market designer is unlikely to bear any fruits, especially if one of the primary aims involves undoing an existing institution. For such an ambition to hold water, not only must the model of an aspiring market designer be very realistic, but also her arguments for a reform have to be *airtight*. Thus, unlike a commissioned market designer, the formal analysis of an aspiring market designer has to play a heroic role! Moreover, the aspired reform has to provide a very clear *value* to authorities and other stakeholders. This, in turn, requires a thorough understanding of what really matters to them. Importantly, mainstream economic considerations alone (eg. preference utilitarianism) may not be sufficient to establish this value. To summarize, to achieve the ambitious task of undoing an existing institution, an uninvited but aspiring market designer needs to provide a very clear value for all stakeholders, and must do so with respect to *their* actual desiderata and not solely based on mainstream (and typically preference utilitarian) desiderata in economics. These pragmatic considerations were the basis of my unconventional approach to market design.

[8]This challenge is not unique to my policy efforts by any means. For example, when they redesigned the Israeli Medical Internship Match in 2014, one of the main lessons a team of aspiring market designers reached from their successful efforts was "the 'Do No Harm' principle, which states that (almost) all participants should prefer the new mechanism to the old one" Alon et al. (2015).

Unlike the mainstream paradigm for market design, the existing institution plays a central role in minimalist market design. A design economist is unlikely to discover every single policy goal of the stakeholders. However, the existing institution itself may hold additional information about the system which may be difficult or even impossible to obtain. That is, even when an existing institution is deeply flawed, it may still reflect many important aspects of the problem an aspiring market designer may not even be aware of. A dominant view in market design is that, other things being equal (such as the potential value offered through the intervention), the closer a proposed reform is to the actual system that is in place, the higher is the chances that the stakeholders may be compelled to pursue it. This view reflects itself as the following principle under the minimalist approach: In proposing a reform, maintain as many elements of the original institution as possible, and only interfere with elements that are *clearly broken* with respect to stakeholders' own objectives, often due to technical challenges.[9] The aim here is to present the stakeholders with alternatives that feel very similar to the original institution, except that they escape the shortcomings of the original one. Ideally, one would like the central planner to feel as if "this is the institution we intended to design at the first place." This is why I identify this approach as one that is *minimalist*.

The initial role of an aspiring market designer is viewed and presented as one of a supporter under minimalist market design. The only interference with the existence institution involves correction or enhancement of its imperfect elements that require technical expertise. In my experience, not only this approach makes it easier to establish trust, but it also makes it easier for the stakeholders to "own" an aspired reform. For an aspiring market designer, following this approach helps to avoid taking any (intentional or unintentional) normative position (other than the normative objectives of the stakeholders themselves) in an initial interaction with likely skeptical stakeholders. Thereby, it helps them to see that the aspired reform does not harbor any ideological agenda or ulterior motive. In this regard, providing pro-bono support can be also very valuable (and perhaps even necessary in some cases) in establishing trust.

1.4 Roadmap for the Rest of the Manuscript

The remainder of this manuscript is organized as follows. In Section 2, I describe the settings where the minimalist approach may be most useful as an institution design paradigm, and provide guidance on its effective execution. In 3, I discuss the evolution

[9]Strictly speaking, such a minimal deviation from the original system must be covered as one of the proposed alternatives, although it does not have to be the only one.

of the minimalist market design through my research and policy interactions on school choice in the period 1997-2005. This section details how my unsuccessful policy attempt in 1997 to reform the Turkish national college admissions mechanism later influenced my successful policy intervention to reform the Boston Public Schools student assignment mechanism over 2003 and 2005. How two subsequent school choice reforms in England in 2007 and Chicago in 2009 provide external validity to minimalist market design is also discussed in Section 3. In Section 4, I discuss how our joint efforts with Alvin Roth and Utku Ünver on kidney exchange further contributed to evolution of minimalist market design. Sections 5-7 are devoted to recent applications of market design where the minimalist approach is followed religiously, and succeeded in informing or influencing policy. These applications are US Army's branching process of its cadets to military specialties (Section 5), Supreme Court judgments on affirmative action in India (Section 6), and pandemic medical resource allocation during Covid-19 (Section 7). In Section 8, I contrast minimalist market design with the mainstream paradigm for the field. I conclude in Section 9.

2 Advice for an Aspiring Market Designer

The scope of market design is described as follows by the NBER Market Design Working Group (NBER, 2008):

> "Market design" examines the reasons why market institutions fail and considers the properties of alternative mechanisms, in terms of efficiency, fairness, incentives, and complexity. Research on market design is influenced by ideas from industrial organization and microeconomic theory; it brings together theoretical, empirical, and experimental methods, *with an aim of studying policy-relevant tradeoffs with practical consequences*. [Emphasis mine]

As emphasized in Section 1.2, the axiomatic methodology plays a central role in execution of minimalist market design. Thomson (2001) describes the key elements of an axiomatic study as follows:

> 1. It begins with a specification of problems, and a formulation of a list of desirable properties for solutions for the domain.
>
> 2. It ends with (as complete as possible) descriptions of families of solutions satisfying various combinations of the properties.

Minimalist market design is a framework for integrated research and policy efforts where the axiomatic methodology is utilized in a particular way.[10] Pragmatic considerations due to policy aspirations strongly influence the research program under this framework. As such, this framework can be especially useful for market design studies where eventual policy impact is a main consideration. In this regards, it is of utmost importance to emphasize, that, as a policy device, minimalist market design is intended for institutions which are governed by honest and democratically elected officials who have the sincere goal of improving institutions. Any *official* or *publicly disclosed* policy goal of these democratically elected officials are considered as *legitimate*, and institutions are improved, mainly based on these objectives.[11]

Alternatively, minimalist market design can also be utilized as an epistemic tool, which can be used to assess to what extent adopted institutions are in line with officially stated or publicly known objectives. In this role, any deliberate or unintended deviations from the legitimate objectives of the institution can also be revealed. An example for this role of minimalist market design can be seen in Sönmez and Ünver (2022) in the context of a contested Constitutional Amendment in India.

2.1 A Classification of Market Design Applications

The potential of the minimalist approach to lead to a successful institution design that ultimately informs policy depends on several aspects of the application. The following three questions can be helpful to assess the potential promise of minimalist vs. mainstream frameworks to guide a successful design:

1. Is the need for a change in the existing system (if one exists) established or it is merely aspired by an outsider?

2. Does the proposal involve the introduction of a new system or the replacement of an existing one?

3. Are all key desiderata of stakeholders consistent with the neoclassical economics,

[10] The role of axiomatic methodology in market design goes far beyond its central role under minimalist market design, and it is beyond the scope of this essay. See, for example, Schummer and Serizawa (2019), for the role of axiomatic characterizations in market design.

[11] Here, I acknowledge that, the existing institution itself may embed various *illegitimate* goals in the system. By maintaining as much of the existing institution as possible, a design guided by the minimalist approach may also inherit some of these aspects. In applications where the legitimate goals imply a single design, this cannot happen. However, in applications where there are multiple designs that satisfy the legitimate objectives, it can. Therefore, the best practice in those cases is to give a complete description of these institutions. This exercise is referred to as a *full characterization* in axiomatic methodology.

or do they include essential ones that remain beyond the scope of neoclassical paradigm?

While the minimalist approach can also be deployed in applications where a design economist is commissioned to design a brand new institution or reform an existing one, the case for it becomes stronger for aspired market design efforts by an outsider, especially if (i) the efforts require to revoke an existing institution and (ii) the key desiderata for the stakeholders include ones which are rarely considered by mainstream economists or some of the institutional details remain outside the scope of neoclassical paradigm.

2.2 A Guide on Execution of Minimalist Market Design

Minimalist market design is most adequate for applications where stakeholders have clearly stated objectives, and it has two potential roles as a design paradigm.

The first role of the minimalist approach is to serve as a framework that generates realistic advice for institution redesign when the existing system suffers from a number of shortcomings. Studies that utilize the first role of the minimalist approach include Balinski and Sönmez (1999); Abdulkadiroğlu and Sönmez (2003) for school choice, Roth et al. (2004, 2005b, 2007, 2006) for kidney exchange, Sönmez and Switzer (2013); Sönmez (2013); Greenberg et al. (2023) for US Army's branching process, Sönmez and Yenmez (2022a,b); Sönmez and Ünver (2022) for affirmative action in India, and Pathak et al. (2020d, 2022); Rubin et al. (2021); White et al. (2022) for pandemic medical resource allocation.

The second role of the minimalist approach is epistemic: It serves as a framework for the *formulation and analysis of plausible allocation mechanisms* based on the objectives of stakeholders themselves, whether the existing system is *flawed* or not. Studies that utilize the epistemic role of the minimalist approach include Dur et al. (2018) for Boston's neighborhood priority policy in school choice, Dur et al. (2020) for affirmative action for Chicago's elite high schools based on socioeconomic criteria, and Pathak et al. (2020a) for H-1B visa allocation in the US.

The main focus of this manuscript is the first role of my minimalist approach as a tool for institution design or reform. As such, I next summarize the steps and prerequisites I consider essential in execution of this framework for this more ambitious role.[12]

Step 1. Find an actual problem: This is a big undertaking. Therefore, following this framework is plausible only if your scholarly efforts have a counterpart in practice. Can you explain the problem and your insights on it to your friends who are not academic

[12]Depending on the application, for example if there is no existing system in place, some of these steps can be discarded. Similarly, several steps can be discarded if the only aim is analysis.

economists? Can you imagine writing a news story on these ideas? Naturally, the more important the problem is, the better!

Step 2. Understand the problem in and out: In order to solve a real-life problem, you need to understand it exhaustively. If all goes well, at some point you will interact with authorities and various other stakeholders to advocate for your practical ideas. In many cases, you may be seen as a "liability" if your efforts expose the limitations of an existing institution. You will likely interact with authorities who may have designed the "flawed" institution. They will have all the reasons to discredit and dismiss your efforts. Thus, as a bare minimum, you need to have a thorough understanding of the topic, so that you may perhaps have a reasonable expectation to convince the stakeholders that you can rather be a valuable "asset." Succeeding in this undertaking requires familiarity not only with literatures that relate to the application, but also with other relevant materials from the field. For example, in my collaborations, we

- studied dozens of papers in the transplantation literature prior to advocating for a centralized kidney exchange clearinghouse in New England (Roth et al., 2004),
- absorbed dozens of court rulings prior to proposing a reform of a flawed affirmative action procedure that was mandated by a Supreme Court judgment in India (Sönmez and Yenmez, 2022a), and
- thoroughly learned the main considerations in medical ethics, public healthcare and emergency medicine literatures prior to advocating a class of pandemic medical resource allocation procedures during the Covid-19 pandemic (Pathak et al., 2020d).

Step 3. Formulate a realistic and analytically tractable model: Understanding the problem in depth is only the beginning. You need to have a model that is reasonably realistic. You have to assess which elements of the problem are essential and which features are superfluous. If you aspire to influence policy through your research, then you need a model that is both sufficiently realistic and also analytically tractable. This is unfortunately one of the most challenging aspects of integrated efforts on research and policy. Often the practical problem at hand is so complicated that no sufficiently realistic model is analytically tractable. Applications of this especially nature include incentive auctions (Leyton-Brown et al., 2017; Milgrom, 2017; Kominers and Teytelboym, 2020) and refugee matching (Delacrétaz et al., 2016; Andersson, 2019; Hadad and Teytelboym, 2022). Such applications may not be the best candidates to adopt minimalist market design.

Minimalist market design is fully aligned with the following main thesis in Watts (2017): "Social sciences should be more solution-oriented." As such, the following quote

from this paper is also right on the spot for applications which are best candidates of the minimalist approach.

> "Identifying problems that have this 'Goldilocks' property of being neither too easy nor too hard is difficult, but one possible direction is to draw inspiration from engineering, and place more emphasis on building tangible devices and systems that have specific, well-defined properties."

Step 4. Identify key policy objectives of stakeholders: Issues that are of main interest for academic economists may not be the same as those that matter in the field. Research that is conducted without understanding the primary objectives of the stakeholders is unlikely to generate any insights or practical tools that are of immediate value to them. Therefore, if one of your primary aims is to generate research that informs policy, then you have to understand what matters in the field.

The history of an institution often provides important clues on what matters for its stakeholders. As institutions evolve, various features are introduced to fix certain issues or to address certain concerns discovered by earlier generations of policymakers. The current generation may not even be fully aware of the intention behind those concerns or might not articulate them explicitly as part of their overall objectives. As such, these features might contain information on some "legitimate" objectives of the policymakers even though they no longer explicitly state them as objectives.

This brings me to an important warning. Do not assume that the objectives of policymakers or stakeholders need to have any resemblance to standard assumptions in neoclassical economics. At this phase, you really cannot think like a mainstream economist. Neoclassical analysis largely relies on a *preference utilitarian* framework. The primary objective in this framework is maximization of some form of an aggregate measure of preference satisfaction. Of all my successful market design efforts, however, *kidney exchange* is the only one where preference utilitarianism adequately captured one of the key objectives of the stakeholders in the field.[13] For this application, there is a very natural and objectively important welfare measure in the number of lives saved through kidney exchanges, and as such, welfare gains presented in Roth et al. (2004, 2005b, 2007) received favorable response from transplant surgeons. In *school choice*, on the other hand, it was mainly considerations related to *incentive compatibility* that ultimately led to a series of reforms advocated in Abdulkadiroğlu and Sönmez (2003). For the case of *pandemic allocation of scarce medical resources*, it was largely *equity* related considerations that made

[13]This statement is subject to the following caveat. Since the practice of kidney exchange does not involve any monetary transfers, the key desiderata in this setting is not *utilitarianism*, but rather its ordinal variant *Pareto principle* (Broome, 2001).

bioethicists and experts in emergency healthcare endorse and adopt policy recommendations in Pathak et al. (2020d). For the case of India's *affirmative action* policies, it was purely *equity* related considerations that led to a recent reform parallel to the one advocated in Sönmez and Yenmez (2022a). Finally, it was both *equity* related and *incentive compatibility* considerations that played central role in US Army's reform of its *branching process* at West Point and ROTC as advocated in Sönmez and Switzer (2013).

One word of caution. There are many settings where you may not be able to clearly define or translate the objectives of stakeholders. In my view, at least in its first role as a tool for generating realistic policy advice, the minimalist approach may not hold too much of a promise for those applications.

Step 5. Determine whether the original institution is a good choice for the key objectives: Your best bet to receive attention of various stakeholders is to establish that the existing institution fails at least one of their key objectives. Clearly, if the existing institution is already a good choice for the key objectives of the stakeholders, then there is no need for a reform. The broad structure of the framework, however, is still valuable to analyze the existing system. After all, direct policy impact is not the sole aim of researchers in market design.

Step 6. If the institution in place fails key objectives, then find the sources of these failures: Even if an existing institution fails some of the most important objectives of the stakeholders, convincing them to engage in a costly change is not an easy task. In particular, stakeholders are unlikely to pursue a reform that overhauls the entire institution. Apart from the increased difficulty and cost of bigger changes, many existing elements of an institution may serve additional purposes. Hence, it is important to rebuild the institution by remaining true to its main structure. In order to do that, you need to identify the sources of the failures. This stage of the process is also useful to optimize your model. For example, you can set the primitives of the model based on which elements of the existing institution can be maintained and which elements need to be altered or removed.

Step 7. Interfering only with the sources of failures, design an alternative system that satisfies all key objectives: If you are able to identify the sources of the failures, assuming that the key objectives are collectively feasible, then the next step is correcting them. Since you are directly addressing the source of any issue, these corrections will likely lead to an alternative system that corrects the failures through a minimal interference with the original system. Think of yourself as a "surgeon" who conducts a "minimally invasive" procedure.

This aspect of the minimalist approach help you to gain trust of various stakeholders. After all, you are not trashing the entire institution, but instead merely repairing its ele-

ments detrimental to objectives of the stakeholders. Therefore, your efforts can be easily interpreted as an improvement of their own institution, thus making it easier for various stakeholders to "own" your proposed reform.

An additional effort that will help you to gain trust of various stakeholders is to identify *all* institutions (such as allocation mechanisms) that satisfy the key objectives of the stakeholders, rather than focusing only one that satisfies these objectives. In axiomatic methodology this type of a result is known as an *axiomatic characterization* of a class of rules that satisfy the desired axioms.[14] As later emphasized in Section 8.2.3, focusing on a single institution that satisfies the key objectives of the stakeholders (when there are many) may potentially introduce certain biases into the system with potentially important distributional consequences. By presenting the stakeholders with a complete picture of what is feasible, you are maintaining *informed neutrality* between reasonable normative positions (Li, 2017), thereby making it clear that your recommendation is completely impartial. In rare cases, there will be a unique rule that delivers the desiderata. This is considered the gold standard in axiomatic methodology, provided that the axioms all correspond to actual desiderata. Naturally, the desired reform is most clear in those cases.

Step 8. Establish the potential practical value of the alternative system: If you came this far, then your research is of potential value to stakeholders. Before engaging them to explore whether they may be receptive of your policy ambitions, it may be a good idea to support your conceptual and theoretical ideas with experimental, computational or empirical methods. In addition, it is also a good idea to gather as much field or anecdotal evidence as possible to show that your research is relevant. In that regard, media coverage of your research on a reputable outlet may be especially helpful to convince the stakeholders to explore the potential value of your research. For example, as later discussed in section 3.3.1, a *Boston Globe* story on Abdulkadiroğlu and Sönmez (2003) was instrumental in securing the initial interaction with officials at Boston Public Schools to discuss the failures of their *Boston school choice mechanism* and its two potential alternatives.

This is a good time to approach policymakers or other stakeholders to explore a potential collaboration aimed for transforming your ideas into policy impact.

Step 9. If necessary, tinker on the design with additional input from the stakeholders: Once a partnership is established with authorities, you are no longer bound to many constraints that directly affected both your research questions and your proposed institu-

[14]See, for example, Moulin (1988, 2004), Thomson (2001, 2011), and Schummer and Serizawa (2019).

tion in Steps 1-8. After all, you are no longer an outsider! If you have additional paths for further improvements, either due to various elements of the original institution you did not dare to interfere with or due to feedback from your new collaborators, you can pursue these ideas as an insider.

Observe that, this last step is fundamentally different than the earlier ones. You can think of Steps 1-8 as efforts that will hopefully convince policymakers or system operators that you are a "worthy" partner in this endeavor. As a result, many elements of the minimalist approach are admittedly "conservative." The approach in Step 9, however, need not be as conservative any more. Similarly, the role of theory can also be toned down in this step. In that sense, there is a potentially stronger role in Step 9 both for alternative methodologies including those in computational, experimental and empirical economics. Thus, the open ended tinkering step of institution design in my framework more or less can be thought as the stage you are essentially "commissioned" to guide the design.[15]

It is important to reiterate that, even if there is a globally optimal institution for the application, your aim under the minimalist approach is neither finding this optimal institution nor proposing it to authorities prior to reaching to this tinkering phase. Assuming that one even exists, an optimal institution may often involve a major departure from the existing one, thereby making it harder to convince authorities to pursue a reform.[16] Various considerations, including delicate issues that are not explicitly discussed, the potential to upset sensitive balances between interest groups, or even the difficulty of "saving face" may constrain which institutions authorities may be comfortable to consider. Since many flawed institutions in the field are also hard to analyze, it may be difficult to compare them with optimal institutions. This is why, as a first (but the most important) step of an aspired reform process, it is essential to start with a design that is as close as possible to the original institution. If a partnership with authorities can be established and the initial reform can be carried out, then it becomes much easier to present more substantial

[15]It is tempting to associate Step 9 of my framework as the "tinkering" phase of policy design in Esther Duflo's influential *Richard T. Ely Lecture* "The Economist as Plumber" (Duflo, 2017). While this association is natural, there are some important distinctions between the roles of the tinkering phase in the two frameworks. In Duflo's framework, the role of the tinkering phase is making tweaks in prescribed policy to correct any issues that may arise in field implementation. Such issues can emerge due to the gap between the theoretical analysis and the actual problem. Thus, the tinkering phase is particularly valuable in settings where the primary role of theory is building intuition. In my framework, in contrast, there should not be a mismatch between theory and practice at a level that could lead to any serious issues. The role of the tinkering phase is further improving the institution with the additional flexibility which might be gained by the design economist at this stage.

[16]An important exception here is applications where the authorities are aware of the necessity of a reform, and commissioned the design or redesign of the institution to an expert in economic design.

deviations from the original institution in later stages of a redesign process. Since major technical failures of the original institution is removed with the initial reform, at this stage it becomes much easier to analyze and demonstrate the potential value of larger reforms by relaxing many other aspects of the original institution. Assuming that a "globally optimal" institution exists, one can think of this tinkering phase as an attempt to get closer to this optimum, potentially giving higher weight to principles that are more prominent in mainstream economics research.

3 Evolution of Minimalist Market Design: School Choice

Minimalist market design evolved through a series of integrated research and policy efforts on allocation of college seats to students in Turkey (Balinski and Sönmez, 1999) and school choice in the US (Abdulkadiroğlu and Sönmez, 2003; Chen and Sönmez, 2006; Ergin and Sönmez, 2006; Pathak and Sönmez, 2008, 2013a).

3.1 Research and Policy Efforts on Turkish College Admissions

Balinski and Sönmez (1999) plays an important role in my career. It was my first research project where I paid close attention to institutional details, and interacted with authorities upon completion for possible policy impact. It is my first integrated effort in research and policy which relied on *normative economics* to pursue a reform of a major real-life institution. It was also my first failure in my policy efforts, the earliest one of many to come, but not without teaching me several valuable lessons that influenced the evolution of my minimalist approach to market design.

Allocation of school seats based on a standardized test (or another form of an objective performance measure) is a widespread practice worldwide. At least since my childhood, this has also been the case in my homeland Turkey, from admissions to competitive secondary schools to centralized allocation of college seats nationwide. Assuming that there are no distributional objectives, solution of this resource allocation problem is straightforward when there is only a single institution with multiple identical seats. The institution simply admits the highest score students up to its capacity (or all students in case of insufficient demand). The problem is not much harder when there are multiple institutions that all priority-rank applicants with a single standardized test, and allocate all seats in the system through a centralized process. In this case, while the presence of multiple institutions introduces heterogeneity to school seats, there is a simple preference revelation mechanism (i.e., a *direct mechanism*) which imitates the natural dynamics of a queue.

Students submit their rankings over all institutions, and the pooled positions of all institutions are allocated to them one-at-a-time, based on their submitted preferences, and following their rankings in the standardized test. Once it is any given student's turn in the procedure, she is awarded her highest-ranked school which still has an available seat. This intuitive mechanism is called a *simple serial dictatorship* (SSD) (Satterthwaite and Sonnenschein, 1981).

3.1.1 No Justified Envy

Overcoming favoritism and corruption is one of the main reasons why so many countries or local authorities allocate school seats centrally, using results of objective standardized tests. This practice increases the legitimacy of the allocation process. As such, respecting the results of the standardized test is typically important for institutions that allocate school seats in this way. This principle, which is important not only for centralized allocation of school seats but also for priority-based allocation of various other unit-demand indivisible goods, can be formalized with the following normative axiom.

Definition 1 (Balinski and Sönmez (1999))**.** [17] *An allocation of school seats to students satisfies* ***no justified envy****, if, there is no school s and two distinct students i, j such that,*

1. *student j is assigned a seat at school s,*
2. *student i strictly prefers school s to her own assignment, and*
3. *student i has a higher score than student j for the standardized test for school s.*

Clearly, in cases where the axiom fails due to existence of a school s and pair of students i, j which satisfy the above given conditions 1-3, student i would have a legitimate concern, and even perhaps channels available for litigation in some countries.

When priority order of applicants is identical at all institutions, SSD is the only direct mechanism that satisfies *no justified envy* and *Pareto efficiency*.[18] This result supports the implementation of this mechanism for centralized admissions to prestigious public middle schools (Anadolu Liseleri) and high schools (Fen Liseleri) in Turkey, at the time Balinski and Sönmez (1999) was published.[19]

[17] This axiom is called *fainess* in Balinski and Sönmez (1999). Referral to this axiom through a lack of *justified envy* is first done in Abdulkadiroğlu and Sönmez (2003), where it is called *elimination of justified envy*.

[18] Throughout the paper, we adopt the following standard convention: For any axiom that is defined for the outcome of a problem, a direct mechanism satisfies the same axiom if its outcome satisfies the property at all instances of the problem.

[19] Since then, at least some of these mechanisms are replaced.

3.1.2 Multi-Category Serial Dictatorship vs Student-Optimal Stable Mechanism

For college admissions in Turkey, however, the problem is somewhat more complex. While a single standardized test with multiple sections is used to allocate college seats nationwide, this test is used to construct multiple rankings of students, where each ranking differs from others in the weights assigned to the sections of the test. The central planner exogenously maps each college to one of these rankings. For example, the ranking used for engineering schools puts higher weight for mathematics questions than the ranking used for medical schools. This version of the problem is a bit more complex, because, evaluation of students relies on multiple rankings. Thus, the mechanism SSD is no longer fit to solve the problem, as now there doesn't exist a single list from which to rank order students.

Turkish authorities, nonetheless, overcame this complexity by repeated implementation of SSD for each ranking of the students, and the removal of all but the highest-ranking tentative assignments of students at the end of any phase in case they received seats at multiple colleges. It is easy to see that this procedure terminates in finite iterations. Balinski and Sönmez (1999) refers to the resulting direct mechanism as the *multi-category serial dictatorship* (MCSD).

At first glance, this mechanism appears fairly compelling. But, a close inspection reveals an equivalence, which in turn raises a red flag. Loosely speaking, MCSD is equivalent to (i) interpreting each ranking of students as the uniform preference relation of colleges which are mapped to this ranking, and (ii) selecting the *college-optimal stable matching* of the induced *two-sided matching problem*. For any researcher who is familiar with the seminal work in Gale and Shapley (1962), this equivalence immediately invites the following question: Why would authorities use a procedure that generates an outcome equivalent to the college-optimal stable matching in an environment where colleges are not agents whose welfare matter, but rather public goods to be fairly rationed? This line of reasoning also comes with an alternative mechanism as a replacement: Construct the same "sister" two-sided matching market, but instead select its *student-optimal stable matching*. Abdulkadiroğlu and Sönmez (2003) refers to the resulting direct mechanism as the *Gale-Shapley student optimal stable mechanism* (SOSM).[20]

[20] Balinski and Sönmez (1999) refers to the same mechanism as the *Gale-Shapley student-optimal mechanism*. Since then, most papers in the literature refers to this mechanism as the *Deferred Acceptance* mechanism. I am personally not a big fan of this latter terminology, since the *student-proposing deferred acceptance algorithm* is only a specific procedure–one of many–which generates the outcome of this mechanism.

3.1.3 Theoretical Dominance of the Student-Optimal Stable Mechanism

In a system where the desideratum of *no justified envy* is indispensible, SOSM has clear advantages over not only MCSD, but also over any other direct mechanism. For a starter, it *Pareto dominates* any other direct mechanism that satisfies *no justified envy* (Gale and Shapley, 1962; Balinski and Sönmez, 1999).[21] Moreover, its welfare advantage over MCSD is only one of the reasons why SOSM is better suited for the job. In order to describe two others, we next formulate four desiderata for this resource allocation problem.

Definition 2. *An outcome satisfies **individual rationality**, if no student is assigned a seat at an unacceptable school.*

Definition 3. *An outcome satisfies **non-wastefulness**, if no school s is left with an idle seat, unless all students prefer their assignments to a seat at school s.*

In addition to *no justified envy*, SOSM and MCSD both satisfy these two basic desiderata. They differ, however, in the following two:

Definition 4. *A direct mechanism satisfies **strategy-proofness**, if no student can ever receive a strictly preferred assignment by misrepresenting her preferences.*

Definition 5. *A direct mechanism **respects priority improvements**, if no student ever receives a strictly less preferred assignment due to an increase in one or more of her rankings at a school while the relative ranking of everyone else remains constant.*

MCSD is neither *strategy-proof*, nor does it *respect priority improvements*. Thus, not only a student can benefit from misreporting her preferences under MCSD, but also she can even be penalized under this mechanism due to an increased performance in the standardized test. In contrast, not only SOSM is the only direct mechanism that satisfies *no justified envy*, *individual rationality*, *non-wastefulness*, and *strategy-proofness* (Alcalde and Barberà, 1994), but it is also the only direct mechanism that satisfies *no justified envy*, *individual rationality*, *non-wastefulness*, and *respects priority improvements* (Balinski and Sönmez, 1999).

3.1.4 Failed Policy Attempt in Turkey and Lessons Learned

As a fresh Ph.D., I was exhilarated upon these discoveries. My model was exact, and, in my mind at least, the superiority of my proposed mechanism over the mechanism in place

[21] Importantly, unlike when there is a single uniform ranking of students at all schools, *no justified envy* and *Pareto efficiency* are incompatible in general. Therefore, SOSM is not *Pareto efficient* unless the problem has additional structure which ensures this property.

was clear cut. I had something of value to offer to my homeland. Surely authorities would welcome my discovery and correct their flawed mechanism, or so I thought. After several correspondences via mail and a meeting with the head of the centralized clearinghouse ÖSYM,[22] I received a formal letter from Ankara that kindly turned down my proposal.[23]

The letter indicated that the leadership at ÖSYM found academic value in Balinski and Sönmez (1999).[24] They acknowledged that there can be multiple solutions that respects the cut-off score condition,[25] MCSD gives one of them, whereas SOSM gives another, and there can also be other ones. They also indicated that, while in theory the two mechanisms could generate very different outcomes, they saw this as a very low probability event. They further indicated that, with 1997 data (which includes more than a million students and thousands of colleges) the two mechanisms generated the same outcome. They concluded that, in light of their findings, there is no reason to reform their mechanism.

I learned several valuable lessons from this experience. Leadership at ÖSYM spent valuable time and resources to explore the merits of my policy proposal. While I failed in my ultimate objective of making policy impact with my research, my proposal received serious consideration. Their diligence gave me the hope that, perhaps, next time I might succeed. Given their emphasis on solutions that respect cut-off scores, I was correct in my hypothesis that, at least in the Turkish context *no justified envy* was the most important desideratum. On the other hand, the authorities did not even comment about the lack of *strategy-proofness*, *respect for priority improvements*, or even the potential *Pareto inferiority* of their mechanism. They clearly understood that the two mechanisms can generate different outcomes, but since their simulation of SOSM with their most recent data for the 1997 placement generated the exact same outcome as the actual match, they concluded that the failures I identified must correspond to low probability events.

My two main lessons from this experience were the following:

1. No matter how accurate my model and clean my analysis might be, my theoretical analysis alone will likely not cut it for my policy ambitions, and that I need to present more concrete value to the stakeholders in order to be able to influence policy.

2. How good the mechanism I advocate is unlikely to be very important for the au-

[22]ÖSYM is the acronym for Ögrenci Seçme ve Yerleştirme Merkezi, which translates to English as Student Selection and Placement Center.

[23]See Figure 1 for a copy of the letter.

[24]My policy efforts proceeded the submission of my paper for scholarly publication.

[25]In Lemma 1, Balinski and Sönmez (1999) shows the equivalence between the *no justified envy* axiom and the existence of a list of supporting cut-off scores.

thorities, unless I also show that their current mechanism is really bad.

Seven years later, these two lessons guided my interactions with the authorities at Boston Public Schools.

3.2 Initial Research on School Choice

Shortly after Balinski and Sönmez (1999) was published, I realized that students were assigned seats at schools annually via similar centralized clearinghouses in the US as well, not for college admissions, but for K-12 admissions at several major school districts. This mode of centralized assignment of (typically public) school seats to students was advocated as an alternative to neighborhood assignment, and it was called *school choice*.

At first, the school choice problem appeared completely isomorphic to the student placement problem formulated and analyzed in Balinski and Sönmez (1999), except, rather than performance at standardized tests, typically other exogenous criteria were used to determine student priorities at schools. If that was the case, perhaps there was no room for additional formal analysis. After all, the problem was already solved in Balinski and Sönmez (1999) with SOSM as its unambiguous winner.

However, after examining the field implementation at several school districts, I arrived to the conclusion that school choice was a bit different than Turkey's student placement. More precisely, school choice offered more flexibility in its potential solutions, and in particular, it wasn't as clear as in Turkey that *no justified envy* was indispensable as a desideratum. I arrived to this conclusion because of two reasons.

The first reason was the broad structure of the criteria used to construct priority rankings of students at schools at various school districts. Unlike Turkey, reliance on standardized tests in order to priority rank students at schools was a rare occurrence in the US. In contrast, factors such as proximity of the home address to the school or the presence of a sibling already attending a school were among the more common practices in constructing priority rankings of students. When *no justified envy* is indispensable for a mechanism, it enforces full compliance to these priority rankings. In Turkey students would spend as much time preparing for national standardized tests as they would do at their schools for their education. Thus, it made sense to enforce full compliance to results of these nationwide tests in placement of students to competitive schools. But full compliance for a priority order at a school that is granted due to a home address or even a lucky lottery draw in some cases must have been less essential. The second reason was more direct. Of all student assignment mechanisms in the US we documented at more than a dozen school districts, there wasn't a single one that satisfied *no justified envy*. Presumably, if

no school district bothered to design a system which abides by this desideratum, it must have been potentially dispensable.

Based on this discovery, I decided to explore the formal implications of relaxing the *no justified envy* axiom. In my mind, the main difference between school choice and student placement in Turkish colleges was the possible dispensability of the *no justified envy* for the former. The flexibility to drop or relax this axiom was valuable for me due to the incompatibility between *no justified envy* and *Pareto efficiency* that was established in Balinski and Sönmez (1999). Naturally, my next objective was the design of a *Pareto efficient* mechanism without sacrificing any other plausible property of the SOSM such as *strategy-proofness* or *respect for priority improvements*.[26]

3.2.1 A Pareto Efficient Alternative to SOSM: Top Trading Cycles Mechanism

In order to address a shortcoming of a mechanism, often it is helpful to understand its source. The incompatibility between *no justified envy* and *Pareto efficiency* is due to following types of situations: There can be a student i whose priority at a school s is not high enough to secure a seat at school s, and yet it is high enough to "block" a Pareto improving trade between a student j who has sufficiently high priority at school s and student k who has sufficiently high priority at school t. If student j prefers school t to school s and student k prefers school s to school t, due to *no justified envy* they are unable to engage in a Pareto improving trade whenever student i has higher priority at school s than student k.[27] Thus, the cost of enforcing *no justified envy* is the loss of these types of Pareto improving trades between priorities. While trading priorities that are earned via standardized tests may be implausible, why wouldn't authorities allow for such trades in an application where school priorities are determined by factors such as proximity of the school to home? This idea immediately provided a natural connection between school choice and the *house allocation with existing tenants* model (Abdulkadiroğlu and Sönmez, 1999) that unifies the *housing markets* model (Shapley and Scarf, 1974) and the *house allocation* model (Hylland and Zeckhauser, 1979).

In both Shapley and Scarf (1974) and Hylland and Zeckhauser (1979), a number of indivisible objects, say houses, are allocated to a number of individuals with unit demands. The difference between the two models is that, Shapley and Scarf (1974) is a private-ownership economy where each individual owns a single house, whereas Hylland and Zeckhauser (1979) is a collective-ownership economy. The main solution concept for

[26] For school choice, *Pareto efficiency* already implies *individual rationality* and *non-wastefulness*.

[27] This observation is also the basis of *efficiency-adjusted deferred acceptance mechanism* (EADAM) in Kesten (2010), along with related ideas in Ehlers and Morrill (2019) and Reny (2022).

housing markets is the *core*, a single-valued mechanism whose outcome can be obtained with *Gale's top trading cycles* algorithm, famously discovered by David Gale during an early presentation of the paper by Herbert Scarf (Scarf, 2009). The main solution concept for house allocation is SSD where houses are allocated one-at-a-time for a given priority order. We extend these two models in Abdulkadiroğlu and Sönmez (1999), and formulate a generalized *top trading cycles* (TTC) mechanism which reduces to core for the special case of housing markets and to SSD for the special case of house allocation. This version of TTC allows individuals to trade their priorities over collective-ownership houses (called vacant houses) with their private houses (called occupied houses). Since priority order for each collective-ownership house is identical in Abdulkadiroğlu and Sönmez (1999), there is no use for a trade of priorities between two individuals. In school choice, in contrast, priorities are no longer identical at all schools. Thus, we simply adopted the TTC mechanism developed in Abdulkadiroğlu and Sönmez (1999) by dropping the private-ownership objects, and introducing heterogeneity for priority orders of schools. The resulting (school choice version of) the *Top Trading Cycles* (TTC) mechanism simply trades priorities of students whenever they lead to Pareto improvement. In Abdulkadiroğlu and Sönmez (2003), we proposed TTC as an alternative to SOSM for environments where full enforcement of priorities can be dispensed with.

As a mechanism for school choice, TTC is similar to SOSM in that, it also satisfies *individual rationality*, *non-wastefulness*, *strategy-proofness* and *respect for priority improvements*. On the other hand, TTC differs from SOSM by satisfying *Pareto efficiency*, albeit at the cost of losing *no justified envy*. By Balinski and Sönmez (1999), SOSM is the clear winner in applications where *no justified envy* is indispensable. In Abdulkadiroğlu and Sönmez (2003), we formulated TTC as a main alternative for applications where *no justified envy* is merely a secondary desideratum. Since we could not even find a single school district at the time which used a mechanism that satisfies *no justified envy*, we saw TTC as a strong contender against SOSM for school choice in the US.

3.2.2 Boston Mechanism

One of the biggest lessons from my experience with the Turkish authorities was the following: Availability of a good mechanism, even if it is theoretically perfect, is still not sufficient by itself to convince policymakers to engage in a costly reform. One also has to establish that the mechanism they use is clearly inferior to the proposed alternatives based on criteria that matters for the stakeholders. In my earlier interactions with the Turkish authorities, I simply failed to establish sufficient value for a reform that replaces MCSD with SOSM. At least with the 1997 data, the outcome of MCSD was the same as

the outcome of SOSM. In theory, this equivalence could have been an artifact of potential preference manipulation by the students, but there was no apparent reason (such as field evidence) to believe that this could be the case. Maybe, I thought, MCSD wasn't too bad after all... So, I turned my attention to finding real-life mechanisms that are more visibly flawed according to criteria which are likely to be important for the stakeholders.

Of all mechanisms we documented in Abdulkadiroğlu and Sönmez (2003) at more than a dozen major school districts in the US, one that stood out was the mechanism that was used for allocation of K-12 public school seats at Boston Public Schools (BPS). Indeed, of all mechanisms we documented at the time, this mechanism was the only one that was implemented in more than one school district. After learning about the history of this mechanism, we arrived to the conclusion that Boston may likely be the first school district that adopted this mechanism. As such, we named it as the *Boston mechanism*.[28]

In terms of its mechanics, the Boston mechanism is one of the simplest direct mechanisms one can imagine for school choice. Under this procedure the outcome of the mechanism is determined in several steps, first by assigning seats at the first-choice schools of students, next by assigning students unmatched from the first step seats at their second-choice schools, and so on. At every step of the procedure, any given school admits the highest priority students in consideration until all its seats are awarded. Informally speaking, the mechanism first handles the first choices, then the second choices, etc., literally in the most obvious way.

To its advantage, if we take the submitted student preferences at face value, then the outcome of the Boston mechanism is *Pareto efficient*. After all, in a very direct way this mechanism makes it a higher priority to accommodate first choices of students compared to their their second choices, and it similarly makes it a higher priority to accommodate any given ranked choices of students compared to their choices that are ranked lower in their submitted student preferences. But exactly because of the same mechanics, on the other hand, it also harbors strong incentives for students to manipulate their preferences. Since the Boston mechanism makes it such a high priority to assign seats at any school to those students who rank them first in their submitted preferences, it is really not a good idea for students to *waste* their first choices with schools they are unlikely to *afford* due to their low priorities at their target schools. We soon discovered that we were not the first ones to make this observation. There were several news stories guiding parents on this tricky aspect of the Boston mechanism. For example, the following quote is from Tobin (2003).[29]

[28]These days the Boston mechanism is also called the *immediate acceptance mechanism*.

[29]For similar statements from school districts that use the Boston mechanism, see Ergin and Sönmez

> "Make a realistic, informed selection on the school you list as your first choice. It's the cleanest shot you will get at a school, but if you aim too high you might miss. Here's why: If the random computer selection rejects your first choice, your chances of getting your second choice school are greatly diminished. That's because you then fall in line behind everyone who wanted your second choice school as their first choice. You can fall even farther back in line as you get bumped down to your third, fourth and fifth choices."

These discoveries convinced me that school districts which use the Boston mechanism may be more receptive to our reform ideas than the Turkish authorities. But before making my move, this time I decided to build a much stronger case against the Boston mechanism than I was able to make against the MCSD. In particular, I decided to explore to what extent the vulnerability of the Boston mechanism to strategic manipulation affects its efficiency.

Since the Boston mechanism is not *strategy-proof*, its efficiency analysis is not a straightforward exercise. In a laboratory experiment Chen and Sönmez (2006), we examined both the efficiency and to what extent students are engaged in strategic behavior for the Boston mechanism and its competitors SOSM and TTC. Our experimental analysis revealed that, while the Boston mechanism is *Pareto efficient* in the absence of strategic manipulation, in our designed environment it has lower efficiency than both SOSM and TTC. Indeed, in our experiment SOSM outperformed not only the Boston mechanism, but also TTC.[30] In order to further support the experimental evidence in Chen and Sönmez (2006), in Ergin and Sönmez (2006) we also showed that SOSM outperforms the Boston mechanism in terms of efficiency with a complete information equilibrium analysis of the latter mechanism.

(2006) for additional news stories, Abdulkadiroğlu and Sönmez (2003) for a statement from the education literature, and Pathak and Sönmez (2008) for meeting minutes of a parents group.

[30]While SOSM and TTC are both *strategy-proof*, in our experiment the subjects were not given this important information. As a result, many of them engaged in strategic behavior under these mechanisms and reduced their efficiency, but more so for TTC than SOSM. In real-life implementation, it is in the best interest of a school district to educate participants on the *strategy-proofness* of these mechanisms. Indeed, the fact that a school district can suggest students to be truthful without taking any risk is one of the most important benefits of adopting a strategy-proof mechanism. Hence, by not educating the subjects on the *strategy-proofness* of SOSM and TTC, in our experimental setup we analyzed these mechanisms in an environment that is unfavorable for them. Despite this treatment, both mechanisms outperformed the Boston mechanism, thus increasing our confidence that they are likely to be more efficient than the Boston mechanism in real-life implementation. There is, however, disagreement on this point in some of the follow up literature. For example, using approaches from mechanism design, Abdulkadiroğlu et al. (2011) argue that the Boston mechanism can be more efficient than SOSM in some environments.

3.3 Policy Impact at Boston Public Schools

With the main analysis in Balinski and Sönmez (1999), Abdulkadiroğlu and Sönmez (2003), the supporting analysis in Chen and Sönmez (2006), Ergin and Sönmez (2006), and anecdotal evidence of strategic behavior, we were ready to make our move against the Boston mechanism. However, it was one additional development that provided us with the impetus to approach the leadership at BPS for a potential reform of their student assignment mechanism.

3.3.1 Boston Globe Story on Abdulkadiroğlu and Sönmez (2003)

A few weeks after Abdulkadiroğlu and Sönmez (2003) was published, a reporter named Gareth Cook interviewed us about our analysis of the Boston mechanism and its alternatives. The resulting story in the *Boston Globe* provided us with the perfect opportunity to approach the leadership at BPS (Cook, 2003).

In preparing his story on Abdulkadiroğlu and Sönmez (2003), Gareth Cook communicated not only with parents who were frustrated with the Boston mechanism, but also with the officials at BPS and Boston School Committee. The following quotes are from this story:

> "Officials with the Boston public schools and the Boston School Committee readily acknowledge that parents are frustrated with the current system, and officials said at a School Committee meeting this week that they would make changing the system a priority. [...]
>
> "For every parent who feels frustrated about a policy, there is always a parent who will feel frustrated about an alternative," said Christopher M. Horan, chief of staff for the Boston public schools. Horan said he was intrigued by the economists' work and considered their suggestion a serious alternative. [...]
>
> Of course, no new system can create more seats at the most sought-after schools. But all parents interviewed by the Globe said that it would be a huge relief simply to write a truthful answer to the question: What school do you want?
>
> "A lot of the alienation some parents have toward the choice system is solely attributable to the alienation of not making your first choice your first choice," said Neil Sullivan, the father of four children who have attended Boston public schools."

3.3.2 Collaboration with Officials at Boston Public Schools

Not only did the Boston Globe story gave a very significant boost for our policy efforts at BPS, but it also reinforced my belief that I was on the right track on my broader strategy to influence policy. The vulnerability of the Boston mechanism to strategic manipulability was indeed a big burden for the families. Thus, the value of our proposed mechanisms in SOSM and TTC also became more visible with this story. With this important breakthrough, it became apparent that this was the right time to communicate with officials at BPS. In an e-mail message that included the Boston Globe story along with the four papers Balinski and Sönmez (1999), Abdulkadiroğlu and Sönmez (2003), Chen and Sönmez (2006) and Ergin and Sönmez (2006), I expressed to Superintendent Tom Payzant our desire to collaborate with their office for a potential reform of their school choice mechanism.

After receiving a reply to my e-mail message from Valerie Edwards, then Strategic Planning Manager at BPS, I had a phone discussion with her explaining our ideas and underlying motives. The officials at BPS initially seemed to be upset about the mayhem that was caused with the Boston Globe story, and indicated that they have no funding for me for these interactions. I tried to convince her that our driving force was a combination of scholarly and public service oriented pursuits, and that all our efforts are meant to be on a pro bono basis. My assurances facilitated an invitation to BPS to present the details of our policy proposal, and its expected benefits to the city. Following the phone discussion, I invited my co-author Atila Abdulkadiroğlu and Alvin Roth to the meeting I secured with officials at BPS. In October 2003, I gave a presentation on the merits of the potential reform we propose. Roth joined this meeting with Parag Pathak, who was then a first year graduate student at Harvard University under his guidance.

During my presentation, it became clear that, more so than anything else, it was the *strategy-proofness* of SOSM and TTC that secured this meeting. Given the more clear comparison between SOSM and the Boston mechanism due to Ergin and Sönmez (2006), in this meeting I focused mostly on SOSM as a plausible alternative for BPS. The group at BPS, however, were very well-prepared for the papers I had sent, and in the meeting they also inquired about our thoughts on TTC. By the end of this meeting, they were convinced that the Boston mechanism does not serve the city well, and it likely alters the submitted preferences. Since the city was using the preference information also to assess the popularity of its schools, a disconnect between submitted and true preferences were also of concern for the officials at BPS. They were also convinced that adoption of a *strategy-proof* mechanism will increase both the transparency of the system and parental satisfaction.

At the end of the meeting, officials at BPS decided to form a Student Assignment Task Force to evaluate the city's assignment process including our proposed reform. The task

force was formed in December 2003, and submitted its report and recommendations in September 2004 (Landsmark et al., 2004).

In order to support our proposed reform, officials at BPS also provided us with student preference data from earlier years under the Boston mechanism, and requested an empirical analysis of the extent of strategic behavior. This analysis, reported in Abdulkadiroğlu et al. (2006), corroborated the presence of strategic behavior under the Boston mechanism, and used by the city to support the reform. While the task force recommended adoption of the TTC rather than SOSM, the city at the end decided to adopt SOSM.

3.3.3 2005 School Choice Reform at BPS

In their May 2005 School Committee meeting open to the public, officials at BPS explained their recommendation to discard the Boston mechanism as follows:[31]

- The current process forces families to STRATEGIZE.
- Strategizing is imperfect because families don't know:
  - what their random number will be.
  - what schools other families are choosing.
  - how many others they're competing with.
- Assignment becomes a high-stakes gamble for families.
- Undermines families' trust in the BPS system.
- Families should not have to sacrifice their true preferences.
- Families should be able to be forthright about their choices.
- The system, not families, should compensate for mismatches between preferences and priorities.

Thus, the vulnerability of the Boston mechanism to strategic manipulation and the broader implications of this vulnerability dominated the decision to discard this mechanism. The key role strategy-proofness played in their recommendation was further emphasized as follows:[32]

- The current BPS assignment algorithm makes it risky for parents to rank an over-demanded school first, unless they have a high priority at that school.

[31] This itemization is directly taken from page 14 of an official 2005 BPS presentation to Boston School Committee (BPS Strategic Planning Team, 2005).

[32] This itemization is directly taken from page 36 of an official 2005 BPS presentation to Boston School Committee (BPS Strategic Planning Team, 2005).

- A Strategy-Proof Algorithm:
  - Removes the risk from ranking schools in order of true preference.
  - Eliminates the need for strategizing.
  - Adds "transparency" and clarity to the assignment process, by allowing for clear and straight forward advice to parents regarding how to rank schools.
  - "Levels the playing field" by diminishing the harm done to parents who do not strategize or do not strategize well.

Officials at BPS recommended the adoption of a *strategy-proof* mechanism for several reasons, including the transparency gained with the ability to offer straight-forward advice to parents, as well as its role to level the playing field for underprivileged parents who may not be able to strategize well. This last point was later formalized in Pathak and Sönmez (2008).

The appeal of adopting a *strategy-proof* mechanism made SOSM and TTC as natural replacements for the Boston mechanism. The officials at BPS explained their recommendation of SOSM as follows:[33]

- The Gale-Shapley Deferred Acceptance Algorithm will best serve Boston families, as a centralized procedure by which seats are assigned to students based on both student preferences and their sibling, walk zone and random number priorities.
- Students will receive their highest choice among their school choices for which they have high enough priority to be assigned. The final assignment has the property that a student is not assigned to a school that he would prefer only if every student who is assigned to that school has a higher priority at that school.
- Regardless of what other students do, this assignment procedure allows all students to rank schools in their true order of preference, without risk that this will give them a worse assignment than they might otherwise get.

Thus, the desiderata *no justified envy* and *strategy-proofness* were the main reasons for the BPS recommendation for SOSM.

[33]This itemization is directly taken from page 37 of an official 2005 BPS presentation to Boston School Committee (BPS Strategic Planning Team, 2005).

Finally, officials at BPS explained their hesitation to recommend TTC, despite its *strategy-proofness* and *Pareto efficiency*, as follows:[34]

- The Top Trading Cycles Algorithm allows students to trade their priority for a seat at a school with another student. This trading shifts the emphasis onto the priorities and away from the goals BPS is trying to achieve by granting these priorities in the first place.
- This trading of priorities could lead families to believe they can still benefit from strategizing, as they may be encouraged to rank schools to which they have priority, even if they would not have put it on the form if the opportunity for trading did not exist.
- The behind the scenes mechanized trading makes the student assignment process less transparent.

Even when priorities were not earned by standardized exams, officials at BPS were not comfortable with the idea of trading of priorities. Thus, the failure to satisfy *no justified envy* was seen as a handicap for this mechanism. In addition, officials were worried that, while TTC is *strategy-proof*, this feature may not be clear to families, and lead them to engage in strategic behavior. The officials were also worried that the mechanics of TTC were less transparent than the mechanics of SOSM which can be supported by cut-off scores.

In June 2005 the Boston School Committee voted to replace the Boston mechanism with SOSM. The city adopted SOSM starting the next school year, and has been using this mechanism for allocation of K-12 public school seats since then. The strong role various axioms played in both the successful policy efforts in Boston and the earlier unsuccessful ones in Turkey played an instrumental role in the initial development of minimalist market design .

3.4 External Validity for Minimalist Market Design: School Choice Reforms in England and Chicago

Following the reform at BPS, and two subsequent reforms in Chicago and England which had strong parallels, we made the following point in Pathak and Sönmez (2013a):

> "The Boston episode challenges a paradigm in traditional mechanism design that treats incentive compatibility only as a constraint and not as a

[34]This itemization is directly taken from page 38 of an official 2005 BPS presentation to Boston School Committee (BPS Strategic Planning Team, 2005).

> direct design objective, at least for the specific context of school choice. Given economists' advocacy efforts, one might think that this incident is isolated, and the Boston events do not adequately represent the desirability of nonconsequentialist objectives as design goals. To demonstrate otherwise, we provide further, and perhaps more striking, evidence that excessive vulnerability to "gaming" is considered highly undesirable in the context of school choice. Officials in England and Chicago have taken drastic measures to attempt to reduce it, and remarkably the Boston mechanism plays a central role in both incidents."

A signature feature of minimalist market design is that it is driven more by axioms than the mechanisms. At least, not by the good mechanisms design economists advocate for. It starts with an identification of which desiderata really matters for various stakeholders, and then proceeds with identification of various failures of the existing mechanisms based on these desiderata. The axiom-driven approach is a result of my thesis that stakeholders may potentially pay attention to alternative good mechanisms only if this stage in the advocacy process is already reached. I refer to this stage in a potential redesign as the initial stage of the *reform path*. In Boston, the officials explored alternatives to the Boston mechanism only after discovering its vulnerability to preference manipulation. This discovery was the initial stage of the *reform path*. Subsequently, officials selected a mechanism that escapes this failure, i.e., a *strategy-proof* mechanism. This was the second stage of the *reform path*. In my view, this two-stage *reform path* followed under the minimalist approach *imitates* the natural evolution of mechanisms.

Building on our analysis in Pathak and Sönmez (2013a), I will next discuss two subsequent reforms that followed the exact same reform path, although, in these cases, without any involvement of design economists. Due to this strong parallel, these two reforms provide *external validity* for my assertion that the minimalist approach "imitates" the natural evolution of mechanisms.

3.4.1 2007 Ban of the Boston Mechanism in England

In England, the nationwide 2003 School Admissions Code mandated that local authorities, an operating body similar to a US school district, should coordinate student admissions through a centralized mechanism. With the 2003 code, two classes of mechanisms were recommended. The first of these two classes was the SOSM and its "capped" versions where the maximum number of schools that can be ranked in student preferences are limited at a fixed number. The second one was a generalization of the Boston mecha-

nism called a *first preference first system* and its capped versions. Four years later, however, all versions of the first preference first systems including the Boston mechanism were banned throughout England with the 2007 School Admissions Code. As a result, all local authorities in England was using variants of SOSM by 2007.

The official justification for the ban of the first preference first system in England was parallel to the justification given by the BPS officials two years earlier for their recommendation to discard the Boston mechanism. According to the officials at England's Department for Education and Skills, "the 'first preference first' criterion made the system unnecessarily complex to parents" (School Code 2007, Foreword, p. 7). Moreover, Education Secretary Alan Johnson remarked that the first preference first system "forces many parents to play an 'admissions game' with their children's future."

Thus, just as in the 2005 school choice reform at BPS, the vulnerability of a mechanism to strategic manipulability and related concerns has lead to its demise in England as well. For our purposes, what is most important here is the underlying reform path of the 2007 school choice reform in England. More so than its own virtues, SOSM and its variants emerged as the primary mechanism in England because of a number of related and important failures of its main competitor based on desiderata that were important enough to change the School Admissions Code in England.

3.4.2 2009 School Choice Reform at Chicago Public Schools

A similar reform to those in BPS and England also took place in Chicago in 2009, although in a more abrupt way. The district abandoned a capped version of the Boston mechanism used for allocation of seats at selective high schools in the middle of the allocation process in 2009. A few months after the preferences were submitted under the capped Boston mechanism, but before the placements were announced, officials at Chicago Public Schools (CPS) asked the students to resubmit their preferences under a capped version of SOSM. This incidence was reported in a *Chicago Sun-Times* story as follows (Rossi, 2009):

> "Poring over data about eighth-graders who applied to the city's elite college preps, Chicago Public Schools officials discovered an alarming pattern.
>
> High-scoring kids were being rejected simply because of the order in which they listed their college prep preferences.
>
> "I couldn't believe it," schools CEO Ron Huberman said. "It's terrible."

> CPS officials said Wednesday they have decided to let any eighth-grader who applied to a college prep for fall 2010 admission re-rank their preferences to better conform with a new selection system."

In addition to the manipulability of the capped version of the Boston mechanism, its failure of *no justified envy* was also a major concern in Chicago. Thus, in a redesign where the reform path parallels those in Boston and England, the failure of the Boston mechanism to satisfy two desiderata that was deemed critical for the system led to its demise in yet another major school district, along with the adoption of a variant of SOSM. Remarkably, these failures must have been so unacceptable that, the officials could not even wait for the next academic year to correct their mechanism.

3.5 Contrast with 2003 School Choice Reform at New York City

Along with the 2005 school choice reform in Boston, two other successful applications of matching market design in mid 2000s were (i) a "similar" school choice reform in New York City (Abdulkadiroğlu et al., 2005b) and (ii) the establishment of centralized kidney exchange clearinghouses in the U.S. (Roth et al., 2005a). Naturally, the success of these applications, and especially the school choice reforms at New York City and Boston, were attributed to similar reasons. First focusing on the New York City school reform in this section and later on the social acceptance of organized organized kidney exchange in many countries in Section 4.6, I will argue otherwise. In my opinion, both the reasons for and also the manner in which they happened are fundamentally different in all three market design applications.

The key differences between these three applications are related to the classification of market design applications discussed in Section 2.1. Unfortunately, the lack of differentiation between the driving forces of these reforms in subsequent literature led to an over emphasis on the importance of various technicalities at the expense of broader lessons offered by them. Adoption of a design methodology guided by this classification may assist the efforts of an aspiring design economist who aims to influence policy via research.

In 2002, New York City Department of Education (NYCDOE) faced the following three issues with the assignment of rising high school students to more than 500 programs (Abdulkadiroğlu et al., 2005b):

1. Of nearly 100,000 students, approximately 30% had been assigned to a school that was not included in their submitted preference lists.

2. The system was vulnerable to strategic preference manipulation by the students in a way that is similar to the Boston mechanism.

3. A number of schools were able to conceal capacity from the central administration, and preserve seats for allocation outside the system.

Based on these failures, the NYC DOE Director of Strategic Planning contacted the eminent market designer Alvin Roth in May 2003, and inquired whether the matching process that was used for the US Medical match could be appropriately adopted for designing a new high-school matching process. Just as the SOSM, the *Roth and Peranson heuristics* (Roth and Peranson, 1999) that is used for the US Medical match is also based on Gale and Shapley's celebrated individual-proposing deferred acceptance algorithm. Therefore, by the time a team of market designers were involved in the re-design of the high school assignment process in New York City, the need for a reform was already established, and the authorities were in search of expert opinion to fix their broken system. Consequently, a leading expert in matching market design was "commissioned" for a redesign of the system. Moreover, the authorities were already leaning towards adopting a version of the SOSM.

Since the 2003 New York City high school assignment reform is an example of (what I refer to as) commissioned market design, the lessons it offers are very different from those under the 2005 BPS school choice reform. Indeed, with the exception of the final tinkering phase, all other steps of the institution redesign process I outlined in Section 2.2 is automatically bypassed under this reform. Apart from the practical value it generated for the students at New York City, the main contribution of this reform to the market design literature is twofold: First, it increased the visibility of school choice as a successful application of the field in earlier phases of market design. Second, it fostered a rich follow up empirical school choice literature through papers such as Abdulkadiroğlu et al. (2014) and Abdulkadiroğlu et al. (2017).

4 Kidney Exchange

One of the most unexpected applications of market design which contributed to visibility and success of the field is kidney exchange. Within a few years after the formulation of the theoretical framework for organized kidney exchange in Roth et al. (2004, 2005b, 2007) and Roth et al. (2006), our efforts transformed living donor kidney donation in many countries (Purtill, 2018), and started saving hundreds of lives every year (Rose, 2019). When our co-author Alvin Roth shared the Sveriges Riksbank Prize in Economic

Sciences in Memory of Alfred Nobel in 2012 with Lloyd Shapley, kidney exchange was the most prominent theme in the award ceremony speech of Torsten Persson as a member of the prize committee.[35]

How did three economists manage to develop the tools for and helped to establish the infrastructure which regularly touches so many lives? I will next argue that, some of the key ideas in minimalist market design played a big role in this impact.

4.1 Paired Kidney Exchange and List Exchange

Utku Ünver and I were faculty members at Koç University in İstanbul in early 2000s. Utku spent the academic year 2002-2003 at Harvard University, visiting Alvin Roth. During his visit, Roth mentioned that the *house allocation with existing tenants* model (Abdulkadiroğlu and Sönmez, 1999) has a direct application called "kidney exchange" in healthcare. Our first joint paper Sönmez and Ünver (2005) happened to be on that very model.

Naturally, the connection of our work to an application in healthcare made us very excited. Subsequently, we learned that kidney exchange refers to two types of arrangements called *paired kidney exchange* and *list exchange*. Both arrangements involve kidney patients and their willing living donors. But typically due to immunological incompatibilities, either blood-type incompatibility or tissue-type incompatibility, a transplant from a donor and her paired patient is either infeasible or less than ideal. Both types of kidney exchanges were developed by doctors to bypass this barrier to living donation.

A *paired kidney exchange* involves an exchange of donors between two kidney patients, each of whom is incompatible with her own donor, but compatible with the other patient's donor. Hence, it is essentially an in-kind gift exchange between two patient-donor pairs to overcome biological incompatibility. This concept was originally proposed by a transplant surgeon in Rapaport (1986), and it has been practiced in South Korea starting with early 1990s (Park et al., 1999). The idea gained traction in the US in early 2000s, after it was declared to be ethically acceptable by the *Live Organ Donor Consensus Group* (Abecassis et al., 2000). A handful of paired kidney exchanges were carried out in the US prior to our involvement in 2004. The biggest challenge was, there was no organized system or even a database to facilitate these exchanges. In early 2000s, existing routines to discover paired kidney exchanges were restricted to rudimentary practices such as discoveries in places like dialysis rooms during discussions between patients and their donors.

[35] Award ceremony speech by Torsten Persson is available in `https://www.nobelprize.org/prizes/economic-sciences/2012/ceremony-speech/`.

A list exchange (also called an *indirect exchange*) is introduced in Ross and Woodle (2000), and involves an exchange of a kidney from an incompatible living donor of a patient and a kidney from the deceased-donor list. The patient receives priority in the deceased-donor queue if her incompatible donor instead donates a kidney to the queue. Since it only involves a single patient-donor pair, compared to paired kidney exchange, a major appeal of list exchange is its organizational simplicity. However, one major ethical concern pointed out by Ross and Woodle (2000) was the likely detrimental impact of this practice on blood-type O patients whose options are restricted to a kidney from the deceased-donor queue. Patient-donor pairs that have a blood-type O patient are much more likely to volunteer for a list exchange than pairs with a blood type O donor.[36] This is especially worrisome in the US, because blood type O is disproportionately more common among some minority groups.

4.2 Relation to Abdulkadiroğlu and Sönmez (1999)

Upon learning about this very exciting potential application in healthcare, Utku and I expressed to Roth our interest in pursuing a joint research project with him on kidney exchange. Roth initially declined our invitation due to two reasons. The first reason was, he did not believe economists could write this paper by themselves, without an expert in transplantation. The second reason was, he thought kidney exchange was a direct application of the house allocation with existing tenants model, and therefore he thought, there wasn't much formal analysis left to carry out.

His reservations were perfectly valid. The parallel with Abdulkadiroğlu and Sönmez (1999), discussed in Section 3.2.1, is based on the following observations. From a modeling perspective, in the context of kidney exchange,

- patients with incompatible (or less than ideal) living donors play a similar role to existing tenants who desire to receive more-preferred houses than the houses they currently occupy,
- living donors of patients play a similar role to occupied houses by existing tenants,
- patients in deceased-donor lists who have no living donors play a similar role to newcomers who do not currently occupy any house, and

[36]There are four blood types A, B, O, and AB. In the absence of other complications, a blood-type O kidney can be transplanted to any patient, a blood-type A kidney can be transplanted to patients who have blood types A or AB, a blood-type B kidney can be transplanted to patients who have blood types B or AB, and a blood-type AB kidney can be transplanted only to a patients who have blood type AB.

- deceased-donor kidneys or living-donor kidneys from non-directed donors play a similar role to vacant houses.[37]

Despite this strong parallel between kidney exchange and Abdulkadiroğlu and Sönmez (1999), Utku and I believed that there was high value to pursue this project. In our view, kidney exchange was a perfect example of a "Goldilocks" problem. One reason for our optimism was the ethical concerns due to list exchanges, and the possibility of modifying the variant of the TTC mechanism in Abdulkadiroğlu and Sönmez (1999) to address these concerns. Another reason was the value of simulating the number of transplants which could be obtained through an organized system. Finally, after absorbing a few dozen papers on kidney exchange and kidney transplantation, we were confident that this project could be pursued by economists alone. We shared our thoughts with Roth, and suggested that, perhaps he could decide whether he would like to join us in this project after seeing its first draft.

Roth gave us his blessing to go ahead if we were so determined. Utku and I did some additional reading on the topic, and started working on formal and computational aspects of the model. Ignoring the presence of a baseline model in Abdulkadiroğlu and Sönmez (1999) for a moment, in terms of the fit between the actual application and its formulation in theoretical research, kidney exchange was a far more challenging application of institution design than school choice. Not only did kidney exchange involve far more details and considerations from more distant fields (eg. transplantation, immunology, and medical ethics), there was often no consensus in many aspects of the problem in their respective literatures.[38] Therefore, from the beginning, it was apparent that there was no single best model for kidney exchange.

4.3 First Kidney Exchange Model in Roth, Sönmez and Ünver (2004)

In contrast to our objectives in school choice where we advocated for a few very refined policy recommendations, our focus in kidney exchange at this stage was merely providing intuition on the virtues of,

1. setting up a database for patient-donor pairs, and

2. organizing kidney exchanges through a systematic mechanism.

[37] In Roth et al. (2004), the analog with vacant houses was only given for deceased-donor kidneys. The same analogy was later introduced for non-directed donor kidneys in Roth et al. (2006), which also introduced and advocated for non-simultaneous *donor chains* initiated by non-directed (a.k.a. good samaritan) donors.

[38] For example, as thoroughly discussed in Roth et al. (2004), the literature was unclear on whether a reduction in HLA mismatch between the patient and donor would increase graft survival or not.

Our efforts paid off, and after inspecting the first draft, Roth decided to join our project. Shortly after, we circulated our study in September 2003, and published a shorter version in Roth et al. (2004). Adopting Abdulkadiroğlu and Sönmez (1999) to kidney exchange, and building on earlier innovations of doctors (i.e., paired kidney exchange and list exchange), our main contribution in Roth et al. (2004) can be summarized as follows: The number of transplants from kidney exchanges can be increased by several orders of magnitude, while avoiding any harm to the pool of blood type O patients on deceased-donor list at the same time.[39] That is, we could improve upon both of the main desiderata emphasized in earlier kidney exchange literature in transplantation, by directly using enhanced versions of innovations in this literature, and merely by organizing kidney exchanges more efficiently. Therefore, Roth et al. (2004) can be seen as an exercise in minimalist market design, albeit the role of axiomatic methodology in its analysis is not as prominent as in school choice presented in Section 3.

The main root cause of the shortcomings of existing kidney exchange programs were (1) the absence of a database which contained living donor information, and (2) the lack of a systematic mechanism to organize these exchanges. A secondary root cause of these shortcomings was the restriction of both types of kidney exchanges to their simplest forms that only involve the smallest possible number of patient-donor pairs. For paired kidney exchange this number is two, and for list exchange it is one. We showed that, the effectiveness of a kidney exchange program could be increased considerably by allowing for 3-way or larger direct exchanges, or adopting larger donor "chains" initiated by volunteers of list exchanges. By addressing these shortcomings using their own innovations, in Roth et al. (2004) we presented to members of the transplantation community both a methodology and a class of mechanisms which together offer significant improvements on both desiderata discussed in the literature.

[39] According to UNOS database, during the period 2001-2004, 63 transplants were performed in the US through pairwise kidney exchanges. In the same period, the number of living-donor kidney transplants was 25,404 and the number of deceased-donor kidney transplants was 34,801 in the country. Therefore 0.25% of living donor kidney transplants and 0.1% of all kidney transplants were obtained through paired kidney exchanges in the US in period 2001-2004. These numbers increased orders of magnitude after the introduction of organized kidney exchange. In period 2019-2022, 4019 living-donor kidney transplants were due to kidney exchanges in the US. In the same period, the number of all living-donor kidney transplants was 23,935 and the number of deceased-donor kidney transplants was 72,451 in the country. Therefore, even though the number of living-donor kidney transplants decreased in the US (likely) due to a considerable increase in the number of deceased-donor transplants, the number of living-donor transplants from kidney exchanges increased by a factor of 64. As a result, in period 2019-2022, 16.79% of living-donor kidney transplants and 4.2% of all kidney transplants were obtained through kidney exchanges in the US. Data available at `https://optn.transplant.hrsa.gov/data/view-data-reports/national-data/`.

4.4 Second Model in Roth, Sönmez and Ünver (2005b) and Establishment of New England Program for Kidney Exchange

New England was the first region in the US which embraced kidney exchanges. Approved by the United Network for Organ Sharing (UNOS) Board of Trustees in the Fall 2000, a kidney exchange program was established in New England (UNOS region 1) in February 2001 (Delmonico et al., 2004).[40] In addition to uncontroversial paired kidney exchanges, list exchanges were also arranged by the program despite the ethical concerns. Inclusion of the more controversial form of kidney exchange in the program was defended in Delmonico et al. (2004) by the following familiar principle:

> "This exchange program has a clear utilitarian goal: to have more recipients undergo successful transplantation by expanding the pool of compatible live donors."

Indicative of the concerns of this decision, however, much of the discussion in Delmonico et al. (2004) involves the precautions taken in the region to mitigate the adverse impact of the program on blood type O patients on the deceased-donor waiting list.

At this early phase, the program did not collect data on willing living donors of its kidney patients. As a result, from 2001 to 2004, only 5 paired kidney exchanges were arranged by the program Roth et al. (2005b).[41] Since it only involves a single patient-donor pair, arranging a list exchange can be expected to be a lot easier. However, a prerequisite for eligibility for list exchange was to assure that no paired kidney exchange is feasible between the patient and any other patient registered in all 14 transplant centers in New England. According to Delmonico et al. (2004),

> "The duration that the RTOC [Renal Transplant Oversight Committee] will wait for a live donor exchange pair to come forward from another center has not been regulated, although the general practice has been to

[40] UNOS is the non-profit that oversees organ transplants under contract with the US federal government.

[41] According to UNOS database, during the period 2001-2004, 10 transplants were performed in New England through 5 pairwise kidney exchanges. In the same period, the number of living-donor kidney transplants was 1364 and the number of deceased-donor kidney transplants was 1443 in New England. Therefore 0.73% of living donor kidney transplants and 0.36% of all kidney transplants were obtained through paired kidney exchanges in New England in period 2001-2004. These numbers increased by an order of magnitude after the introduction of organized kidney exchange. In period 2019-2022, 197 transplants were performed in New England through kidney exchanges. In the same period, the number of living-donor kidney transplants was 1199 and the number of deceased-donor kidney transplants was 2381 in New England. Therefore 16.43% of living-donor kidney transplants and 5.4% of all kidney transplants were obtained through kidney exchanges in New England in period 2019-2022. Data available at `https://optn.transplant.hrsa.gov/data/view-data-reports/regional-data/`.

> ask such pairs to wait a minimum of one month, in order to avoid flooding the system with 'unnecessary' list exchanges. If no such pair is identified, the center can proceed with the live donor list exchange process."

As a result, arranging list exchanges also involved operational challenges in New England. Nevertheless, 17 of these exchanges were carried out in New England between February 2001 and December 2003.

Shortly after the circulation of our paper in September 2003, Roth secured a meeting with Dr. Francis Delmonico, the Chief Medical Officer at New England Organ Bank. Out of sheer luck, this meeting was arranged at a time when members of New England transplantation community were open minded about ideas that could improve their relatively new kidney exchange program. Naturally, members of the transplantation community had a lot less experience with organizing a system of exchanges than ethical and medical aspects of the resulting transplants.

During the meeting, Delmonico was intrigued by our simulations, but he expressed a few reservations about our model. His first reservation was easy to address. Given the potential number of transplants offered by an organized system, Delmonico did not think there was any need to include the more controversial list exchanges to the system. His second and third reservations, however, were more substantial, and they required additional analysis. Delmonico indicated that, since all procedures in a kidney exchange must be performed simultaneously by the consensus statement of transplantation community in Abecassis et al. (2000), at that point in time they could only consider two-way exchanges. In addition, he did not like the notion of patients having preferences over compatible kidneys. According to Delmonico, the only relevant information on patient preferences should have been whether a kidney is compatible with the patient or not.

The adjustments needed in our original model to accommodate Delmonico's reservations were fairly straightforward. However, at the time, we were not familiar with the formal techniques that would be needed to analyze this new model. This could have posed a very serious problem had abstract theory not come to our rescue! Fortunately, just a few months earlier, economists Anna Bogomolnaia and Hervé Moulin published a paper on a closely related theoretical model, although under an assumption which precluded its adoption to kidney exchange (Bogomolnaia and Moulin, 2004). If only we could provide an analysis for the more general version of the model we needed, we could then address Delmonico's reservations. Building on foundational work of Gallai (1963, 1964) and Edmonds (1965, 1971) in discrete optimization, this is exactly what we did in Roth et al. (2005b).

The progress we made in our second paper on kidney exchange was well-received by

the members of New England's transplantation community, and it formed the basis of the New England Program for Kidney Exchange (NEPKE) founded by our team of three design economists along with doctors Francis Delmonico and Susan Saidman (Roth et al., 2005a). Approved by the Renal Transplant Oversight Committee of New England in September 2004, NEPKE became the first organized kidney exchange system in the world which utilized formal techniques from market design and optimization.

4.5 Tinkering Phase: Three-Way Exchanges and NDD-Initiated Chains

In order to operationalize NEPKE, it was necessary to set up a web-based data entry system which enables each transplant center to enter their own patient and donor information to the system. This process and settling the bureaucratic requirements for NEPKE took about a year. During that period, Utku coded the software for NEPKE using a priority matching algorithm we formulated in Roth et al. (2005b).[42] Even though Delmonico initially indicated that they could only carry out two-way kidney exchanges in New England, for our research purposes, Utku also coded priority matching algorithms that allowed for larger size kidney exchanges.

After NEPKE became operational in 2006, for a few years, New England kidney exchanges were determined by Utku's software. Every few months, our team would receive anonymized patient-donor data from NEPKE, and we would run his software to derive any new kidney exchanges. This was a very exiting period for us. We were literally saving lives with our ideas. Hence, as soon as anonymized data arrives from NEPKE, Utku and I would immediately inspect it to guess how many transplants the software would determine.

In one of these episodes, the number of transplants obtained by the software turned up one transplant more than we thought it was even feasible when three-way exchanges are allowed in the system. This observation was a big surprise. At the time, our intuition for maximal-size kidney exchange was due to Roth et al. (2005b), admittedly in a model which only allowed for two-way exchanges. To offset this caveat, we would then use some of the technical details in our proofs to estimate the maximum number of transplants if larger-size exchanges are also allowed. This unexpected discovery revealed that our intuition was apparently incomplete.

Subsequently, we carried out a careful analysis of the impact of allowing for larger-size kidney exchanges on the number of transplants. Based on this analysis, when we

[42] When only two-way exchanges are feasible, a priority matching also maximizes the number of patients who receives a transplant (Roth et al., 2005b).

discovered that, due to a formal structure induced by blood types of patients and their donors,

1. in a large patient-donor pool the maximum number of transplants can be attained if three-way and four-way kidney exchanges are allowed, and

2. much of these gains over two-way exchanges are due to three-way exchanges.[43]

Given these results, we were able to convince our partners in New England to allow for three-way kidney exchanges in the system, and published our findings in Saidman et al. (2006) and Roth et al. (2007).[44]

Our collaboration with Drs. Delmonico and Saidman also resulted in another important discovery. Prior to this collaboration, altruistic donors were not a major source of livings donor kidneys in the US. Indeed, according to UNOS database, only 8 such transplants were conducted in the US before 2000.[45] However, this number was increasing in early 2000s, and it offered a possibility to start donor chains with an altruistic *non-directed* (NDD) donor, rather than a patient-donor pair who volunteers for list exchange. Moreover, since they do not interfere with the deceased-donor waiting lists, these NDD-chains were not subject to the same type of ethical concerns which hindered utilization of list exchanges in NEPKE.

NDD chains also offered another possibility. In their consensus statement , Abecassis et al. (2000) urged all procedures in kidney exchange to be performed simultaneously, mainly to avoid a situation where the donor of a pair donates a kidney as part of a donor exchange, but her intended patient cannot receive a transplant later on, because the other donor backs out or becomes unavailable. However, this was much less of a concern with an NDD chain which starts with an altruistic donation. Since all patients receive a transplant before their paired-donor donates it to the next patient in the chain, the worst that could happen is the chain remaining shorter than it could be. Because of these observations, we formulated *non-simultaneous* NDD chains in Roth et al. (2006). While this idea was never practiced by NEPKE, it was later embraced by another kidney exchange program, *Alliance for Paired Donation* (APD) launched in 2006 in midwest.[46] Due to its logisti-

[43]For small pools with 25 patient-donor pairs, the gain was approximately a 30% additional transplants from kidney exchanges. In large pools with 100 patient-donor pairs, this increase reduced to 20% or so additional transplants from kidney exchanges.

[44]With three-way exchanges allowed in our system, a priority matching no longer guaranteed maximizing the number transplants in the system. Consequently, we adopted an alternative algorithm which maximized the number of transplants à la Roth et al. (2007).

[45]Data available at `https://optn.transplant.hrsa.gov/data/view-data-reports/national-data/`.

[46]Starting with 2006, our team also established a partnership with APD. Based on Roth et al. (2007) and Roth et al. (2006), from its inception APD included three-way and four-way exchanges in their allocation

cal advantages, the role of non-simultaneous NDD chains in kidney exchange programs considerably increased over time (Agarwal et al., 2019).

4.6 Contrast with 2005 School Choice Reform in Boston

Kidney exchange illustrates that the minimalist approach is also valuable as a methodology that provides intuition, in complex environments where a realistic model may be unattainable. The success of our efforts in kidney exchange, however, must be evaluated with a number of peculiarities of the application. Two factors, in particular, greatly affected the success of our efforts in kidney exchange. The first one is, the primary desideratum for economists–increasing the number of transplants–was also a first order desideratum for medical doctors. But perhaps more importantly, we were not trying to replace an elaborate institution with a new one. On the contrary, we were offering a range of techniques that have potential to increase the value of earlier innovations in transplantation literature, most notably paired kidney exchange and list exchange, orders of magnitude.

Since we were not critical of an existing institution, we did not risk anything more than wasting valuable time of medical professionals. In my view, this is one of the main reasons why our initial model and analysis in Roth et al. (2004)–despite its deviations from the vision of officials in New England Organ Bank–were not dismissed by Dr. Delmonico. Instead, he was pleasantly surprised that economists have something useful to offer, and they suggested us we modify certain aspects of our model to better fit his vision and constraints on kidney exchange. This guidance resulted in Roth et al. (2005b), which proved to be far more useful for medical doctors than Roth et al. (2004), and along with a number of follow up papers in Saidman et al. (2006), Roth et al. (2006) and Roth et al. (2007), it served as a blueprint for many kidney exchange clearinghouses worldwide to come.

5 US Army's Branching Process

Since many elements of minimalist market design *imitates* the natural evolution of real-life institutions, my earlier efforts in school choice that shaped this approach were largely a result of my instincts. The same is also the case for our joint efforts in kidney exchange. At that early stage in my academic career, I was not consciously following any given

mechanism, and included non-simultaneous NDD chains shortly after. Just as NEPKE's software, the software used by APD from 2006 to 2008 was also coded by Utku Ünver. See Anderson et al. (2015) for the details of our subsequent partnership with APD.

framework. Only after observing the similarities between the engineered school choice reform in Boston and the subsequents natural reforms in England and Chicago, it became clear that the methodology that emerged from my integrated research and policy efforts over the years may be the basis of a promising institution design framework more broadly. Consequently, starting with the branching process of cadets to Army branches in the US in early 2010s, I religiously followed the minimalist approach in several subsequent applications of market design. US Army's branching process of cadets to military specializations is the first of these applications.

Together with Lieutenant Colonel Kyle Greenberg and Parag Pathak, in Fall 2020, I guided a reform of the US Army's branching processes at United States Military Academy (USMA) and Reserve Officer Training Corps (ROTC), which took effect with Class of 2021 in both institutions. In Greenberg et al. (2023), we present the first direct application–and subsequent proof of concept–of the minimalist market design paradigm as a whole. The focus in Greenberg et al. (2023) is largely on this final and successful phase of a decade-long efforts on research and policy on this application. In the rest of this section, in contrast, I largely focus on initial phases of my efforts with (then) Major Tobias Switzer which sow the seeds for this policy impact.

5.1 My Introduction to US Army's Branching Process

In May 2011, I received an unusual e-mail from Major Tobias Switzer, a young US Air Force officer who sought my feedback on his master's thesis (Switzer, 2011) from the Catholic University of Chile.[47] Following the basic structure of Balinski and Sönmez (1999) and adopting the *no justified envy* axiom to his framework, Switzer (2011) studies the branching process of cadets to military specialties at the United States Military Academy (USMA).[48] Upon reading his thesis, I observed that the problem he studied was fascinating and his critique of the mechanism used at West Point (henceforth the *USMA-2006 mechanism*) was valid. However, one aspect of the thesis I questioned was the practical viability of the alternative mechanism proposed in Switzer (2011). This was a time when I just learned about the school choice reforms at Chicago and England, and systematically started looking at potential applications of institution redesign with a minimalist mindset. As a result of this mindset, my skepticism of Tobias's alternative mechanism was rooted in its deviation from the minimalist approach.

The starting point of Switzer (2011) is consistent with the minimalist approach:

[47] As of this writing, Tobias Switzer is a Colonel at the U.S. Air Force.

[48] Following the terminology introduced in Balinski and Sönmez (1999), Switzer (2011) also refers to the *no justified envy* axiom as fairness.

Switzer (2011) starts the analysis by identifying a number of key policy objectives for the Army, and establishes that the USMA-2006 mechanism fails some. However, deviating from the minimalist approach, in design of an alternative mechanism Switzer (2011) alters a policy parameter which has nothing to do with the failure of the USMA-2006 mechanism. From a pure academic perspective, there is nothing wrong with this methodology. Indeed, these types of choices are carried out in other institution design paradigms on a regular basis. From my perspective, however, this choice was a major barrier against the policy relevance of his proposal. Therefore, interpreting the proposed mechanism as one that interferes with an Army policy choice, I made the following point in my e-mail reply:

> "If I were to design a mechanism to correct the deficiency, I would have suggested exactly what you did in terms of the cadet preferences, but I would have kept the 2 types of positions separate. For the first type of positions the priority would be based on cadet merit ranking and for the second type of position the priority would be adjusted based on whether the cadet is willing to pay the additional price or not. I think this proposal would have been "close" to the current algorithm and it would have still handled the deficiencies that you pointed out. In a way, I felt you adjusted the mechanism a little too much."

Subsequently, I learned from Tobias that his proposal was indeed not pursued by the relevant Army offices. The failures of the USMA-2006 mechanism observed in Switzer (2011) along with my alternative proposal, the *Cadet-Optimal Stable Mechanism (COSM)*, resulted in a collaboration between us which materialized in Sönmez and Switzer (2013).

5.2 History of Branching Process and the BRADSO Incentive Program

Tobias's research strategy in following the basic structure of Balinski and Sönmez (1999) in his thesis made sense, because, there are many similarities between the US Army's branching process and the Turkish student placement problem earlier discussed in Section 3.1. Army's branching process involves assigning USMA cadets to branches in their senior year. Branching among the 17 Army career specialties (such as Aviation, Infantry, Military Intelligence, etc.) plays an important role in a cadet's career progression. Each fall the Army announces the number of positions available to USMA cadets at each branch. Prior to 2006, the allocation of these positions was implemented with a *simple serial dictatorship* that is induced by a cadet performance ranking called the *Order of Merit List* (OML). Let's refer to this mechanism as *SSD-OML*. Under SSD-OML, cadets submit their preference rankings over branches, and the highest OML-ranked cadet receives her

first choice branch, the next highest OML-ranked cadet receives her top choice branch among the remaining positions, and so on. Therefore, cadet claims over positions at Army branches simply depended on their performance rankings prior to 2006, a practice that makes sense given the importance of hierarchy in the Army. Moreover, due to the importance of trust both among cadets themselves and also between cadets and the USMA leadership, another key advantage of this mechanism was in its *strategy-proofness*. Naturally, a system which allows cadets to be out gamed by other cadets or the system would not be helpful to foster trust among its participants.

In response to historically low retention rates among junior officers, starting with the Class of 2006, the Army introduced a second avenue for cadets to receive access to branches of their choices. The idea was giving cadets elevated priority for a fraction of positions at any branch of their choices if they would commit for a three years of *Active Duty Service Obligation* (ADSO) in addition to the default five years. This incentive scheme is known as the *Branch-of-Choice (Active Duty Service Obligation)* (BRADSO) program. Since many senior officers in the Army were against interfering with a system that purely allocates positions based on performance ratings, this mode of access to branches was limited to 25% of the positions at each branch.[49] Priority for the remaining 75% of the positions at each branch continued to be based on the OML.

Naturally, adoption of the BRADSO program required the Army to modify its branching mechanism. Essentially, the idea was extending their original mechanism SSD-OML which basically allocates all positions with a single performance ranking in a way that can accomodate two criteria. Army's modification was simple. Under the USMA-2006 mechanism, in addition to their preferences over branches, cadets were also asked to select a set of branches for which they would like to invoke the BRADSO program to receive preferential access to the last 25% of the positions. Given the submitted strategies of cadets, a procedure similar to SSD-OML was used to allocate the positions, except, once the initial 75% of the positions were assigned at any given branch, the second criteria kicked in to allocate its remaining positions. A cadet who received a position at a given branch,

[49] See, for example the following quote from Appendix E of Colarusso et al. (2010):

> "The branch and post incentives also raised concerns. Devoted supporters of the ROTC and West Point Order of Merit (OML) system for allocating branches and posts objected that low OML cadets could "buy" their branch or post of choice ahead of higher OML cadets. Since branch and post assignments represent a zero sum game, the ability of cadets with a lower OML ranking to displace those above them was viewed by some as unfair or as undermining the OML system. However, rather than undermining the legacy system or creating inequities, the branch and post incentives program makes willingness to serve a measure of merit in branching and posting, thus providing taxpayers a fair return on their officer accessions investment."

say Infantry, was then charged the additional three years of ADSO only if (i) he received one of the last 25% of Infantry positions and (ii) he volunteered for the Infantry BRADSO incentive.

As natural as this modification sounds, it has a number of failures that were discovered in Switzer (2011). Most notably, a cadet could receive a less-preferred outcome than some of her peers despite having a higher OML ranking, merely because she volunteered for the BRADSO incentive for her assigned branch. Formally, the USMA-2006 mechanism fails to satisfy the following natural extension of the *no justified envy* axiom.

Definition 6 (Switzer (2011); Sönmez and Switzer (2013))**.** [50] *An assignment of branches to cadets along with their "prices" (i.e., ADSO charges) satisfies* ***no justified envy****, if, there is no branch b and two distinct cadets c, d such that,*

1. *cadet d is assigned a position at branch b at some price t,*
2. *cadet c strictly prefers branch-price pair (b, t) to her own assignment, and*
3. *cadet c has a higher OML ranking than cadet d.*

The failure of *no justified envy* under the USMA-2006 mechanism essentially indicates a failure of integrating two allocation criteria harmoniously in designing an allocation mechanism. Exactly because of the same failure, the USMA-2006 mechanism also harbors incentives to game the system, either by misreporting branch preferences or by hiding willingness for the BRADSO incentives.

The root cause of both failures of the USMA-2006 mechanism is twofold. First, the strategy space of this mechanism is not sufficiently rich to properly represent cadet preferences. For example, if a cadet volunteers for the BRADSO incentive for her first choice branch, it still remains unclear whether she prefers her first choice branch at increased price to her second choice branch at its cheaper base price. Despite this ambiguity, by considering each cadet for all positions at her first choice before considering her for the base-price positions at her second choice, the USMA-2006 mechanism de facto operates as if a cadet who volunteers for the BRADSO incentive for her first choice branch always prefers an increased-price position at her first choice to the base-price position at her second choice. Fortunately, addressing this issue is relatively straightforward with a simple adjustment of the strategy space of the mechanism. Rather than asking cadets to submit their preferences over branches along the set of branches for which they volunteer for the BRADSO incentive, asking them to submit their preferences over branch-price pairs

[50] Following the terminology in Balinski and Sönmez (1999), this axiom is also referred to as *fairness* in Switzer (2011) and Sönmez and Switzer (2013).

would fix this issue. The second source of the failures is more subtle. A cadet who volunteers for the BRADSO incentive for a branch pays the increased price whenever she receives one of the last 25% of its positions, even if she would still receive this position at the base price without volunteering for the BRADSO incentive. From a technical perspective, addressing this second issue is more challenging, unless the problem is simplified.

5.3 Alternative Mechanism by Switzer (2011)

In order to address the first source of issues under the USMA-2006 mechanism, Switzer (2011) amends the strategy space of cadets as we discussed above. That is, cadets submit their preferences over branch-price pairs under Tobias's proposed mechanism. The second source of issues, however, is more complicated as we indicated. Switzer (2011) addresses this challenge as follows: For each branch, he defines a priority ranking of cadet-price pairs where

1. any pair with the increased price has higher priority than any other pair with the base price, regardless of the cadets in these pairs, and otherwise
2. the relative ranking between two pairs with the same price is determined by the OML.

Observe that, under Tobias's priority structure all units at a given branch use the exact same criteria for allocation where the price is always the primary consideration.[51] Thus, the simplification Switzer (2011) uses to manage the second source of the failures is aggregating the two criteria of the Army into a single priority ranking of cadet-price pairs. As its outcome function, Tobias's mechanism then relies on a procedure that is reminiscent of SSD, except, cadets make their applications to branches together with their intended prices and branches use the adjusted priorities over cadet-price pairs to evaluate these applications. Since a cadet can make two applications for any given branch, one at the base price and another at the increased price, Tobias's procedure allows branches reject a cadet who was earlier tentatively admitted with a base price, due to subsequent applications with the increased price, thereby introducing an iterative structure similar to the McVitie and Wilson (1970) version of the celebrated deferred acceptance algorithm (Gale and Shapley, 1962).

It is easy to see that Tobias's procedure terminates in finite steps, and the resulting mechanism satisfies *no justified envy* and *strategy-proofness*, thus addressing the failures of

[51] This particular design choice by Tobias was the basis of my skepticism for the viability of this mechanism for the Army. After all, for the reasons discussed in footnote 49, Army provided the volunteers of BRADSO incentives with elevated priority only in a fraction of the positions.

the USMA-2006 mechanism. From a research perspective this is a well-executed thesis. From a policy perspective, however, Tobias's proposal strongly interferes with some potentially delicate balances. While at the time I did not know why the Army restricted the use of the BRADSO incentives to a fraction of the positions, I knew that this policy decision was unlikely to be arbitrary. Whereas the USMA-2006 mechanism uses two criteria to allocate the positions, Tobias's proposed mechanism reduces them into a single aggregate criterion. That is why I thought this aspect of the mechanism is likely a "deal-breaker," and decided to refine Tobias's mechanism in a way that uses both criteria in exactly the same way the Army used.

5.4 Relation to Matching with Contracts and Cadet Optimal Stable Mechanism

One question in my mind was the following: Why did Tobias not use the Army's dual-criteria priority structure in his proposed mechanism? After all, the remaining elements of his mechanism could still be used with this modification, but this mechanism would be much closer to the USMA-2006 mechanism. Then, I made the following observation which puts his choice into perspective. The version of the mechanism with the Army's dual-criteria priority structure is much harder to analyze than the version with a single criterion. Indeed, Switzer (2011) is a special case of the celebrated *matching with contracts* model (Hatfield and Milgrom, 2005) where the choice rules for branches that capture Tobias's aggregated priority structure satisfy the following well-known condition:

Definition 7. *Consider a choice rule $C(.)$ which selects a feasible set of cadet-price pairs from any set of available cadet-price pairs. Then, choice rule $C(.)$ satisfies the* ***substitutes*** *condition, if, whenever a cadet-price pair gets selected among a set of pairs, it still gets selected from a set-wise smaller set due to removal of some other pairs.*

Moreover, the outcome function of Tobias's proposed mechanism reduces to the *cumulative offer process* by Hatfield and Milgrom (2005). Throughout their analysis, Hatfield and Milgrom (2005) assume that the substitutes condition along with another one called *independence of rejected contracts* (IRC) are satisfied by choice rules of all institutions.[52] Since the choice rule at each branch satisfies both conditions under Tobias's priority structure, Theorem 4 in Hatfield and Milgrom (2005) immediately implies that the axiom *no justified envy* is satisfied by Tobias's mechanism. Furthermore, since the choice rule at each

[52]The assumption of the IRC condition is implicit in Hatfield and Milgrom (2005). See Aygün and Sönmez (2013) for details.

branch also satisfies another condition called *the law of aggregate demand* (LAD) under Tobias's priority structure, by Theorem 11 in Hatfield and Milgrom (2005) his mechanism also satisfies *strategy-proofness*.

Under the Army's dual-criteria priority structure, however, the resulting branch choice rules no longer satisfy the substitutes condition. The reason is the following: Consider a set of cadet-price pairs that includes both the base-price and the increased-price pairs for a given cadet c. A branch could select the increased-price option for the cadet and thus reject the base-price option from this set of pairs, and yet make the reverse selection rejecting the increased-price option from a set-wise smaller set with less competition. The failure of the substitutes condition is the main technical challenge for analyzing Tobias's proposed mechanism with the Army's original priority structure. However, the Army's dual-criteria priority structure satisfies the following weaker substitutes condition:

Definition 8. *Consider a choice rule $C(.)$ which selects a feasible set of cadet-price pairs from any set of available cadet-price pairs. Then, choice rule $C(.)$ satisfies the* ***unilateral substitutes*** *condition, if, whenever a cadet-price pair (c,t) gets selected among a set of pairs where (c,t) is the only pair that involves cadet c, the pair (c,t) still gets selected from a set-wise smaller set due to removal of some other pairs.*

Thanks to a very important generalization of Hatfield and Milgrom (2005) by Hatfield and Kojima (2010), the cumulative offer mechanism still satisfies *no justified envy* and *strategy-proofness*, provided that choice rules satisfy the unilateral substitutes condition along with IRC and LAD. Importantly, the branch choice rules induced by the Army's dual-criteria priority structure satisfy all three technical conditions (Sönmez and Switzer, 2013). Hence, the cumulative offer mechanism implemented under the Army's dual-criteria priority structure is well-defined and well behaved! Thus, a modest change in the strategy space of the mechanism along with the natural adaptation of its outcome function recovers all failures of the USMA-2006 mechanism. This mechanism is referred to as the *cadet-optimal stable mechanism* (COSM) in Sönmez and Switzer (2013), and proposed to the Army as a minimalist amendment of the USMA-2006 mechanism.

5.5 Failure of Efforts to Reform the USMA-2006 Mechanism

Despite several attempts with related officials, for many years our efforts to collaborate with the Army for a re-design of their branching mechanism did not succeed. In that period, my long time collaborator Parag Pathak started teaching my research on Army branching in his graduate Market Design at MIT, and independently advocated it to

USMA officials. Several years later, in 2019, I finally learned why the Army initially did not pursue a potential reform of the USMA-2006 mechanism.

As we discussed in Section 5.2, the first root cause of the failures of the USMA-2006 mechanism is the following: Its strategy space is not sufficiently rich to capture all details of cadet preferences over branch-price pairs. But, exactly because of the same reason, any failure of the *no justified envy* axiom rooted in this first issue was also "invisible" for the Army. When a cadet receives his first choice branch at the increased price, but instead prefers his second choice at the base price, this information was simply unavailable under the strategy space of the USMA-2006 mechanism. In contrast, the second root cause of the failures of the USMA-2006 mechanism has more tangible implications. Recall that the second issue was due to some cadets needlessly paying the increased price under the USMA-2006 mechanism for their assigned branch even though they would have received the same branch at its base cost had they not volunteered for its BRADSO incentives. This issue was more "visible," because cadets who are adversely affected by this anomaly could observe that there are lower OML-ranked cadets who receive the same branch at its base cost. Despite this challenge, however, it could be simply managed by a manual adjustment of the outcome by foregoing the additional ADSO charge by any affected cadet.

Therefore, any anomalous outcome under the USMA-2006 mechanism was either invisible due to its strategy space, or it could be corrected with a simple manual adjustment. With cadet preference analysis we carried out several years later, it also became clear that the scale of these types of failures affected about 2% of the cadets on average under the USMA-2006 mechanism (Greenberg et al., 2023). Just as the benefits from replacing MCSD mechanism with SOSM for Turkish colleges admissions were not sufficiently large to justify a costly reform for the officials many years earlier, the benefits from replacing the USMA-2006 mechanism with COSM were not sufficiently large to justify a costly reform of the US Army's branching system.

5.6 Talent-Based Branching Program and the Redesign of US Army's Branching System

It would take several years and Army's integration of a second program with its branching system to convince the Army officials that COSM is indeed the mechanism that serves its policy objectives the best.

In 2012, the Army introduced a Talent-Based Branching (TBB) program which introduced heterogeneity into branch priorities. Under the TBB program, branches rate cadets

into one of three tiers, high, medium, and low. Until 2019, these ratings remained a pilot initiative. For the Class of 2020, the Army decided to integrate them into the branching process, constructing priorities at each branch first by the tier and then by the OML within the tier. In order to avoid undermining the TBB program with BRADSO incentives, cadets who volunteered for the BRADSO incentives at a branch only received higher priority within their own tier for the branch. Since USMA-2006 mechanism was not equipped to accommodate these changes, a new mechanism was designed and implemented for the Class of 2020. We refer to this mechanism which only survived one year as the *USMA-2020* mechanism.

Under the new mechanism the Army maintained the same strategy space as in previous years. Using an adjusted priority order of cadets that takes both TBB ratings and increased-price willingness into consideration, the new mechanism used the individual-proposing deferred acceptance algorithm (Gale and Shapley, 1962) to determine the branch assignments. As for the ADSO charges, following the reverse-priority order of cadets at any given branch and subject to a cap of 25% of the positions, cadets who volunteer for the BRADSO incentives are charged the increased price, and the rest of the cadets are charged the base price.

In addition to inheriting the same root causes of the failures of the USMA-2006 mechanism, the USMA-2020 mechanism was also plagued by a third one: Even though the number of positions allocated via the BRADSO program was kept at 25% of the total capacity at each branch, cadets received elevated priority for all its positions upon volunteering for BRADSO incentives. While this design choice made it possible to accommodate the heterogeneity in branch priorities by using the vanilla version of the deferred acceptance algorithm,[53] it also resulted in a more problematic version of *no justified envy* failures that could not be manually corrected. To make the matter worse, the same issue also introduced a second type of incentive compatibility failure. Not only volunteering for BRADSO incentives could still hurt cadets just as in the USMA-2006 mechanism, it could also profit them under the USMA-2020 mechanism due to receiving elevated priority at a branch without paying the increased price. The end result was a mechanism that is highly complex to participate in, and one with more widespread and costly failures.

[53]Indeed, the following quote from the *U.S. Army News* story O'Connor (2019) suggests that, the design of USMA-2020 mechanism was inspired by the NRMP's medical match:

> "The cadets' branch rankings and the branches' cadet preferences will then determine a cadets' branch using a modified version of the National Resident Matching Program's algorithm, which won a Nobel Prize for Economics in 2012 and pairs medical school graduates with residency programs."

Before a formal analysis was carried out by our team, the USMA leadership already recognized these issues with the USMA-2020 mechanism. A major concern emerged as an erosion of cadets' trust in the Army's branching process due to a visible lack of incentive compatibility especially for over-demanded branches such as Military Intelligence, and failures of *no justified envy* especially when they are not manually corrected ex-post. To mitigate these concerns, the USMA leadership decided to execute a dry run of the USMA-2020 mechanism to inform cadets of the potential cutoffs for each branch.

As emphasized in the following quote from a September 2019 U.S. Army news article O'Connor (2019), the goal of the dry run was to improve transparency and help cadets to optimize their submitted strategies:

> "We're going to tell all the cadets, we're going to show all of them, here's when the branch would have went out, here's the bucket you're in, here's the branch you would have received if this were for real. You have six days to go ahead and redo your preferences and look at if you want to BRADSO or not." Sunsdahl said. "I think it's good to be transparent. I just don't know what 21-year-olds will do with that information."

The same quote, however, also indicates that USMA leadership recognized the challenges in cadets optimizing their strategies under the USMA-2020 mechanism. Given the challenges of the new mechanism, at this stage, the Army established a collaboration with our group for a redesign of their branching mechanism, with Lieutenant Colonel Kyle Greenberg leading the reform efforts at USMA. Whereas the USMA-2006 mechanism was not bad enough to justify a costly reform of the Army's branching system, the USMA-2020 mechanism was.

Starting with the Class of 2021, our collaboration with the Army resulted in the adoption of COSM at USMA with Army's dual-criteria priority structure (Greenberg et al., 2023). Pleased with the new mechanism, the Army also decided to adopt it for the Reserve Officer Training Corps (ROTC), the second main program the US Army relies on to recruit and train its officers.[54] Systematically following all its elements since its inception in 2011, our joint research and policy efforts to reform the US Army's branching system serves as a proof of concept for the minimalist approach (Greenberg et al., 2023).

[54]Sönmez (2013) shows that the shortcomings of the previous ROTC branching system are more severe than under the USMA-2006 mechanism.

6 Formulation and Implementation of Normative Criteria: Equitable Allocation of Public Positions in India

One of the technical challenges Army officials faced integrating BRADSO incentives with the branching system was the need to design a mechanism which allocates some positions with one criterion, and others with a second. While officials had no difficulty rigorously defining and implementing allocation policies based on a single criterion, using a second criterion to allocate some of the positions proved to be a formidable task. This type of challenge in designing real-life allocation mechanisms is not peculiar to Army officials. Technical aspects of mechanisms such as the Army's branching system are fairly complex, and expecting a fully satisfactory design from officials who have no expertise in design economics is hardly a reasonable expectation. This is one of the reasons why it is important for academic market designers not to restrict their focus on general economic principles such as preference utilitarianism. Formulation, analysis and implementation of various normative criteria is an important direction where market designers can, and indeed have been providing useful guidance in various field applications. As it is emphasized in Li (2017),

> "Market design must speak about ethics because policymakers sometimes need help expressing what they want. [...] A policymaker may be familiar with the details of their environment, and yet not know how to state their ethical requirements in precise terms."

And even when they do, policymakers or other decision makers are not trained to design mechanisms which abide by ethical or other forms of principles. And yet, they design such systems all the time. For example, despite their lack of expertise in formal analysis, the justices in India have been formulating the normative principles that guide the affirmative action policies of the country for decades. Indeed, in many cases they even design the mechanisms which are meant to implement these principles.

6.1 Affirmative Action in India

Our next application pertains to one of these cases, where a flawed design that was mandated by a Supreme Court judgment *Anil Kumar Gupta (1995)* resulted in countless lawsuits in the country, before it was corrected after 25 years in a subsequent judgment *Saurav Yadav (2020)* of the Supreme Court. The judgment in *Saurav Yadav (2020)* provides external validity for the minimalist approach, for it parallels policy advice earlier provided in Sönmez and Yenmez (2022a).

Affirmative action for various disadvantaged groups is embedded into the 1950 Constitution of India through articles 14-18.[55] In field applications, these protective policies are implemented through a *reservation system* which sets aside a certain fraction of positions in public jobs and seats at public schools for various protected groups. Naturally, the Constitution itself does not provide any rigorous formula to implement these policies. Nevertheless, in a landmark Supreme Court judgment *Indra Sawhney (1992)*, the justices formulated these provisions in a rigorous way, at least for the more basic versions of the reservation system.[56]

Throughout Section 6, we restrict our attention to the version of the problem studied in Sönmez and Yenmez (2022a), where a public institution allocates several identical positions based on merit scores of applicants along with their memberships in protected groups. In the absence of affirmative action, this problem reduces to the most basic single-school version of the student placement problem we discussed in Section 3.1, and therefore it has a straightforward solution through a *simple serial dictatorship* induced by merit scores. This simple mechanism is adjusted in India to accommodate two types of affirmative action policies, a primary policy called *vertical reservations* (VR) and a secondary policy called *horizontal reservations* (HR).[57]

6.2 Vertical Reservations, Migration and the Over-and-Above Choice Rule

Under the VR policy, a fraction of the positions are exclusively set aside for each of a number of protected groups. Unlike the VR-protected positions, the remaining *open-category* (or *open*) positions can be awarded to any applicant.

Up until the *103rd Constitutional (Amendment) Act, 2019*, the target groups for the primary VR policy were restricted to groups whose members had suffered marginalization and discrimination based on their hereditary social (i.e., caste or tribal) identities. These groups are mainly Scheduled Castes (SC), Scheduled Tribes (ST) and Other Backward Classes (OBC). From a technical point of view, the social identity based vertical reservation system meant that no individual could be a member of multiple VR-protected groups. While VR protections are also provided to individuals in economic disability since 2019 with the enactment of the 103rd Amendment,[58] members of the earlier and so-

[55] This segment of the Constitution is referred to as *Equality Code* in India.

[56] Considered the main reference on the reservation system in India, this case is popularly known as the *Mandal Commission* case.

[57] The VR policy is referred to as *reservations proper* in paragraph 95 of *Indra Sawhney (1992)*.

[58] This more recent vertical category is called *Economically Weak Segments* (EWS.)

cial identity based VR-protected groups are excluded from its scope,[59] thereby still maintaining the *non-overlapping* structure of VR-protected groups in the country.

The defining property of the VR policy is formulated as follows in *Indra Sawhney (1992)*:[60]

> "It may well happen that some members belonging to, say Scheduled Castes get selected in the open competition field on the basis of their own merit; they will not be counted against the quota reserved for Scheduled Castes; they will be treated as open competition candidates."

Therefore, this key mandate from the Supreme Court assures that the VR-protected positions are allocated to members of their target groups who truly need positive discrimination, and not allocated to those who deserve an open position solely based on merit.

One subtle (but very important) aspect of the above quote from *Indra Sawhney (1992)* is its use of a rudimentary technical tool, which is often referred to as *migration* (a.k.a. *mobility*) in Indian legal terminology. In India, the group of individuals who do not belong to any VR-protected category are referred to as the *general* category. Unlike a VR-protected category, say SC, where category-SC positions are exclusively reserved for members of SC, the open-category positions are not exclusively reserved for members of the general category. Indeed, in order to emphasize this point, the justices explicitly indicate in the above quote that "the reservations under Article 16(4) do not operate like a communal reservation." But, because the Indian legal terminology does not differentiate between categories of individuals and categories of positions, despite the "mismatch" between the two concepts, the terms "open" and "general" are used interchangeably in legal documents. The notion of *migration* is likely a byproduct of this misleading aspect of the legal terminology. For example, when a member of SC receives an open position on her merit due to VR policy, she is considered to have "migrated" from SC to the general category. Effectively, designers of the reservation systems in the country, despite the complex legal requirements, try to "simplify" the system by dividing the set of applicants in partitions and using SSD to allocate positions available for each partition. And whenever a natural partition does not exist, they rely on the notion of migration to artificially create one. In my view, the use of this rudimentary technical tool along with a second one called *adjustments* considerably aggravate the legal and practical challenges faced in implementation of India's reservation system.[61]

[59] This exclusion is highly controversial in India. See Sönmez and Ünver (2022) for a case study in minimalist approach to market design which analyses this exclusion in 103rd Amendment.

[60] See paragraph 94 of the judgment.

[61] See, for example, Section 5 in Sönmez and Yenmez (2022b) for the detrimental impact of reliance on

In the absence of the secondary horizontal reservations, it is straightforward to implement the VR policy as follows with a two-step procedure that is known as the *over-and-above choice rule*: Open positions are allocated in the first step to applicants with highest merit scores. Then, in the second step, positions reserved for each VR-protected group are allocated to the remaining individuals with highest merit scores from these groups. Observe that, this procedure consists of repeated implementation of the SSD, first for the open category, and next for each VR-protected category.[62]

6.3 Horizontal Reservations and Adjustments

Target groups for the secondary HR policy are independent of hereditary social identities, and they include protected groups such as persons with disabilities and women. While an applicant can be a member of multiple HR-protected groups, in order to simplify the presentation, I will focus on the case where an individual can belong to at most one HR-protected group (*non-overlapping HR protections*). This restriction is without loss of generality, and as shown in Sönmez and Yenmez (2022a), all analytical results extend to the case with *overlapping HR protections*.

Unlike the VR policy which is precisely defined in *Indra Sawhney (1992)*, the following description of the HR policy in the same judgment is less clear:[63]

> "Horizontal reservations cut across the vertical reservations that is called inter-locking reservations. To be more precise, suppose 3% of the vacancies are reserved in favour of physically handicapped persons; this would be a reservation relatable to Clause (1) of Article 16. The persons selected against this quota will be placed in the appropriate category; if he belongs to S.C. category he will be placed in that quota by making necessary adjustments; similarly, if he belongs to open competition (O.C.) category, he will be placed in that category by making necessary adjustments. Even after providing for these horizontal reservations, the percentage of reservations in favour of backward class of citizens remains - and should remain - the same."

For example, it is unclear what exactly the *necessary adjustments* refer to, and how they are to be made. While this ambiguity on the notion of "adjustments" and how to implement

these rudimentary technical tools in India.

[62] As it is shown in Sönmez and Yenmez (2022b), the practice of repeated implementation of SSD in reservation systems is also prevalent in applications where positions are heterogenous across multiple institutions.

[63] See paragraph 95 of the judgment.

the HR policy are later cleared by a subsequent judgment of the Supreme Court in *Anil Kumar Gupta 1995*, the detrimental implications of reliance on rudimentary technical tools to implement complex normative criteria further intensified in the country.[64]

Anil Kumar Gupta 1995 clarifies the following two characteristics of the HR policy, which differentiate it from the VR policy.

1. The HR policy is implemented as *soft reserves*. That means, while the members of the protected group receive preferential treatment for the HR-protected positions, these positions are not exclusively set aside for these individuals. Any HR-protected position that still remains after all members of the protected category receive a position, then they can be awarded to other eligible individuals.

2. Positions that are "earned" via merit (either from open category or a VR-protected category) still count against the HR-protected positions. Therefore, the HR policy is implemented on a "minimum guarantee" basis.

Possibly to avoid complications that can emerge due to overlaps between "property rights," the justices also recommended the HR policy to be implemented within each vertical category, including the open category.[65] For example, if there are horizontal reservations for women, then women are provided with preferential access for a fraction of the positions in each category (i.e., open, SC, ST, OBC, etc.) separately.

In order to operationalize the HR policy, this policy could be implemented for any given category with the following procedure called the *minimum guarantee* choice rule (Hafalir et al., 2013): Given a set of individuals who are eligible for the positions at the given category, in the first step, the HR-protected positions for any HR-protected group are allocated to its beneficiaries with highest merit scores. In the second step, any remaining positions (including the unused HR-protected positions) are allocated to remaining individuals who have highest merit scores. If the justices of the Supreme Court were accustomed to formal modeling and analysis, they could have embedded the implementation of horizontal reservations within the implementation of vertical reservations simply as follows: Instead of using SSD to allocate positions at each vertical category (including the open), they could have used the minimum guarantee choice rule. That is, in the first step the open positions are allocated with the minimum guarantee choice rule, and in the second step the positions at each VR-protected category are allocated to remaining

[64]The formulation of the HR policy in *Anil Kumar Gupta 1995* is further clarified in a subsequent Supreme Court judgment *Rajesh Kumar Daria(2007)*.

[65]This mode of HR policy is referred to as *compartmentalized* horizontal reservations in *Anil Kumar Gupta (1995)*.

eligible individuals again with the minimum guarantee choice rule. Following Sönmez and Yenmez (2022a), I refer to this mechanism as the *two-step minimum guarantee* (2SMG) choice rule.

The justices, however, are rarely accustomed to formal modeling, and naturally they are unfamiliar with the minimum guarantee choice rule. As a result, in *Anil Kumar Gupta (1995)* the justices formalized and used the notion of "adjustments" to operationalize the HR policy. Under their mechanism, open positions are tentatively allocated with SSD in the first step, and the VR-protected positions are subsequently allocated to remaining eligible individuals again with SSD.[66] Then comes the use of "necessary adjustments" to accommodate the HR policy in a third step. So, for example, if the women minimum guarantee is not accommodated for some category, say SC, at the end of the first two steps, then the lowest merit score SC men who are tentatively admitted are replaced by the highest merit score unmatched SC women to accommodate the HR policy within category SC.

There is, however, one tricky aspect of this adjustment process. Suppose that, the minimum guarantee constraints are short by one woman both for the open category and also for the VR-protected category SC. Then, if there is an unmatched woman from SC, it is not entirely clear whether she should replace a man from the open category for the adjustment process or a man from the SC category. The justices responded to this type of technical challenge by also partitioning the "adjusters" into distinct groups, and restricting access for open-category horizontal adjustments to members of the general category only. In my view, this design choice may have been affected with the way the notion of migration is used under the VR policy. An unmatched SC woman by the end of step 2 has not migrated to the general category by this stage of the procedure, and perhaps this may be why she was deemed ineligable for an adjustment within the open category. Whatever the underlying reasonings were, with this design choice the set of individuals entitled for horizontal adjustments at each vertical category conveniently becomes uniquely defined for the third step of the procedure. Following Sönmez and Yenmez (2022a), I refer to this mechanism, mandated in India between years 1995 and 2020, as the *SCI-AKG* choice rule.

6.4 Failures of the SCI-AKG Choice Rule and Its Minimalist Correction

In order to see what is wrong with the SCI-AKG choice rule, it is useful to relate it to the minimum guarantee choice rule. The following notion, heavily used in legal documentation in India to describe various normative principles or reservation mechanisms,

[66] Observe that, these two steps together give the over-and-above choice rule.

is especially helpful to describe the connection between the two choice rules.

Definition 9. *A member of a VR-protected category receives the status of a* ***meritorious reserved candidate****, if she is among the highest merit score applicants who deserve an open category position.*

As it is shown in Sönmez and Yenmez (2022a), the SCI-AKG choice rule can be alternatively defined as follows in two steps: Restricting consideration to members of the general category and meritorious reserved candidates, open positions are allocated in the first step using the minimum guarantee choice rule. Then, for each VR-protected category, reserved positions are allocated in the second step also using the minimum guarantee choice rule.

Observe that, from a consequentialist perspective, the only difference between the choice rules SCI-AKG and 2SMG is the set of applicants who compete for the open positions in the first step. Whereas all applicants are considered for open positions under the 2SMG choice rule, only members of the general category and meritorious reserved candidates are considered under the SCI-AKG choice rule. Therefore, unless she is a meritorious reserved candidate, a member of a VR-protected category is denied access to HR-protected positions in open category.

This difference between the two choice rules immediately identifies the root causes of the failures of the SCI-AKG choice rule. With the exception of the recent EWS category, a member of a VR-protected category is not required to declare membership for her category.[67] Therefore, by claiming her VR protections, an individual loses her open category HR protections under the SCI-AKG choice rule. Thus, this mechanism fails a form of *incentive compatibility* axiom, first formulated in Aygün and Bó (2021). More visible in the field, it also fails the following version of *no justified envy* tailored to the current context:

Definition 10 (Sönmez and Yenmez (2022a))**.** *An allocation of positions across vertical categories (including open) to applicants satisfies* ***no justified envy****, if, there is no category v and two distinct applicants i, j who are both eligible for category v, such that,*

1. *applicant j is awarded a position at category v,*
2. *applicant i receives no position at all, and*
3. *applicant j neither has a merit score that is as high as the score of applicant i, nor awarding her a category-v position at the expense of applicant i increases the number of HR-protected positions that are honored at category v.*

[67] In contrast, documenting ineligibility for social identity (i.e., caste or tribal) based VR-protected categories is a prerequisite to claim membership for EWS. That typically requires documentation of forward caste membership in India.

Observe that, for any category v and two applicants i, j who are both eligible for this category, awarding a position to applicant j at the expense of applicant i cannot be justified either through meritocracy nor through affirmative action. And yet, this key social justice axiom fails under the SCI-AKG choice rule, exactly because, members of VR-protected groups are ineligible to compete for the open-category HR-protected positions (unless they are meritorious reserved candidates). Thus, consistent with minimalist market design, elimination of the root cause of the failures of the SCI-AKG choice rule merely involves a removal of this exclusion, which immediately results in the 2SMG choice rule.

6.5 External Validity for the Minimalist Approach by the Supreme Court of India

The first draft of Sönmez and Yenmez (2022a) was circulated in March 2019 as the Boston College working paper Sönmez and Yenmez (2019). Following the minimalist approach, we have shown that the Supreme Court-mandated choice rule SCI-AKG (in some cases) reverses the intended affirmative action measures by its failure of *no justified envy*.[68] We have also documented that, for more than two decades, this failure resulted in countless litigations in the country, and disrupted the recruitment processes on a regular basis. Since the failure of *no justified envy* under the choice rule SCI-AKG became especially worrisome in states which mandate horizontal reservations for various groups, several high court judgments in these states directly contradicted the Supreme Court judgment *Anil Kumar Gupta (1995)*. As a resolution, in Sönmez and Yenmez (2019) we formulated the 2SMG choice rule as a minimalist alternative to SCI-AKG choice rule.

Subsequent to the circulation of Sönmez and Yenmez (2019) and in a judgment that provided external validity to minimalist market design, the Supreme Court revoked the SCI-AKG choice rule in *Saurav Yadav (2020)*. Perhaps most importantly, the justices mandated the axiom *no justified envy* in India with their judgment. In addition, the justices also endorsed the choice rule 2SMG as one that satisfies *no justified envy*, even though they did not mandate it explicitly. Importantly, the reform was the consequence of the failure of a key social justice axiom–*no justified envy*–under the choice rule mandated by the Supreme Court. The first order issue for the justices was the enforcement of a key principle, and their advocacy for a specific mechanism came only as a secondary consideration. Therefore, just as in the case of the earlier school choice reforms in Boston, Chicago, England and the branching reform by the US Army, the reform of the Supreme Court's mecha-

[68] In Sönmez and Yenmez (2019), the SCI-AKG choice rule is referred to as the SCI-VHR choice rule, and the *no justified envy* axiom is referred to as *elimination of justified envy*.

nism is the direct consequence of a major failure of the existing mechanism based on a very important principle.

There is one subtle aspect of the judgment *Saurav Yadav (2020)* which is very important, even though it is not well-understood in India. In addition to mandating the *no justified envy* in this judgment, the justices also made the following important clarification for implementation of VR policy in the presence of HR policy. By *Indra Sawhney (1992)*, a VR-protected position cannot be awarded to beneficiaries who deserve an open position on the basis of merit. However, this landmark judgment did not explain who deserves an open position in the presence of horizontal reservations. This vagueness is finally removed under *Saurav Yadav (2020)*, where an individual who deserves an open position is legally defined as one who deserves an open category position on the basis of merit with or without invoking the HR protections. Due to this important clarification, the following axiom is also mandated by *Saurav Yadav (2020)*:

Definition 11 (Sönmez and Yenmez (2022a))**.** *An allocation of positions across vertical categories (including open) to applicants satisfies* ***compliance with VR protections****, if, no applicant is assigned a VR-protected position, provided that she deserves an open-category position*

a. either due to her merit score, or

b. due to increasing the number of HR-protected positions that are honored within open-category.

This clarification is highly consequential, because, subject to not discarding positions (*non-wastefulness*) and honoring HR protections (*maximal accommodation of HR protections*), the only choice rule that satisfies *no justified envy* and *compliance with VR protections* is the 2SMG choice rule (Sönmez and Yenmez, 2022a). Therefore, while the justices have not explicitly mandated the choice rule 2SMG in *Saurav Yadav (2020)*, they have de facto mandated it in the country, for there exists no other choice rule that satisfies the explicit mandates of the judgment.[69]

7 Pandemic Medical Resource Allocation During Covid-19

Covid-19 pandemic revealed yet another vital resource allocation problem where minimalist market design proved to be very useful (Pathak et al., 2020d). Thanks to the central focus this approach places on the needs of the stakeholders, over the course of a year,

[69]The 2SMG choice rule is mandated in the state of Gujarat under the High Court judgment *Tamannaben Ashokbhai Desai (2020)*.

we were able to communicate our ideas with dozens of healthcare officials when these ideas were most useful. The same focus also helped our team to convince many of these officials or experts in medical ethics and public healthcare to advocate for and adopt the reserve systems we designed for equitable allocation of vaccines and therapies on real time, as the need arise (Persad et al., 2020; Schmidt, 2020; Schmidt et al., 2020, 2021; Rubin et al., 2021; Pathak et al., 2021, 2022; White et al., 2022).

7.1 The Toughest Triage

At the onset of the Covid-19 pandemic the world faced a challenge unlike any other for decades. In a perspective piece in the *New England Journal of Medicine*, Truog et al. (2020) reflected upon some of these challenges the world was beginning to face.

> "Although rationing is not unprecedented, never before has the American public been faced with the prospect of having to ration medical goods and services on this scale."

In the same issue of the *New England Journal of Medicine*, Emanuel et al. (2020) outlined the desirable ethical principles for allocation of scarce medical resources in crisis situations, and urged healthcare officials worldwide to develop the guidelines and procedures to implement them:

> "The need to balance multiple ethical values for various interventions and in different circumstances is likely to lead to differing judgments about how much weight to give each value in particular cases. This highlights the need for fair and consistent allocation procedures that include the affected parties: clinicians, patients, public officials, and others. These procedures must be transparent to ensure public trust in their fairness."

At the time Emanuel et al. (2020) and Truog et al. (2020) were first published online in March 2020, the rationing of ventilators and intensive care units (ICUs) was already underway in Northern Italy (Rosenbaum, 2020). Upon exploring with Parag Pathak and Utku Ünver how these ethical principles were operationalized for allocation of ventilators and ICUs, we made an important discovery, one that made it clear that it is time to put our expertise into good use. Little did we know that, for nearly a whole year from that time on, the three of us would end up setting aside all unessential activities and devote all our time and energy to contribute to the global fight to combat Covid-19.

As the recommended allocation rule for crisis rationing of ventilators and ICUs, state guidelines in the US almost uniformly suggest some form of a *priority point system*. In

these guidelines, the point score of a patient is most often determined by a measure of mortality risk called *Sequential Organ Failure Assessment* (SOFA) score.[70] I refer to this specific priority point system as the *SOFA system*.[71]

While a single utilitarian ethical principle, i.e., *saving most lives*, determined who receives a ventilator or an ICU in crisis situations under most state guidelines in the US, we made the following observation in two of the most elaborate guidelines from New York State and Minnesota: During their deliberations in preparing these guidelines, members of both task forces wanted to accommodate a second ethical principle known as the principle of *instrumental value*. Under this principle, individuals who can help save additional lives are given special consideration in allocation of vital resources. As it can be seen in the below-given quotes from these guidelines, however, members both task forces could not figure out how to operationalize the *instrumental value* principle along with their primary principle of *saving most lives* without risking outcomes they deem unacceptable.

> "[...] 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."
>
> Vawter et al. (2010), MN Dept. of Health

> "[...] 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."
>
> Zucker et al. (2015), NY Dept. of Health

Task forces for healthcare crisis management guidelines usually consist of experts from medicine and medical ethics and officials in healthcare. Naturally, members of these professions usually have no formal expertise in designing allocation mechanisms. Moreover, literatures on medical ethics and public healthcare traditionally rely on various forms of priority systems for allocation of scarce medical resources, including when they accommodate multiple ethical values. For example, at the onset of Covid-19, the leading

[70] This procedure can be thought as a simple serial dictatorship induced by the SOFA score.

[71] SOFA scoring system is first introduced in Vincent et al. (1996) on behalf of the Working Group on Sepsis-Related Problems of the European Society of Intensive Care Medicine. Under this system, 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 across the six organ groups determine the SOFA score of the patient, which then determines her priority for a ventilator or an ICU. In recent years, however, many expressed concerns that the SOFA system discriminates against certain groups. See, for example, Tolchin et al. (2021) for one such study.

allocation system which accommodated multiple ethical principles for allocation of ventilators was a priority point system by White et al. (2009). Through a modification of the SOFA system, their system accommodated three ethical principles as follows: It used a coarsening of patient SOFA scores to accommodate the principle of *saving most lives*, and added points to accommodate two additional principles, *saving the most years of life* and *life-cycle* principle.[72]

Naturally, in their pursuit to accommodate the *instrumental value* principle in addition to the principle *saving most lives*, members of New York State and Minnesota task forces also experimented with a similar methodology, and contemplated to award extra points to essential personnel in addition to their scores from the SOFA system. But since this alternative procedure has the potential to allocate all units to essential personnel in extreme scarcity situations, they gave up upon not only this procedure, but also the *instrumental value* principle altogether. Essentially, the task forces in New York State and Minnesota attempted to design a new ventilator rationing system through a minimalist intervention of the SOFA system of their own, but failed to reach an acceptable system in this way. Another minimal intervention of the SOFA system, however, would have resulted in a potentially acceptable alternative.

7.2 Advocacy of Pandemic Reserve Systems in Pathak et al. (2020d)

Rather than adjusting the scoring rule under the SOFA system, the task forces could have instead used patient SOFA scores to determine their priorities for a fraction of the ventilators, and use a second priority ranking for the remaining units. In order to accommodate the *instrumental value* principle, this second priority ranking would have to give some form of heightened priority for essential personnel. Note that, the idea here is similar to the reservation system discussed in Section 6 for allocation of public positions in India. We refer to any such allocation rule which uses different priority rankings of individuals to allocate different portions of the scarce resources as a *reserve system*.

When Covid-19 hit the world in early 2020, I was writing a chapter on reserve systems for a book project we have been pursuing for several years with Parag and Utku on "matching and market design." As soon as we discovered the challenges faced by the task forces in New York State and Minnesota, we decided to repurpose the chapter as a manuscript we can circulate within weeks on equitable allocation of scarce medical resources. Reserve systems similar to one discussed in Section 6 on affirmative action in

[72]Life-cycle principle asserts that younger patients who had the least opportunity to live stages of life should be given higher priority for the scarce medical resource.

India have been used for decades in various real-life settings as a prominent tool to reach compromises between various groups with competing objectives. These settings include affirmative action for allocation of government positions and public school seats (Hafalir et al., 2013; Dur et al., 2020; Aygün and Bó, 2021; Sönmez and Yenmez, 2022a), balancing priorities for school seats between neighborhood population and broader community (Dur et al., 2018), and allocation of immigration visas in the US (Pathak et al., 2020a). While our book chapter was a unified presentation of these reserve systems, repurposing it for our purposes was not all that easy for one technical reason.

7.2.1 A Generalized Reserve System to Balance Various Ethical Principles

Up until the time when Covid-19 pandemic started in early 2020, virtually all reserve systems studied in the literature had one common feature. There is a baseline priority ranking of individuals, such as one that is determined with a centralized test. All portions of the scarce resource rely on this baseline ranking in allocation, but for some portions, also giving some form of preferential treatment to various groups of individuals.

While the task forces in New York State and Minnesota could have done the same by giving heightened priority to essential personnel in a fraction of ventilators, in general, a more flexible reserve system was needed in order to operationalize the ethical principles outlined in Emanuel et al. (2020). Essentially, our new application of market design in public healthcare called for a reserve system where priority ranking of individuals for any portion of the scarce resource could be constructed with any criteria, without necessarily having a connection to a baseline priority ranking. With a target of analyzing subtleties of generalized reserve systems in short order while our ideas still have a potential to contribute the on-going global fight against Covid-19, we invited my colleague Bumin Yenmez to our project. His addition to our team increased our pace in analyzing various technical aspects of the problem, and allowed us to complete and circulate the first version of our paper Pathak et al. (2020d) in April 2020, within two weeks after our initial engagement with this vital resource allocation problem.[73]

Formally, in a reserve system, units of the scarce resource is divided into multiple segments called *categories*, and units in each category is allocated based on a category-specific priority ranking. It is essentially a *categorized priority system*, a terminology we have used with our collaborators from medical ethics and emergency healthcare in a followup paper Sönmez et al. (2021) when we first introduced the idea to member of the broader medical community. While the idea of a reserve system is very intuitive, it has

[73]The first version of Pathak et al. (2020d) is available as NBER working paper 26951 Pathak et al. (2020e).

one aspect which can cause unintended distributional consequences, unless this subtlety is well-understood by the system operators. In Section 6, we have seen a prime example of this in the context of affirmative action policies and court rulings in India. Other settings where this subtlety afflicted implementation include allocation of public school seats in Boston (Dur et al., 2018) and assignment of H-1B visas in the US (Pathak et al., 2020a). In order to avoid any confusion by healthcare officials in implementation of our reserve system for Covid-19 allocation of vital medical resources, we made this subtle aspect of the problem the main focus of our formal analysis in Pathak et al. (2020d).

7.2.2 Maintaining Informed Neutrality Between Reasonable Normative Principles

The subtlety of reserve systems comes from an under-appreciation of what happens when individuals can receive units from multiple categories. If this cannot happen, i.e., if each individuals is eligible for units from at most one category, then the reserve system is effectively same as a separate priority system in each category. For this simple case, allocation of units in different segments do not interfere with each other.

In most applications, however, at least some individuals are eligible for units in multiple categories. When an individual is eligible for units in two different categories, even though she does not care which unit she receives, the selection affects the outcome for remaining individuals. System operators and broader public often do not appreciate how important this aspect of a reserve system is (Pathak et al., 2020b). In order to avoid any unintended distributional consequence due to this subtlety, we characterized in Pathak et al. (2020d) all outcomes which satisfy the following three basic desiderata:

Definition 12. *An outcome* ***complies with eligibility requirements*** *if patients only receive units from categories for which they are eligible.*

Definition 13. *An outcome is* ***non-wasteful*** *if no unit from any category remains idle despite the presence of an eligible patient who remains unserved.*

Definition 14. *An outcome satisfies* ***no-justified envy***,[74] *if no patient remains unserved while a unit from some category c is awarded to a lower priority patient based on the priority ranking at category c.*

An outcome satisfies these three desiderata if and only if it is supported by a list of cutoffs in priorities (Theorem 1 in Pathak et al. (2020d)).

[74]This axiom is called *respect for priorities* in Pathak et al. (2020d). I use the *no-justified envy* terminology to highlight the parallel between analogous axioms in other sections.

Without thoroughly understanding, however, what these differences in outcomes correspond to in policy, they may not mean much to policymakers or system operators. Therefore, we connected various outcomes that satisfy the three basic axioms to additional normative criteria. For example, for cases where there is an underlying baseline priority ranking, we identified outcomes that correspond to *vertical reservations* or *horizontal reservations* we have earlier seen in Section 6. Another result we have shown along these lines is the following: The distribution of the resource can be influenced in ways that systematically benefit or hurt various groups, depending on the sequencing of allocation of units at different categories. In general, the later a category is processed, the better it is for its beneficiaries (Dur et al., 2018, 2020; Pathak et al., 2020d).

Thus, not only we provided the healthcare community with a practical system to balance various ethical principles for allocation of scarce medical resources in Pathak et al. (2020d), but also provided them with the operational details to avoid any unintended consequences.

7.3 Teaming Up with Three Leaders in Bioethics

Timing is everything in market design. A mere two days after Pathak et al. (2020d) was circulated, the following headline from a lead story in *Boston Globe* caught our attention:

> "Who gets a ventilator? New gut-wrenching state guidelines issued on rationing equipment
>
> Preference given to medical personnel, people who are healthy, younger"
>
> Liz Kowalczyk, *Boston Globe*, April 7, 2020

Not only did this story directly relate to the paper we just circulated, it also highlighted in its headline one of our main motivations on priority for medical personnel! Naturally, we were intrigued. The story started as follows:

> "Massachusetts health officials issued guidelines Tuesday to help hospitals make gut-wrenching decisions about how to ration ventilators, should they become overwhelmed with coronavirus patients and run out of critical treatments.
>
> The guidance, which is not mandatory, asks hospitals to assign patients a score that gives preference to healthier patients who have a greater chance of surviving their illness, and living longer overall. It gives additional preference to medical personnel who are vital to treating oth-

> ers, and to women further along in pregnancy. In the event of tie scores, younger patients are given priority.
>
> 'There is a great sense of urgency,' said Dr. Robert Truog, director of the Center for Bioethics at Harvard Medical School and a pediatric intensivist who was part of the group that helped develop the guidelines. 'We realize this all needs to be in place soon. It's very important to have current guidelines that provide very concrete advice to hospitals about how to allocate these resources.' "

According to this story, unlike the task forces in New York State and Minnesota, a similar committee in Massachusetts came up with a system which "gives additional preference to medical personnel who are vital to treating others." Upon reading the "Original Guidance" issued by the *Crisis Standards of Care Advisory Working Group* (Bateman et al., 2020), however, we observed that there was no such preference given to medical personnel at all under the recommended system. That is, the principle of *instrumental value* played no role in the recommended allocation rule. The system recommended in the "Original Guidance" was basically a simplified version of the priority point system of White et al. (2009), with only two ethical principles rather than three. Naturally, we wondered, how *Boston Globe* could possibly make such a major error in its coverage. Subsequently, we observed that, parts of the "Original Guidance" used an ambiguous language which mentioned possible preference given for medical personnel who are vital to treating others, even though the final recommendation did not reflect this consideration.[75]

While this issue serves as a "red herring" in this key document, it still provided us with a very important clue. Why would an otherwise very clear document involve a confusing discussion of the *instrumental value* principle, unless members of the working group found themselves is a dilemma that parallels those earlier faced by the task forces in New York State and Minnesota?

Based on this hunch, later that evening, we sent an e-mail to Robert Truog who was mentioned in the *Boston Globe* story as a member of the working group. We believed sharing our ideas with Robert Truog was especially important. Not only he was the Director of the Center for Bioethics at Harvard Medical School, but he was also the first author of Truog et al. (2020), one of the two articles which got our interest on the topic in the first place. In our e-mail, we included our paper Pathak et al. (2020d) as an attachment, indicated that we were inspired to work on this topic based on the *NEJM* symposium that

[75]The ambiguous language in the "Original Guidance" was later removed in a later "Revised Guidance" issued on April 20, 2020, possibly due to an inquiry by our team about this inconsistency to Robert Truog, who was a member of the working group mentioned in the *Boston Globe* story.

included his paper, and expressed our strong interest to exchange ideas with him in a Zoom meeting sometime soon. Not only did Robert Truog give us a positive response for our meeting inquiry the following day, but he also suggested including two other leaders in medical ethics, Govind Persad and Douglas White, in the meeting.

We were naturally thrilled with his response. Govind Persad was a renowned expert in legal and ethical aspects of healthcare, and he was the second author of Emanuel et al. (2020), i.e., the main reference on this whole exercise. Douglas White was a Professor of Critical Care Medicine at University of Pittsburgh, and he directed the University of Pittsburgh Program on Ethics and Decision Making in Critical Illness. He was also the first author of White et al. (2009), i.e., the main reference on multiple ethical principle priority point systems for ventilator rationing.

It was the minimalist market design which secured us this "dream" meeting. We correctly identified a desiderata–*the instrumental value principle*–which was not reflected in the recommended system of the working group for crisis allocation of ventilators in Massachusetts, and suggested a small tweak of their system which addressed this omission. A few days later, Robert Truog sent us the following suggested agenda for our meeting:

> " 1) Introductions
> 2) Overview of the reserve model (10 min)
> 3) Discuss strengths / weaknesses compared to a points system
> 4) How it would handle specific issues, eg, priority to healthcare workers, preference to the young, and comparing adults and children
> 5) Discuss both practical feasibility and public acceptance of the model
> 6) Next steps "

Interestingly, while Robert Truog set a time cap in our first meeting to discuss the details of our proposed reserve system, he set no such limit to discuss its comparison with the priority point system or its public acceptability and various practical considerations in implementation. In my view, his focus is consistent with my main thesis that, policymakers and system operators care way more about how an institution serves the aims of various stakeholders than its mechanical details. In a follow up e-mail that is also consistent with this assessment, Douglas White emphasized what he is most interested in a reserve system:

> "I'll be most interested to hear what it would 'look like' operationally in any given hospital to do as you suggest: to set aside a portion of ventilators to use one priority order, and another portion which can use another."

Our meeting was one of the most successful and consequential meetings of my career. From that point on, Govind Persad, Robert Truog, and Douglas White embraced the reserve system for pandemic allocation of scarce medical resources. Joining forces with them, we advocated the reserve system to broader bioethics and medical communities in Sönmez et al. (2021). In order to emphasize its minimal deviation from the priority system these communities are accustomed to, we referred to a reserve system as a *categorized priority system* in this paper.

7.3.1 Policy Impact on Allocation of Covid-19 Therapies in Pennsylvania

Only a month after our first encounter with our new partners, we already saw the first tangible outcome of our collaboration. By May 2020, public attention was shifting from triage rationing of ventilators and ICU beds to equitable allocation of scarce therapies. On May 1st, 2020, Gilead's *Remdesivir* became the first antiviral medicine to receive Emergency Use Authorization (EUO) from the US Food and Drug Administration (FDA) for the treatment of COVID-19. Due to overwhelming demand for this medication, the University of Pittsburgh Medical Center (UPMC) developed and adopted a weighted lottery system to implement a transparent and fair approach to allocate scarce medications to treat patients with Covid-19.

With the leadership of Douglas White, UPMC system was designed by our team as a special case of a reserve system, and it was implemented in Western Pennsylvania during the shortage period of Remdesivir (White et al., 2022). The software for the system was also developed and provided by our core team of three design economists.

UPMC system was later endorsed by the Commonwealth of Pennsylvania for the allocation of scarce Covid-19 therapies (Commonwealth of Pennsylvania, 2020).

7.4 Policy Impact During the Covid-19 Vaccine Rollout

Over the next several months, we engaged in various outreach activities to introduce the reserve system to bioethics and emergency care communities. Through these efforts, we introduced the reserve system to several groups, and started collaborating with University of Pennsylvania bioethicist Harald Schmidt who was especially interested in utilizing it to mitigate disparities in healthcare access (Schmidt et al., 2020).

7.4.1 Debates in the US on Priorities for the Covid-19 Vaccine

By August 2020, phase 3 clinical trials for two of the most promising Covid-19 vaccines were already underway, and much of our focus have shifted to the upcoming vaccine roll-out. Since the beginning of the pandemic, there had been a vigorous debate on equitable vaccine allocation. At the beginning, these debates were purely focused on the structure of priority tiers under a presumed priority system. For example, in June 2020, Melinda Gates made the following public statement:

> "We know there are 60 million healthcare workers around the world who are keeping everybody safe. They deserve to get this vaccine first. From there, you want to do tiering in various countries to make sure your most vulnerable populations get it. In our country, that would be Blacks and Native Americans, people with underlying health conditions and the elderly."
>
> U.S. Chamber of Commerce (2020)

Not everyone was, however, in agreement with Melinda Gates. For example, the following opposing view was expressed in a commentary of the Cato Institute:

> "A federal advisory committee recommending priorities for the eventual distribution of a COVID-19 vaccine has floated a very bad idea: according priority to some beneficiaries over others because of their race. If implemented, the regime would very likely be struck down by courts as unconstitutional."
>
> Olson (2020)

More generally, rather than who receives priority, the biggest challenge under any priority system was the notion that some groups receive absolute priority over others.

> "There's no easy solution. Healthcare experts at ACIP and the National Academy have been debating the question among themselves, and no decision will be uncontroversial. But when there aren't enough vaccines for all, someone must inevitably come first."
>
> Goldhill (2020)

Due to its role as a practical tool to reach a compromise between various groups with opposing views, our reserve system started to receive a lot of traction for the upcoming vaccine rollout in this environment.

7.4.2 NASEM Framework for Equitable Vaccine Allocation

In July 2020, Centers for Disease Control and Prevention (CDC) and National Institutes of Health (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 immediately appointed a committee of distinguished experts. In September 2020, NASEM made a discussion draft of its Preliminary Framework for Equitable Allocation of Covid-19 Vaccine available for public commentary (NASEM, 2020a). Even though NASEM suggested a four-tier priority system in its discussion draft, it also included the following expression:

> "Equity is a crosscutting consideration: In each population group, vaccine access should be prioritized for geographic areas identified through CDC's Social Vulnerability Index."

At this point two of our collaborators, Govind Persad and Harald Schmidt played key roles in bringing the reserve system to the attention of the NASEM committee:

In response to the NASEM discussion draft, *JAMA* published the viewpoint "Fairly Prioritizing Groups for Access to COVID-19 Vaccines," by Persad et al. (2020) explicitly endorsing our proposed reserve system in their conclusion.

> "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."

Not only was our collaborator Govind Persad the first author of this viewpoint, Ezekiel Emanuel, i.e., the first author of the main reference Emanuel et al. (2020) in these debates, was its senior author. Thus, our proposed reserve system received a highly visible endorsement for the upcoming vaccine rollout at a key moment.

In response to the discussion draft, our collaborator Harald Schmidt, on the other hand, submitted a written commentary. Upon receiving an invitation by the committee, he also gave a subsequent oral commentary. In his commentary, he inquired about the recommended mechanism to prioritize members of communities identified through CDC's

Social Vulnerability Index. In preparation for this very contingency and in collaboration with Harald Schmidt, weeks earlier we had circulated an NBER working paper Pathak et al. (2020c), illustrating how easily a tiered priority system can be "modified" as a reserve system, by building equity into the system though an index of social vulnerability. Harald Schmidt brought this exercise in minimalist market design to the attention of the committee as a possible mechanism to embed equity in their framework.

In October 2020, NASEM announced its Framework for Equitable Allocation of Covid-19 Vaccine (NASEM, 2020b). Following the recommendation in Persad et al. (2020) and using the exact formulation in Pathak et al. (2020c), NASEM framework formally recommended 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)."

As it can be seen from the above-given quote, NASEM clearly emphasized the distinction of their recommendation from a tiered priority system.

7.4.3 States and Cities which Adopted a Reserve System for Various Phases of the Vaccine Rollout

Within days after the NASEM recommendation, Tennessee became the first state to adapt a reserve system for its vaccine rollout in October 2020. FDA granted emergency use authorization for the Pfizer–BioNTech vaccine and the Moderna vaccine in early December. By that point, to our disappointment, Tennessee remained the only state which adopted the reserve system. Consequently, in early December 2020, in collaboration with Ariadne Labs from Harvard Chan School of Public Health and Department of Medical Ethics and Health Policy from University of Pennsylvania, we co-hosted an online symposium on "Vaccine Allocation and Social Justice" (Ariadne Labs, 2020). One of our aims was to illustrate policymakers how easily equity can be built into vaccine rollout through a reserve system.

The symposium not only helped us to better understand the needs, challenges and perspectives of several jurisdictions, but it also directly contributed to two important developments.

First, it provided our co-organizers from Ariadne Labs with a natural opportunity to bring the reserve system to the attention of the committee responsible for vaccine rollout in Massachusetts. Similarly, it provided our team with an opportunity to bring the reserve system to the attention of California's Surgeon General Dr. Nadine Burke Harris. In a number of group meetings, we introduced the reserve system to Dr. Harris and her team, advocated for its adoption in California as an instrument to build in equity in their upcoming vaccine rollout, and coached members of her team on the subtleties of the reserve system.

In December 2020, Massachusetts became the second state to adopt a reserve system for its vaccine rollout with 20% over-and-above reserve for hard-hit communities. In March 2021, California adopted a particularly ambitious reserve system for its vaccine rollout, with reserve categories both for educators and hard-hit populations. During the initial vaccine rollout from December 2020 to May 2021, at least 12 states, and several major cities including New York City, Chicago, and Washington DC adopted our proposed reserve system at various phases (Schmidt et al., 2021; Pathak et al., 2022).

While equity and social justice considerations have been the driving force in most jurisdictions for the acceptance of the reserve system, it was not the only reason. Phase 1b and Phase 2 Covid-19 Vaccine Rollout in Richmond and Henrico, VA serves as an illustrative example (Richmond City, 2021a,b). Below I present details of Phase 1b, which was deployed in Richmond and Henrico health districts on March 8th, 2021.

Richmond and Henrico Reserve System for Phase 1b Covid-19 Vaccine Rollout

Categories, their share of Covid-19 vaccines and factors that affect category-specific priorities were specified by the health districts as follows:[76]

1. **Phase 1a & Congregate Care** (4% of units)
2. **Adults age 65+** (50% of units)
    - Age (older residents have higher priority)
    - Race and ethnicity (Black, Hispanic/Latinx, and American Indian or Alaska Native residents have higher priority)
    - Burden of disease in the area where a person lives
    - Social Vulnerability Score (SVI) of the area where a person lives
3. **Frontline Essential Workers** (23% of units)

[76]Category-specific priorities are only partially specified in Richmond City (2021a,b).

- Age (older residents have higher priority)
- Race and ethnicity (Black, Hispanic/Latinx, and American Indian or Alaska Native residents have higher priority)
- Burden of disease in the area where a person lives
- Social Vulnerability Score (SVI) of the area where a person lives

4. **People ages 16-64 with Comorbidities** (23% of units)
    - Age (older residents have higher priority)
    - Race and ethnicity (Black, Hispanic/Latinx, and American Indian or Alaska Native residents have higher priority)
    - Socioeconomic status (residents who are under and uninsured have higher priority)

Observe that, Richmond and Henrico reserve system utilized the full generality of the model presented in Pathak et al. (2020d): In particular, while the two categories 2 and 3 used an identical baseline priority ranking (subject to eligibility), category 4 used a related but different priority ranking.

7.5 Policy Impact on Allocation of mAb Therapies in Massachusetts

When we first communicated with Robert Truog in April 2020 as a member of the Crisis Standards of Care Advisory Working Group in Massachusetts, our initial focus was on equitable allocation of ventilators. As I discussed in Section 7.3.1, by May 2020, public attention shifted to allocation of therapies against Covid-19 which started to receive EUO from the FDA. During that period, we met with Dr. Emily Rubin from Massachusetts General Hospital, another member of the Working Group in Massachusetts. While she considered our reserve system for allocation of the antiviral Remdesivir at the Mass General Brigham healthcare system at the time, in this chaotic time when healthcare personnel were extremely overwhelmed, this possibility did not materialize.

Six months later, in November 2020, FDA authorized EUA for three monoclonal antibodies (mAb) for treatment of COVID-19. This is when Emily Rubin reconnected with us, and inquired whether we can support the Working Group as they prepare the Guidance for Allocation of Covid-19 Monoclonal Antibody Therapeutics. Our group supported the Working Group with a reserve system design tailored to the specification for Massachusetts policies, and provided them with an Excel spreadsheet implementation of the

system. Later in November, Massachusetts officially recommended the following reserve system in its Guidance.

Massachusetts Reserve System for Allocation of mAb Therapeutics

Categories, their share of mAb infusions, factors that affect category-specific priorities, and processing sequence of categories were given as follows by the state:

1. **Open Category** (80% of Infusions)
    - *Eligibility*: All patients.
    - *Priorities*:
        * *Tier 1*: Age $\geq$ 65 or Body Mass Index (BMI)$\geq$ 35
        * *Tier 2*: Other patients who satisfy the EUO criteria of the FDA.
        * Within each tier, priority ranking is determined with a uniform lottery.
2. **Vulnerable Category** (20% of Infusions)
    - *Eligibility*: Patients who live in a census tract at the top half of SVI or in a town or city with an incidence rate at the top quartlite
    - *Priorities*:
        * *Tier 1*: Age $\geq$ 65 or Body Mass Index (BMI)$\geq$ 35
        * *Tier 2*: Other patients who satisfy the EUO criteria of the FDA.
        * Within each tier, priority ranking is determined with a uniform lottery.

Processing Sequence of Categories: Open category first, followed by the vulnerable category (Over-and-Above reserve).

Subsequently, Massachusetts Reserve System for Allocation of mAb Therapeutics was implemented by the Mass General Brigham healthcare system. Rubin et al. (2021) report the successful deployment of this system for allocation of scarce Covid-19 therapies in Massachusetts, and how it increased access to socially vulnerable patients.

The following quotes from the Editorial Makhoul and Drolet (2021) in response to Rubin et al. (2021) not only highlights the success of the reserve system for allocation of various scarce medical resources during the Covid-19 pandemic, but also illustrates the promise of minimalist market design in interdisciplinary efforts.

> "This work contributes to a growing body of evidence that reserve systems offer a pragmatic framework for equitably allocating scarce resources. [...]

> As reserve systems become more prevalent, it is important to acknowledge and understand the psychological effects on participants. Not only do reserve systems enable policymakers to allocate resources equitably, but they also signal to participants that expert judgment has been used to design a system for maximal societal benefit. Participants eligible for prioritized categories (eg, patients from high-SVI zip codes) may feel more adequately safeguarded. [...]
>
> Health equity must not only be demonstrated objectively but must also be perceived by participants in the system. [...]
>
> Despite challenges related to administering a time-sensitive, novel therapeutic during a pandemic, Rubin et al. (2021) demonstrate that a reserve system can be used effectively on an individual patient level to prioritize access for certain groups."

8 Contrasts with Paradigms based on Mechanism Design

In this section I will compare and contrast the minimalist approach with the institution design paradigm which builds on traditional mechanism design.

The aim in the latter more traditional approach is the design of an institution which either optimizes an objective function or implements a social choice rule under various rationality assumptions from non-cooperative game theory, and subject to various combinations of *feasibility*, *incentive compatibility* and *stability* constraints. Critically, the starting point of the designer is either an objective function that must be optimized (typically *utilitarian*) or a social choice rule that is deemed desirable. Therefore, beyond informing various constraints, many details of the existing institution have no bearing on the optimal design. Moreover, the objective of the design under this paradigm is often *preference utilitarian*, and in those cases it is not, it is still *consequentialist* (i.e., it only depends on the outcome and nothing else).

This approach to practical design can be valuable in applications where there exists a plausible objective function and the environment is so complex that the primary role of a model is providing intuition on various aspects of the problem. Indeed, in the conclusion of his *Richard T. Ely Lecture*, Hurwicz (1973) emphasizes:

> "The new mechanisms are somewhat like synthetic chemicals: even if not usable for practical purposes, they can be studied in a pure form and so

> contribute to our understanding of the difficulties and potentialities of design."

In contrast, minimalist market design is most useful in applications where stakeholders have objectives that are both well-defined and feasible, although they ended up with an institution which falls short of satisfying some of these objectives, often due to technical challenges. The primary aim under the minimalist approach is finding the institution the stakeholders intended to design in the first place.

Since the primary aim goes beyond providing intuition, the design objectives under the minimalist approach have to correspond to the objectives of the stakeholders themselves, and they often include ones that are *non-utilitarian*. By allowing for a wide range of objectives, including *non-consequentialist* principles such as *transparency*, *simplicity* and *privacy*, following this approach makes it easier to communicate with and convince various stakeholders. Since the ultimate aim is to fix any failure of an institution by only interfering with their root causes, the existing institution plays a central role under the minimalist approach.

As the objectives of the stakeholders play a fundamental role under the minimalist approach, it is most adequate for applications where these objectives can be determined. In my opinion, it is most useful in applications where either the main objectives are compatible with *strategy-proofness* or in those where incentive compatibility is not a main consideration in the first place. While deviations from these ideal conditions may render the minimalist approach less natural or inapplicable in some settings, it has a number of advantages over more mainstream institution design paradigms when they are met. In particular, due to its underlying design philosophy, the minimalist approach escapes many of the criticisms of mainstream approaches to institution design.

Referring to axiomatic methodology as "good properties" approach, Budish (2012) identifies the following three reasons why for some applications of axiomatic approach to market design may be more promising than the mainstream approach:

> "First, it is sometimes difficult to pin down the objective. [...] Second, it is sometimes difficult to pin down the true constraints of the problem. [...] Third, there is a lack of tools. In most matching environments we do not yet know how to solve even the standard Myersonian problem of "maximize social welfare subject to technology and incentive constraints", let alone anything more nuanced."

Essentially, Budish (2012) identifies setups where the mainstream mechanism design approach may be challenging to apply from the start. Since the primary technical methodol-

ogy under minimalist market design is the axiomatic methodology, the three conditions in Budish (2012) also render the minimalist approach more promising than the mainstream paradigm to market design. I will next identify a number of other considerations in choosing a practical design paradigm.

8.1 The Role of Private Information and Incentive Compatibility

A mechanism is called *incentive-compatible* if every participant can obtain the best outcome for themselves by truthful revelation of their private information. There are two main versions of incentive compatibility:

1. *Dominant strategy incentive compatibility*: Truthful revelation of private information is a *dominant strategy*. That is, regardless of what other individuals do, truthful behavior is always optimal for each individual.

2. *Bayesian incentive compatibility*: Truthful revelation of private information is a *Bayesian Nash equilibrium*.

8.1.1 Dominant Strategy Incentive Compatibility vs. Strategy-Proofness

In economic theory, *strategy-proofness* is considered as a special case of *dominant strategy incentive compatibility* where the private information typically takes the form of preferences over outcomes. As far as formal representation is concerned through mathematical relations, the two notions are indeed isomorphic. However, they have a subtle but very important distinction.

Dominant strategy incentive compatibility is a concept in *positive* economics. In an effort to overcome challenges due to private information, it was formulated by Leonid Hurwicz as a *constraint* in his mechanism design setup (Hurwicz, 1960, 1972, 1973). Thus, it only matters to the extent incentive considerations affect the outcome of an interaction between self-interested and rational economic agents. In particular, if the same optimum were to be reached through dishonest revelation of private information, there would be no use for this constraint in this framework. It is a means to an end, not an end in itself.

In contrast, *strategy-proofness* is both a *positive* and at the same time a *normative* concept. It is usually a key design objective for policymakers: That is, it is an end in itself. Indeed, as we have discussed in depth in Sections 3.3.3, 3.4.2 and 3.4.1, it was the main normative axiom that enabled the school choice reforms in Boston, Chicago and England. The importance of *strategy-proofness* in these reforms were largely (if not completely) beyond its impact on the outcomes of these processes. This is also why *strategy-proofness* is

important in a design even if some participants may not fully understand that honest revelation of private information is in their best interests. In many cases, it is an obligation of the system operator to prepare the conditions which nurture honest behavior.

8.1.2 Role of Private Information in Traditional Mechanism Design

The need for an expert for the design of an institution emerges due to the private information held by the participants under the traditional mechanism design (Hurwicz, 1973; Maskin, 2008). Therefore, if there is no private information, there is no room for mechanism design.

Assuming participants who hold private information are *rational* and they engage in *equilibrium* behavior, the aim of the design is the optimization of an objective function (typically utilitarian) subject to *incentive compatibility* constraints, along with other constraints such as *feasibility* and *individual rationality*.

In most cases, the less demanding notion of *Bayesian incentive compatibility* is utilized to model rational behavior, and attention is restricted to direct mechanisms where individuals reveal their private information. The restriction is considered without loss of generality due to a result known as the *revelation principle*, which says that any equilibrium outcome of an arbitrary mechanism can also be obtained as an equilibrium outcome of an incentive-compatible direct mechanism (Myerson, 1981). There is, however, a caveat for this widespread tradition. Revelation principle is silent on issues related to multiplicity of equilibria. For example, it is possible that, while the unique equilibrium outcome may be optimal under a non-direct mechanism, the equilibrium outcomes may also include non-optimal ones under the corresponding direct mechanism.

8.1.3 Role of Private Information in Minimalist Market Design

Unlike the traditional mechanism design, the potential value of minimalist market design is not exclusively tied to the presence of private information. For example, for our application on allocation of homogenous government position in India (Section 6.1) or the design of single-center kidney exchange systems (Section 4), private information was not a main consideration.

Having emphasized this important point, in many applications of the minimalist approach private information does play a major role. In my view, minimalist market design is best fit for settings in which *strategy-proofness* is compatible with other key objectives of the stakeholders. Policymakers can urge the participants to reveal their private information truthfully under a *strategy-proof* mechanism, without risking being wrong, and thus

taking some liability. While the participants may not follow this advice all the time for various reasons, this ability to give straightforward advice is one of the most appealing aspects of a *strategy-proof* mechanism.

8.2 The Role of Non-Utilitarian Principles

A principle is *consequentialist* if it evaluates actions only based on their outcomes. *Utilitarianism* is a consequentialist principle, where only welfare of individuals from the outcome matters. While the typical normative position is utilitarianism in neoclassical economics, the same is not the case in other social sciences. Since market design is an interdisciplinary area, the perspectives from other fields is also important. Likewise, as emphasized by Li (2017), the support for utilitarianism is not as strong among policymakers or the broader population as it is among neoclassical economists. Indeed, of all my policy interactions in more than two decades, kidney exchange has been the only setting where a variant of utilitarianism–the *Pareto principle*–was one of the central desiderata in the field. Unlike many other applications, however, there is a very natural welfare function in kidney exchange in the number of lives saved via transplantation.

By its conceptualization, the default normative position is utilitarian under mechanism design. Naturally, any practical institution design paradigm based on this formal methodology also inherits this key aspect of its antecedent. However, the choice of this normative position is not always benign in practical institution design, especially in contexts in which issues of social justice are particularly important (Li, 2017; Hitzig, 2020).

An advantage of the minimalist approach over design paradigms that are based on the traditional mechanism design is in its flexibility to accommodate a broad range of principles, including those which are not consequentialist. For example, as I have presented in Section 3, *strategy-proofness*–a non-consequentialist principle–has been the key driving force behind the school choice reforms at Boston, Chicago and England.

8.2.1 Transparency

Transparency is a non-consequentialist principle that is considered particularly important by many (van Basshuysen, 2022). Some applications have so many complexities that a realistic model that captures all its features may not be feasible. Naturally, designing a transparent institution may also pose a challenge in these cases. Since I view formulation of a realistic model as a pre-requisite for successful execution of the minimalist approach, I personally do not see any clear advantage of adopting it for these challenging applications.

At the same time, the lack of transparency is a challenge regardless of which paradigm a market designer adopts for these complex applications. For example, while FTC's Incentive Auction (Leyton-Brown et al., 2017; Milgrom, 2017) which reallocated radio frequencies from TV broadcasting channels to wireless broadband services in 2017 is widely considered as one of the success stories in market design, it is also scrutinized by many due to its lack of transparency (Hitzig, 2018; Weyl, 2020; van Basshuysen, 2022).

Since one of its main aspects is interfering only with the root causes of failures in real life institutions, whenever the minimalist approach is viable, it usually fares well in terms of transparency.

8.2.2 The Role of Normative Economics and Informed Neutrality Between Reasonable Ethical Principles

Despite having clear normative objectives in many applications, policymakers often have difficulties formulating them rigorously or designing mechanisms which satisfy them (Li, 2017). Therefore, as exemplified by our applications in Sections 5 and 6, the minimalist approach can be particularly useful in market design applications that involve complex normative criteria.

In some cases, the objectives of the policymakers may uniquely define a mechanism. This is the case both for the U.S. Army's branching process discussed in Section 5 and also for the integration of vertical and horizontal reservation policies in India discussed in Section 6. In these applications, the policy recommendation is fairly straightforward. In most applications, however, this is not the case.

In many applications, not all design objectives of policymakers are compatible. In such cases, a market designer can follow the standard approaches from axiomatic methodology, and explore the implications of various compromises between the design objectives which are mutually exclusive (Moulin, 1988, 2004; Thomson, 2001, 2011). Policymakers then can make the compromises of their choosing, once they understand their options. For example, as we discussed in Section 3.3.3, the most important desiderata for Boston Public Schools officials was *strategy-proofness*, which is a desideratum which is satisfied by both SOSM and TTC. After careful consideration, the officials decided that *no justified envy* along with increased *transparency* are more important than *Pareto efficiency*, and consequently selected SOSM for the city.[77]

In other applications, there may be multiple mechanisms which satisfy policymakers' design objectives. For such applications, the best practice from axiomatic methodology

[77] As we discussed in Section 3.3.3, due to "behind the scenes" mechanized trading of priorities, TTC was considered less transparent than SOSM.

is to characterize all mechanisms which satisfy the objectives of policymakers (Thomson, 2001). While obtaining a unique resolution can be considered compelling by many, enforcing one without a solid justification may also introduce various challenges. For example, as we discuss in Section 8.2.3, it may introduce biases in design which systematically favor certain groups at the expense of others. This best practice from axiomatic methodology is also in line with the following three theses advocated in Li (2017):

1. Market designers should not rely exclusively on preference utilitarianism to evaluate institutions.

2. Market designers should study the connection between designs and consequences, and should not attempt to resolve fundamental ethical questions.

3. The theory and practice of market design should maintain an informed neutrality between reasonable ethical positions.

By focusing on desiderata of policymakers and other stakeholders, the minimalist approach automatically abides by the first two theses. In applications where a specific mechanism is not singled out by these desiderata, the third thesis by Li (2017) on *informed neutrality* requires additional care.[78] Beyond its adherence with the best practices in axiomatic methodology, following this extra step in minimalist approach is valuable to address potential challenges, some of which we discuss next in Section 8.2.3.

8.2.3 Algorithmic Bias and Normative Gap

As markets increasingly operate with rules and algorithms which are designed to achieve a variety of objectives, one important question is whether a design may be biased in problematic ways, unfairly advantaging certain groups at the expense of others (Hitzig, 2018; van Basshuysen, 2022). This phenomenon is called *algorithmic bias*. Focusing on applications in which issues of social, racial and distributive justice are particularly salient, Hitzig (2020) formulates the following related concern: The formulation of social goals and the methodologies of market designers can result in a divergence between the objectives of policymakers and those implemented by the designs of economic engineers. Hitzig (2020) refers to this phenomenon as *normative gap*.

The selection of an objective function by a design economist can be one possible source of algorithmic bias or normative gap. Another source may be potential challenges certain

[78] A case study where informed neutrality plays an especially important role is presented in Sönmez and Ünver (2022) on a recent controversial Constitutional Amendment on affirmative action policies in India.

groups may face optimizing their best interests compared to other groups under mechanisms where a straightforward strategy may not exist.

When executed properly, both issues can be addressed under the minimalist approach. In applications where there is a unique mechanism that satisfies the desiderata of the stakeholders, clearly no such algorithmic bias or normative gap are introduced by the designs guided by the minimalist approach. When there are multiple ways to address the failures of an existing institution, in principle, some of the minimalist interventions may involve algorithmic bias or normative gap. This is why the best practice in these applications is to maintain *informed neutrality* between reasonable normative positions, and present policymakers with a complete (or at least representative) list of minimalist interventions.

It is important to emphasize that policymakers or system operators may also introduce algorithmic bias or normative gap in their institutions themselves, sometimes deliberately and sometimes unintentionally, without any involvement from experts in market design. For example, even though official documents indicate that Boston Public Schools prioritized children at half of the seats in their neighborhood schools from 1999 to 2013, system operators de facto eliminated this policy under the mechanism implemented by the city (Dur et al., 2018). This happened only because the system operators failed to appreciate a subtle implication of a coding decision. Similarly, Pathak et al. (2020a) show how various logistical considerations affected the fraction of H-1B visas awarded to holders of advanced degrees in the US for many years, due to a subtle aspect of mechanisms designed and implemented by system operators. Naturally, such incidences not only introduce algorithmic bias or normative gap in implementation of an institution, they also compromise their transparency as well.

The minimalist approach can be valuable to uncover these unintended policy alterations, and it could be utilized to fix them. For example, analysis in Dur et al. (2018) along with the public testimony to Boston School Committee in Pathak and Sönmez (2013b) resulted in official removal of neighborhood priority in Boston Public Schools in 2013. The following section from a March 2013 speech by Superintendent Carol Johnson to Boston School Committee illustrates the value of the minimalist approach in evaluating and informing public policy:

> "Leaving the walk zone priority to continue as it currently operates is not a good option. We know from research that it does not make a significant difference the way it is applied today: although people may have thought that it did, the walk zone priority does not in fact actually help students attend schools closer to home. The External Advisory Commit-

> tee suggested taking this important issue up in two years, but I believe we are ready to take this step now. We must ensure the Home-Based system works in an honest and transparent way from the very beginning."
>
> Johnson (2013)

8.3 Is Design Economics a Form of Social Engineering?

Drawing upon the "performativity thesis" of Callon (1998) in economic sociology, a number of researchers argue that the way mainstream design economists blend research and policy create a performative frame in real-life implementation, and thereby bring participants and institutions into line with their theoretical models (Mirowski and Nik-Khah, 2007; Santos, 2011; Breslau, 2013; Hitzig, 2018, 2020). The essence of their criticism is captured in the following assertion by Santos (2011):

> "To put it in another way, the efficacy of design economics ultimately hinges on determining the extent to which economists are able to implement their models in the real world and make reality conform to their theoretical constructs" [...]

Essentially, social scientists who advocate this view criticize design economics as being a form of social engineering.

In my view this criticism of design economics deserves careful consideration. Reliance on an objective function which has to be optimized under various constraints is one reason why that may happen under institution designs which follow approaches in mechanism design. Note that, once various constraints are accommodated, any "slack" in the system is used to optimize the objective function under the "template" design process provided by mechanism design.[79] Therefore, the objective function plays a disproportionately important role under design paradigms which are based on mechanism design. Moreover, widespread reliance on *Bayesian incentive compatibility* as a rationality requirement further increases the importance of this objective function, because it corresponds to a weaker constraint. Hence, when the market designer influences the choice of the objective function in the design of a real life institution, the practical allocation problem may indeed start to resemble an abstract model in mechanism design.

In my view, the minimalist approach to institution design escapes this criticism due to its underlying philosophy. External validity presented from Chicago and England in the context of school choice (Section 3.4) and from India in the context of Supreme Court

[79] I am grateful to Shengwu Li for this perspective.

judgments on affirmative action (Section 6.5) present strong evidence that, at least when executed properly, institution designs guided under the minimalist approach should not be interpreted as social engineering.

Ideally, a design guided by the minimalist approach only interferes with root causes of existing flaws, but otherwise it remains true to the original institution. These flaws are defined based on the objectives of the stakeholders themselves, and not based on those prominent in neoclassical economics. While it is true that the minimalist approach is utilized in areas that remains outside economics, it is not used in a way that encourages profit seeking or strategic behavior. On the contrary, the minimalist approach is often deployed in ways that removes the need for such behavior. Thus, institution designs carried out under the minimalist approach directly contradict the following portrayal of the broader agenda of design economists by Santos (2011):

> "Choice architecture and design economics promote a particular version of economics imperialism that goes beyond the mere export of its concepts to territories traditionally occupied by disciplines other than economics. They actually aim at inculcating economic calculus in human deliberation and introducing market-like forms of social interaction where they have been absent."

8.4 Identity of a Design Economist and the Role of Theory

The primary role of a theoretical model is seen as providing intuition under mainstream approaches to market design (McAfee and McMillan, 1996; Roth and Wilson, 2019; Milgrom, 2021). As such, these models are usually developed in abstract contexts, before their practical relevance is considered. Naturally, these models are only loosely connected to real-world applications. When a commissioned market designer engages in design or re-design of a practical institution, the typical practice consists of taking an existing theoretical model, and manipulating it to capture various details of the application.

Three identities attributed to design economists are a "designer" (Hurwicz, 1973), an "engineer" (Roth, 2002), and a "plumber" (Duflo, 2017). The role of a design economist under each of these identities is described as follows in van Basshuysen (2021):

> "The *economist-as-designer* (Hurwicz, 1973) generates models in which properties corresponding to policy goals are defined, and mechanisms designed, that is, algorithms determining institutional outcomes for possible combinations of individual actions, which might bring about the defined goals if instituted in the real world. [...]

> The *economist-as-engineer* (Roth, 2002) conducts experiments to examine whether the model results hold water, as well as computational analyses to quantitatively investigate the trade-offs and limits that the designer previously identified. Drawing on the results of these investigations, the engineer then makes proposals to refine the envisioned algorithm.
>
> The *economist-as-plumber* (Duflo, 2017) implements the designed algorithm in the real world, evaluates its functioning, and mends it if problems arise. In doing so, the plumber attends not only to the algorithm itself, but also to cultural and political issues surrounding the design, such as whether market participants trust that the designed algorithm is unbiased."

In order to capture various aspects of a practical application, "economist the engineer" adjusts the theoretical constructs of "economist the designer," and with the support of experimental, computational or empirical techniques, designs a mechanism for the modified model. "Economist the plumber" takes this process one step further, and tinkers with the design to manage any unforeseen issues that may emerge in field implementation. Since the starting point is always the theoretical models of the "economist the designer," theory clearly plays an important role under the latter two practically oriented identities as well.[80] However, the role of theory is limited to guiding the design in the correct direction. Indeed, a number of researchers argue that the role of theory is exaggerated in market design compared to the role of experimental economics, especially in the context of FCC's spectrum auctions (Guala, 2001, 2005; Alexandrova, 2006; Alexandrova and Northcott, 2009).[81]

In contrast to mainstream design paradigms, theory is custom made for the specific application under the minimalist approach.[82] Adopting this approach is plausible mainly in applications where much of the "heavy lifting" in design can be carried out with theoretical analysis. The main role of experimental, computational, or empirical techniques

[80] See Jackson (2019) for an excellent assessment on the fundamental role of theory in market design and economics in the age of "Big Data."

[81] See also Gul (1997) for a closely related criticism.

[82] This does not mean that existing theory is not important for an application. On the contrary, to be able to build and analyze a custom made theory for an application, it is important to have a deep understanding of related abstract models. Depending on the application, existing theoretical models can play a very prominent role in the custom made model for the application. Examples of this includes the role of Gale and Shapley (1962) on school choice models in Balinski and Sönmez (1999) and Abdulkadiroğlu and Sönmez (2003), and and the role of Hatfield and Milgrom (2005) and Hatfield and Kojima (2010) on cadet-branch matching models in Sönmez and Switzer (2013), Sönmez (2013), and Greenberg et al. (2023). In other applications, a fairly novel custom theory may be necessary. An example of this includes the modeling and analysis of India's vertical and horizontal reservations in Sönmez and Yenmez (2022a).

is quantifying the potential gains from an institution design which already has strong theoretical backing. As a consequence, theory is the primary methodology under the minimalist approach. In addition, the most useful theoretical framework is also different under this approach than paradigms built on mechanism design. While techniques from game theory and mechanism design are still utilized, the key essential theoretical framework is axiomatic methodology.

Finally, the specific manner in which a custom made theory is formulated for an application renders an additional identity for a design economist who is following the minimalist approach: A "surgeon." Just as a surgeon operates on a body, a design economist carves out the root causes of any failures of the existing institution with surgical precision.

9 Conclusion

In this manuscript, I formulated a new paradigm for design economics: Minimalist market design. Even though it is explicitly formulated only now, it already played a significant role in the success of market design. For example, apart from enabling two of the most prominent applications of the field in school choice and kidney exchange, minimalist market design also provided real-time utility to society when it was most useful during the Covid-19 pandemic. This shows that the approach can be deployed in a timely manner to help solve various societal problems. Minimalist market design also received external validity from England and Chicago in the context of school choice, and from India in the context of Supreme Court judgments on affirmative action. All this was achieved by a small minority of design economists. Imagine what can be achieved by this approach if it is to be deployed by a more significant share of design economists.

In closing, here are some of my most important suggestions for design economists who would like to take on this challenge:

1. Find a "Goldilocks" problem which is neither too simple nor too hard.
2. Understand clearly what the objectives of the stakeholders are.
3. Identify a specific problem with what they are doing relative to their objectives.
4. Propose as few changes to what they are doing as are required to solve the problem.
5. Identify specific individuals who have a stake in solving the problem to approach with your proposal.

6. The axiomatic approach is a very effective way of communicating with policymakers.

7. Learn from your mistakes to improve your next design.[83]

[83]The reason aviation is so safe today is, because accidents are one of the main instruments for improving safety.

References

Abdulkadiroğlu, Atila and Tayfun Sönmez, "House Allocation with Existing Tenants," *Journal of Economic Theory*, 1999, *88(2)*, 233–260.

_ and _, "School Choice: A Mechanism Design Approach," *American Economic Review*, 2003, *93* (3), 729–747.

_, Parag A. Pathak, Alvin E. Roth, and Tayfun Sönmez, "The Boston Public School Match," *American Economic Review, Papers and Proceedings*, 2005, *95*, 368–371.

Abdulkadiroğlu, Atila, Parag A. Pathak, Alvin E. Roth, and Tayfun Sönmez, "Changing the Boston School Choice Mechanism," Working Paper 11965, National Bureau of Economic Research January 2006.

Abdulkadiroğlu, Atila, Parag A. Pathak, and Alvin E. Roth, "The New York City High School Match," *American Economic Review, Papers and Proceedings*, 2005, *95*, 364–367.

Abdulkadiroğlu, Atila, Joshua Angrist, and Parag Pathak, "The Elite Illusion: Achievement Effects at Boston and New York Exam Schools," *Econometrica*, 2014, *82* (1), 137–196.

_, Nikhil Agarwal, and Parag A. Pathak, "The Welfare Effects of Coordinated Assignment: Evidence from the New York City High School Match," *American Economic Review*, December 2017, *107* (12), 3635–89.

_, Yeon-Koo Che, and Yosuke Yasuda, "Resolving Conflicting Preferences in School Choice: The "Boston Mechanism" Reconsidered," *American Economic Review*, February 2011, *101* (1), 399–410.

Abecassis, M, M Adams, P Adams, R M Arnold, C R Atkins, M L Barr, W M Bennett, M Bia, D M Briscoe, J Burdick, R J Corry, J Davis, F L Delmonico, R S Gaston, W Harmon, C L Jacobs, J Kahn, A Leichtman, C Miller, D Moss, J M Newmann, L S Rosen, L Siminoff, A Spital, V A Starnes, C Thomas, L S Tyler, L Williams, F H Wright, and S Youngner, "Consensus statement on the live organ donor," *JAMA*, December 2000, *284* (22), 2919–26.

Agarwal, Nikhil, Itai Ashlagi, Eduardo Azevedo, Clayton R. Featherstone, and Ömer Karaduman, "Market Failure in Kidney Exchange," *American Economic Review*, November 2019, *109* (11), 4026–70.

Alcalde, José and Salvador Barberà, "Top Dominance and the Possibility of Strategy-Proof Stable Solutions to Matching Problems," *Economic Theory*, 1994, *4*, 417–435.

Alexandrova, Anna, "Connecting Economic Models to the Real World: Game Theory and the FCC Spectrum Auctions," *Philosophy of the Social Sciences*, 2006, *36* (2), 173–192.

_ **and Robert Northcott**, "306 Progress in Economics: Lessons from the Spectrum Auctions," in "The Oxford Handbook of Philosophy of Economics," Oxford University Press, 03 2009.

Alon, Noga, Slava Bronfman, Avinatan Hassidim, and Assaf Romm, "Redesigning the Israeli Medical Internship Match," 2015. SSRN working paper, `https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2603546`.

Anderson, Ross, Itai Ashlagi, David Gamarnik, Michael Rees, Alvin E. Roth, Tayfun Sönmez, and M. Utku Ünver, "Kidney Exchange and the Alliance for Paired Donation: Operations Research Changes the Way Kidneys Are Transplanted," *Interfaces*, 2015, *45* (1), 26–42.

Andersson, Tommy, "Refugee Matching as a Market Design Application," in Jean-Francois Laslier, Hervé Moulin, M. Remzi Sanver, and William S. Zwicker, eds., *The Future of Economic Design: The Continuing Development of a Field as Envisioned by Its Researchers*, Springer International Publishing Cham 2019, pp. 445–450.

Ariadne Labs, "Symposium: Vaccine Allocation and Social Justice," December 2020. `https://www.ariadnelabs.org/2020/12/08/symposium-vaccine-allocation-and-social-justice/`.

Aygün, Orhan and Inácio Bó, "College Admission with Multidimensional Privileges: The Brazilian Affirmative Action Case," *American Economic Journal: Microeconomics*, August 2021, *13* (3), 1–28.

_ **and Tayfun Sönmez**, "Matching with Contracts: Comment," *American Economic Review*, August 2013, *103* (5), 2050–51.

Balinski, Michel and Tayfun Sönmez, "A Tale of Two Mechanisms: Student Placement," *Journal of Economic Theory*, 1999, *84*, 73–94.

Bateman, Scot, Paul Biddinger, Cheri Blauwet, Peter DePergola II, Deb Enos, Lachlan Forrow, Eric Goralnick, Thea James, Colin Killick, Joshua Kornbluth, Alden Landry, Jennifer Lee-Rambharose, Christine Mitchell,

Emily Rubin, Dean Shapley, Robert Truog, Sally Vitali, Michael Wagner, J. Matthias Walz, and Ellen Weinstein, "Crisis Standards of Care Planning Guidance for the COVID-19 Pandemic," 2020. The Commonwealth of Massachusetts, Department of Public Health, https://www.mass.gov/doc/crisis-standards-of-care-draft-planning-guidance-for-public-comment-october-6-2020.

Bogomolnaia, Anna and Herve Moulin, "Random Matching Under Dichotomous Preferences," *Econometrica*, 2004, *72* (1), 257–279.

BPS Strategic Planning Team, "Recommendation to Implement A New BPS Assignment Algorithm," May 2005. https://www.tayfunsonmez.net/wp-content/uploads/2013/10/BPS-May112005presentation1.ppt.

Breslau, Daniel, "Designing a Market-Like Entity: Economics in the Politics of Market Formation," *Social Studies of Science*, 2013, *43* (6), 829–851.

Broome, J., "Economics and Ethics," in Neil J. Smelser and Paul B. Baltes, eds., *International Encyclopedia of the Social & Behavioral Sciences*, Oxford: Pergamon, 2001, pp. 4146–4152.

Budish, Eric, "Matching "versus" mechanism design," *ACM SIGecom Exchanges*, December 2012, *11* (2), 4–15.

Callon, Michel, "Introduction: The Embeddedness of Economic Markets in Economics," *The Sociological Review*, 1998, *46* (1_suppl), 1–57.

Chen, Yan and Tayfun Sönmez, "School Choice: an Experimental Study," *Journal of Economic Theory*, 2006, *127*, 202–231.

Colarusso, Michael J., Casey Wardynski, and David S. Lyle, *Towards a U.S. Army Officer Corps Strategy for Success: Retaining Talent*, US Army War College Press, 2010.

Commonwealth of Pennsylvania, "Ethical Allocation Framework for Emerging Treatments of COVID-19," 2020. Department of Health, https://www.health.pa.gov/topics/disease/coronavirus/Pages/Guidance/Ethical-Allocation-Framework.aspx.

Cook, Gareth, "School Assignment Flaws Detailed: Two Economists Study Problem, Offer Relief," *Boston Globe*, 2003. September 12, http://archive.boston.com/news/local/articles/2003/09/12/school_assignment_flaws_detailed/.

Delacrétaz, David, Scott D. Kominers, and Alexander Teytelboym, "Refugee Resettlement," 2016. Working Paper.

Delmonico, Francis L., Paul E. Morrissey, George S. Lipkowitz, Jeffrey S. Stoff, Jonathan Himmelfarb, William Harmon, Martha Pavlakis, Helen Mah, Jane Goguen, Richard Luskin, Edgar Milford, Giacomo Basadonna, Michael Chobanian, Beth Bouthot, Marc Lorber, and Richard J. Rohrer, "Donor Kidney Exchanges," *American Journal of Transplantation*, 2004, *4* (10), 1628–1634.

Duflo, Esther, "The Economist as Plumber," *American Economic Review*, May 2017, *107* (5), 1–26.

Dur, Umut, Parag A. Pathak, and Tayfun Sönmez, "Explicit vs. Statistical Preferential Treatment in Affirmative Action: Theory and Evidence from Chicago's Exam Schools," *Journal of Economic Theory*, 2020, *187*, 104996.

_ , Scott Duke Kominers, Parag A. Pathak, and Tayfun Sönmez, "Reserve Design: Unintended Consequences and the Demise of Boston?s Walk Zones," *Journal of Political Economy*, 2018, *126* (6), 2457–2479.

Edmonds, Jack, "Paths, Trees, and Flowers," *Canadian Journal of Mathematics*, 1965, *17*, 449–467.

_ , "Matroids and the greedy algorithm," *Mathematical Programming*, 1971, *1*, 127–136.

Ehlers, Lars and Thayer Morrill, "(Il)legal Assignments in School Choice," *The Review of Economic Studies*, 08 2019, *87* (4), 1837–1875.

Emanuel, Ezekiel J., Govind Persad, Ross Upshur, Beatriz Thome, Michael Parker, Aaron Glickman, Cathy Zhang, Connor Boyle, Maxwell Smith, and James P. Phillips, "Fair Allocation of Scarce Medical Resources in the Time of Covid-19," *New England Journal of Medicine*, 2020, *382* (21), 2049–2055.

Ergin, Haluk and Tayfun Sönmez, "Games of School Choice under the Boston Mechanism," *Journal of Public Economics*, 2006, *90*, 215–237.

Gale, David and Lloyd S. Shapley, "College Admissions and the Stability of Marriage," *American Mathematical Monthly*, 1962, *69*, 9–15.

Gallai, T., "Kritische Graphen. I," *Publ. Math. Inst. Hung. Acad. Sci., Ser. A*, 1963, *8*, 165–192.

_ , "Kritische Graphen. II," *Publ. Math. Inst. Hung. Acad. Sci., Ser. A*, 1964, *8*, 373–395.

Goldhill, Olivia, "Once US healthcare workers get a coronavirus vaccine, who will be next?," August 2020. QUARTZ, https://qz.com/tiktok-china-byte-dance-ban-viral-videos-privacy-1850034366.

Greenberg, Kyle, Parag A. Pathak, and Tayfun Sönmez, "Redesigning the US Army's Branching Process: A Case Study in Minimalist Market Design," 2023. ArXiv, https://arxiv.org/abs/2303.06564.

Guala, Francesco, "Building economic machines: The FCC auctions," *Studies in History and Philosophy of Science Part A*, 2001, *32* (3), 453–477.

_ , *The Methodology of Experimental Economics*, Cambridge University Press, 2005.

Gul, Faruk, "A Nobel Prize for Game Theorists: The Contributions of Harsanyi, Nash and Selten," *Journal of Economic Perspectives*, September 1997, *11* (3), 159–174.

Hadad, Justin and Alexander Teytelboym, "Improving refugee resettlement: insights from market design," *Oxford Review of Economic Policy*, 09 2022, *38* (3), 434–448.

Hafalir, Isa E., M. Bumin Yenmez, and Muhammed A. Yildirim, "Effective affirmative action in school choice," *Theoretical Economics*, 2013, *8* (2), 325–363.

Hatfield, John William and Fuhito Kojima, "Substitutes and Stability for Matching with Contracts," *Journal of Economic Theory*, 2010, *145(5)*, 1704–1723.

_ **and Paul Milgrom**, "Matching with Contracts," *American Economic Review*, 2005, *95*, 913–935.

Hitzig, Zoë, "Economist as Craftsperson in the FCC's 'Incentive Auction,'," 2018. (Blogged Conference version, History of Recent Economics Conference, September 18. https://hisreco.wordpress.com/2018/09/18/economist-as-craftsperson-in-the-fccs-incentive-auction/.).

Hitzig, Zoë, "The normative gap: mechanism design and ideal theories of justice," *Economics and Philosophy*, 2020, *36* (3), 407–434.

Hurwicz, Leonid, "Optimality and Informational Efficiency in Resource Allocation Processes," in Kenneth J. Arrow, Samuel Karlin, and Patrick, eds., *Mathematical Methods in the Social Sciences*, Stanford University Press, 1960.

_ , "On Informationally Decentralized Systems," in "in," North Holland, Amsterdam, 1972.

_ , "The Design of Mechanisms for Resource Allocation," *American Economic Review*, 1973, *2* (62), 1–30.

Hylland, Aanund and Richard J. Zeckhauser, "The Efficient Allocation of Individuals to Positions," *Journal of Political Economy*, 1979, *87(2)*, 293–314.

Jackson, Matthew O., "A crash course in implementation theory," *Social Choice and Welfare*, 2001, *18* (4), 655–708.

_ , "Matching, Auctions, and Market Design," 2013. http://dx.doi.org/10.2139/ssrn.2263502.

_ , "Mechanism Theory," 2014. Available at SSRN: https://ssrn.com/abstract=2542983.

_ , "The Role of Theory in an Age of Design and Big Data," in "The Future of Economic Design: The Continuing Development of a Field as Envisioned by Its Researchers" Springer International Publishing Cham 2019, pp. 523–530.

Johnson, Carol, "Speech to Boston School Committee, March 13," March 2013. Boston Public Schools, Office of the Superintendent, https://www.tayfunsonmez.net/wp-content/uploads/2014/11/3-13-13-superintendent-sc-memo-on-assignment.pdf.

Kesten, Onur, "School Choice with Consent," *The Quarterly Journal of Economics*, 2010, *125* (3), 1297–1348.

Keynes, John Neville, *The Scope and Method of Political Economy*, Macmillan, 1904.

Kominers, Scott Duke and Alexander Teytelboym, "The Parable of the Auctioneer: Complexity in Paul R. Milgrom's Discovering Prices," *Journal of Economic Literature*, December 2020, *58* (4), 1180–96.

Landsmark, Ted, Helen Dajer, Lisa Gonsalves, Samuel Acevedo, Marjorie Bakken, Hiep Chu, Gregory Groover, Peggy Hooper, Sandra McIntosh, Tricia Muse, Lauren Thompson, Bryan Van Dorpe, and Darnell Williams, "Report and Recommendations of the Boston Public Schools," September 2004. Student Assignment Task Force, Submitted to the Boston School Committee, https://www.tayfunsonmez.net/wp-content/uploads/2013/10/BPS-TaskForceReport.pdf.

Leyton-Brown, Kevin, Paul Milgrom, and Ilya Segal, "Economics and Computer Science of a Radio Spectrum Reallocation," *PNAS*, 2017, *114* (28), 7202–7209.

Li, Shengwu, "Ethics and market design," *Oxford Review of Economic Policy*, 2017, *33* (4), 705–720.

Makhoul, Alan T. and Brian C. Drolet, "Reserve System Implementation During the COVID-19 Pandemic," *CHEST*, December 2021, *160* (6), 2005–2006.

Maskin, Eric S., "Mechanism Design: How to Implement Social Goals," *American Economic Review*, June 2008, *98* (3), 567–76.

McAfee, R. Preston and John McMillan, "Analyzing the Airwaves Auction," *Journal of Economic Perspectives*, 1996, *10(1)*, 159–175.

McMillan, John, "Selling Spectrum Rights," *Journal of Economic Perspectives*, 1994, *8(3)*, 145–162.

McVitie, D. G. and L.B. Wilson, "Stable Marriage Assignments for Unequal Sets," *BIT*, 1970, *10*, 295–309.

Milgrom, Paul, *Discovering Prices: Auction Design in Markets with Complex Constraints*, Columbia University Press, 2017.

_ , "Auction Research Evolving: Theorems and Market Designs," *American Economic Review*, May 2021, *111* (5), 1383–1405.

Mirowski, Philip and Edward Nik-Khah, "Markets Made Flesh: Callon, Performativity and the FCC Spectrum Auctions," in "Performativity in Economic Sciences," Princeton: Princeton University Press, 2007.

Moulin, Hervé, *Axioms of Cooperative Decision Making*, Cambridge University Press, 1988.

_ , *Fair Division and Collective Welfare*, MIT Press, 2004.

Myerson, Roger B., "Optimal Auction Design," *Mathematics of Operations Research*, 1981, *6* (1), 58–73.

NASEM, "Discussion Draft of the Preliminary Framework for Equitable Allocation of COVID-19 Vaccine," September 2020. Committee on Equitable Allocation of Vaccine for the Novel Coronavirus, `https://nap.nationalacademies.org/resource/25917/25914.pdf`.

_ , *Framework for Equitable Allocation of COVID-19 Vaccine*, Washington, DC: The National Academies Press, 2020.

NBER, "Market Design Working Group," *The Reporter*, September 2008. https://www.nber.org/reporter/2008number3/news-summer-2008.

O'Connor, Brandon, "Assigning branches to cadets takes on new system," *U.S. Army News*, 2019. September 12, https://www.army.mil/article/227124/assigning_branches_to_cadets_takes_on_new_system.

Olson, Walter, "Government Must Not Assign a Coronavirus Vaccine by Race," August 2020. Cato Institute, https://www.cato.org/commentary/government-must-not-assign-coronavirus-vaccine-race.

Park, K., J. I. Moon, S. I. Kim, and Y. S. Kim, "Exchange donor program in kidney transplantation," *Transplantation*, January 1999, *67* (2), 336–338.

Pathak, Parag A., Alex Rees-Jones, and Tayfun Sönmez, "Immigration Lottery Design: Engineered and Coincidental Consequences of H-1B Reforms," 2020. forthcoming, *Review of Economics and Statistics*.

_ **, _ , and** _ , "Reversing Reserves," 2020. forthcoming, *Management Science*.

_ **and Tayfun Sönmez**, "Leveling the Playing Field: Sincere and Sophisticated Players in the Boston Mechanism," *American Economic Review*, 2008, *98(4)*, 1636–1652.

_ **and** _ , "School Admissions Reform in Chicago and England: Comparing Mechanisms by their Vulnerability to Manipulation," *American Economic Review*, 2013, *103(1)*, 80–106.

_ **, Harald Schmidt, Adam Solomon, Edwin Song, Tayfun Sönmez, and M. Utku "Unver**, "Do Black and Indigenous Communities Receive their Fair Share of Vaccines Under the 2018 CDC Guidelines?," September 2020. NBER Working Paper 27817, https://www.nber.org/papers/w27817.

_ **, Tayfun Sönmez, and M. Utku Ünver**, "Reserve Systems for Allocation of Scarce Medical Resources During the COVID-19 Pandemic The Path From April 2020 to April 2021," *CHEST*, October 2021, *160* (4), 1572–1575.

_ **, _ , _ , and Bumin Yenmez**, "Fair Allocation of Vaccines, Ventilators and Antiviral Treatments: Leaving No Ethical Value Behind in Health Care Rationing," 2020. arXiv:2008.00374.

_ , _ , _ , **and** _ , "Leaving No Ethical Value Behind: Triage Protocol Design for Pandemic Rationing," April 2020. NBER Working Paper 26951, https://www.nber.org/papers/w26951.

Pathak, Parag and Tayfun Sönmez, "Recommendation on Algorithm Processing," February 2013. Testimony to Boston School Committee, https://www.tayfunsonmez.net/wp-content/uploads/2019/05/BPS-SchoolCommitteTestimony.pdf.

_ **, Govind Persad, Tayfun Sönmez, and M. Utku Ünver**, "Reserve system design for allocation of scarce medical resources in a pandemic: some perspectives from the field," *Oxford Review of Economic Policy*, 2022, *38* (4), 924–940.

Persad, Govind, Monica E. Peek, and Ezekiel J. Emanuel, "Fairly Prioritizing Groups for Access to COVID-19 Vaccines," *JAMA*, 10 2020, *324* (16), 1601–1602.

Purtill, Corinne, "How AI changed organ donation in the US," *QUARTZ*, 2018. September 10, https://qz.com/1383083/how-ai-changed-organ-donation-in-the-us.

Rapaport, Felix T., "The Case for a Living Emotionally Related International Kidney Donor Exchange Registry," *Transplantation Proceedings*, June 1986, *18* (3), Suppl. 2: 5–9.

Reny, Philip J., "Efficient Matching in the School Choice Problem," *American Economic Review*, June 2022, *112* (6), 2025–43.

Richmond City, "Phase 2 Is Now Open In Richmond And Henrico!," April 2021. Virginia Department of Health, Richmond City Health Department, https://www.vdh.virginia.gov/richmond-city/2021/04/08/phase-2-is-now-open-in-richmond-and-henrico/.

_ , "Richmond And Henrico Health Districts Expand Vaccine Eligibility To All Phase 1b Groups," March 2021. Virginia Department of Health, Richmond City Health Department, https://www.vdh.virginia.gov/richmond-city/phase-1b-expansion/.

Rose, Ian, "How an economist helped thousands get a new kidney," *BBC*, 2019. December 17, https://www.bbc.com/news/business-50632630.

Rosenbaum, Lisa, "Facing Covid-19 in Italy — Ethics, Logistics, and Therapeutics on the Epidemic's Front Line," *New England Journal of Medicine*, 2020, *382* (20), 1873–1875.

Ross, Lainie Friedman and E. Steve Woodle, "Ethical issues in increasing living kidney donations by expanding kidney paired exchange programs," *Transplantatition*, April 2000, *69* (8), 1539–1543.

Rossi, Rosalind, "8th-Graders' Shot at Elite High Schools Better," *Chicago Sun-Times*, 2009. November 12.

Roth, A. E., T. Sönmez, M. U. Ünver, F. L. Delmonico, and S. L. Saidman, "Utilizing List Exchange and Nondirected Donation through 'Chain' Paired Kidney Donations," *American Journal of Transplantation*, 2006, *6* (11), 2694–2705.

Roth, Alvin E., "Laboratory Experimentation in Economics," *Economics and Philosophy*, 1986, *2*, 245–273.

_ , "The Economist as Engineer: Game Theory, Experimentation, and Computation as Tools for Design Economics," *Econometrica*, 2002, *70* (4), 1341–1378.

_ , "Is Experimental Economics Living Up to Its Promise?," in "Handbook of Experimental Economic Methodology," Oxford University Press, 2015, pp. 13–40.

_ **and Elliott Peranson**, "The Redesign of the Matching Market for American Physicians: Some Engineering Aspects of Economic Design," *American Economic Review*, 1999, *89*, 748–780.

_ **and Robert B. Wilson**, "How Market Design Emerged from Game Theory: A Mutual Interview," *Journal of Economic Perspectives*, 2019, *33* (3), 118–143.

_ **, Tayfun Sönmez, and Utku Ünver**, "Kidney Exchange," *Quarterly Journal of Economics*, May 2004, *119* (2), 457–488.

_ **,** _ **, and** _ , "A Kidney Exchange Clearinghouse in New England," *The American Economic Review*, 2005, *95* (2), 376–380.

_ **,** _ **, and** _ , "Pairwise Kidney Exchange," *Journal of Economic Theory*, 2005, *125*, 151–188.

_ **,** _ **, and** _ , "Efficient Kidney Exchange: Coincidence of Wants in Markets with Compatibility-Based Preferences," *American Economic Review*, 2007, *97* (3), 828–851.

Rubin, Emily, Scott L. Dryden-Peterson, Sarah P. Hammond, Inga Lennes, Alyssa R. Letourneau, Parag Pathak, Tayfun Sonmez, and M. Utku Ünver, "A Novel Approach

to Equitable Distribution of Scarce Therapeutics Institutional Experience Implementing a Reserve System for Allocation of COVID-19 Monoclonal Antibodies," *CHEST*, December 2021, *160* (6), 2324–2331.

Saidman, S. L., A. E. Roth, T. Sönmez, M. U. Ünver, and F. L. Delmonico, "Increasing the Opportunity of Live Kidney Donation by Matching for Two- and Three-Way Exchanges," *Transplantation*, 2006, *81* (5), 773–782.

Santos, Ana C., "Behavioural and experimental economics: are they really transforming economics?," *Cambridge Journal of Economics*, 01 2011, *35* (4), 705–728.

Satterthwaite, Mark A. and Hugo Sonnenschein, "Strategy-Proof Allocation Mechanisms at Differentiable Points," *Review of Economic Studies*, 1981, *48* (4), 587–597.

Scarf, Herbert, "My Introduction to Top-Trading Cycles," *Games and Economic Behavior*, 2009, *66*, 630–631.

Schmidt, Harald, "Vaccine Rationing and the Urgency of Social Justice in the Covid-19 Response," *Hastings Center Report*, 2020, *50* (3), 46–49.

_ , Parag Pathak, Tayfun Sönmez, and M Utku Ünver, "Covid-19: how to prioritize worse-off populations in allocating safe and effective vaccines," *BMJ*, 2020, *371.*

_ , Rebecca Weintraub, Michelle A. Williams, Kate Miller, Alison Buttenheim, Emily Sadecki, Helen Wu, Aditi Doiphode, Neha Nagpal, Lawrence O. Gostin, and Angela A. Shen, "Equitable allocation of COVID-19 vaccines in the United States," *Nature Medicine*, 2021, *27*, 1298–1307.

Schummer, James and Shigehiro Serizawa, "The Role of Characterizations in Market Design," in "The Future of Economic Design: The Continuing Development of a Field as Envisioned by Its Researchers" Springer International Publishing Cham 2019, pp. 201–211.

Sen, Amartya, *On Ethics and Economics*, Blackwell, 1987.

Shapley, Lloyd and Herbert Scarf, "On Cores and Indivisibility," *Journal of Mathematical Economics*, 1974, *1*, 23–28.

Sönmez, Tayfun, "Bidding for Army Career Specialties: Improving the ROTC Branching Mechanism," *Journal of Political Economy*, 2013, *121(1)*, 186–219.

_ **and M. Bumin Yenmez**, "Affirmative Action in India via Vertical and Horizontal Reservations," Boston College Working Papers in Economics #977, March 2019. https://ideas.repec.org/p/boc/bocoec/977.html.

_ **and** _ , "Affirmative Action in India via Vertical, Horizontal, and Overlapping Reservations," *Econometrica*, 2022, *90* (3), 1143–1176.

_ **and** _ , "Constitutional Implementation of Affirmative Action Policies in India," 2022. https://arxiv.org/abs/2203.01483.

_ **and M. Utku Ünver**, "House allocation with existing tenants: an equivalence," *Games and Economic Behavior*, 2005, *52* (1), 153–185.

_ **and** _ , "Market Design for Social Justice: A Case Study on a Constitutional Crisis in India," 2022. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4244354.

_ **and Tobias Switzer**, "Matching with (Branch-of-Choice) Contracts at the United States Military Academy," *Econometrica*, 2013, *81(2).*

_ **, Parag A. Pathak, M. Utku Ünver, Govind Persad, Robert D. Truog, and Douglas B. White**, "Categorized Priority Systems A New Tool for Fairly Allocating Scarce Medical Resources in the Face of Profound Social Inequities," *CHEST*, March 2021, *159* (3), 1294–1299.

Switzer, Tobias, "A Tale of Two Mechanisms: US Army Cadet Branching," 2011. Master's Thesis at the Catholic University of Chile, https://economia.uc.cl/wp-content/uploads/2015/07/tesis_tswitzer.pdf.

Thomson, William, "On the axiomatic method and its recent applications to game theory and resource allocation," *Social Choice and Welfare*, 2001, *18*, 327–386.

_ , "Chapter Twenty-One - Fair Allocation Rules," in Kenneth J. Arrow, Amartya Sen, and Kotaro Suzumura, eds., *Handbook of Social Choice and Welfare*, Vol. 2 of *Handbook of Social Choice and Welfare*, Elsevier, 2011, pp. 393–506.

Tobin, Thomas, "Yep, it's complicated. If you care where your kid ends up, you have to be savvy and alert," *St. Petersburg Times*, 2003. September 14.

Tolchin, Benjamin, Carol Oladele, Deron Galusha, Nitu Kashyap, Mary Showstark, Jennifer Bonito, Michelle C. Salazar, Jennifer L. Herbst, Steve Martino, Nancy Kim, Katherine A. Nash, Max Jordan Nguemeni Tiako, Shireen Roy, Rebeca Vergara

Greeno, and Karen Jubanyik, "Racial disparities in the SOFA score among patients hospitalized with COVID-19," *PLOS One*, 2021, *16* (9), e0257608.

Truog, Robert D., Christine Mitchell, and George Q. Daley, "The Toughest Triage — Allocating Ventilators in a Pandemic," *New England Journal of Medicine*, 2020, *382* (21), 1973–1975.

U.S. Chamber of Commerce, "Bill and Melinda Gates on How to Prioritize Vaccine Distribution," June 2020. YouTube. `https://www.uschamber.com/on-demand/coronavirus-pandemic/bill-and-melinda-gates-on-how-to-prioritize-vaccine-distribution`.

van Basshuysen, Philippe, "How to Build an Institution," *Philosophy of the Social Sciences*, 2021, *51* (2), 215–238.

_ , "Markets, market algorithms, and algorithmic bias," *Journal of Economic Methodology*, 2022, *0* (0), 1–12.

Vawter, Dorothy E., J. Eline Garrett, Karen G. Gervais, Angela Witt Prehn, Debra A. DeBruin, Carol A. Tauer, Elizabeth Parilla, Joan Liaschenko, and Mary Faith Marshall, "For the Good of Us All: Ethically Rationing Health Resources in Minnesota in a Severe Influenza Pandemic," 2010. Minnesota Pandemic Ethics Project, Minnesota Department of Health, `https://www.health.state.mn.us/communities/ep/surge/crisis/ethics.pdf`.

Vincent, J. L., J. Takala R. Moreno, S. Willatts, A. De Mendonça, H. Bruining, C. K. Reinhart, P. M. Suter, and L. G. Thijs, "The SOFA (Sepsis-related Organ Failure Assessment) score to describe organ dysfunction/failure," *Intensive Care Medicine*, 1996, *22*, 707.

Watts, Duncan J., "Should social science be more solution-oriented?," *Nature Human Behavior*, 2017, *1*, 0015.

Weyl, Glen, "How Market Design Economists Helped Engineer a Mass Privatization of Public Resources," *ProMarket*, 2020. May, 28.

White, Douglas B., Erin K. McCreary, Chung-Chou H. Chang, Mark Schmidhofer, J. Ryan Bariola, Naudia N. Jonassaint, Govind Persad, Robert D. Truog, Parag Pathak, Tayfun Sonmez, and M. Utku Unver, "A Multicenter Weighted Lottery to Equitably Allocate Scarce COVID-19 Therapeutics," *American Journal of Respiratory and Critical Care Medicine*, 2022, *206* (4), 503–506.

_ , **Mitchell H. Katz, John M. Luce, and Bernard Lo**, "Who Should Receive Life Support During a Public Health Emergency? Using Ethical Principles to Improve Allocation Decisions," *Annals of Internal Medicine*, 2009, *150* (2), 132–138.

Zucker, Howard A, Karl P. Adler, Donald P. Berens, Rock Brynner, Karen Butler, Yvette Calderon, Carolyn Corcoran, Nancy Neveloff Dubler, Paul J. Edelson, Joseph J. Fins, Rev. Francis H. Geer, Samuel Gorovitz, Cassandra Henderson, Hassan Khouli, Fr. Joseph W. Koterski, Hugh Maynard-Reid, John Murnane, Karen Porter, Robert Swidler, Sally True, Stuart C. Sherman, Susia A. Han, and Valier Gutmann Koch, "Ventilator Allocation Guidelines," 2015. New York State Task Force on Life and the Law, New York Department of Health. `https://www.health.ny.gov/regulations/task_force/reports_publications/docs/ventilator_guidelines.pdf`.

T.C.
YÜKSEKÖĞRETİM KURULU
ÖĞRENCİ SEÇME VE YERLEŞTİRME MERKEZİ

Başkanlık
Sayı: B.30.1.ÖSM.0.00.10.00/909-51606

26 Kasım 1997

Sayın Y. Doç. Dr. Tayfun Sönmez,
Department of Economics
University of Michigan
Ann Arbor, Michigan 48109-1220
USA

Öğrenci Seçme ve Yerleştirme Sınavı (ÖSYS) Sisteminde kimi aksaklıklar bulunduğu görüşüyle bu aksaklıkları çözmeye yönelik öneriler getiren "A Tale of Two Mechanisms in Student Placement Problems" adlı makaleniz Merkezimizce incelenmiştir. Bu incelemede,

1. Makalenizde önerilen modelin bilimsel olarak tutarlı olduğu ve akademik değer taşıdığı,
2. Bir yerleştirme problemi için kuramsal olarak minimum puan koşulunu sağlayan birden çok çözüm bulunabileceği, ÖSYS sisteminin bunlardan birini, makalede önerilen algoritmanın ise bir diğerini çözdüğü ve teorik olarak bu iki çözüm dışında başka çözümlerin de bulunabilme olasılığının olduğu,
3. Uygulama açısından bakıldığında, makalede önerilen algoritmanın ÖSYS'de kullanılması sonucunda kuramsal olarak çok uç noktalarda farklı bir sonuç verebileceği, ancak bu olasılığın son derece az olduğu,
4. Merkezimizde, makalede önerilen algoritma, simülasyon çalışmasıyla 1997 ÖSYS tüm aday kitlesi üzerinde uygulanarak yerleştirme yapıldığı, bu çalışmada elde edilen sonuç ile 1997 ÖSYS gerçek yerleştirme sonucu arasında herhangi bir fark bulunmadığı,
5. Bu bulgular ışığında, ÖSYS'de algoritma değişikliğine gidilmesinin uygun olmayacağı

sonucuna varılmıştır.

Yukarıda da belirtildiği gibi, çalışmanızın kuramsal olarak tutarlı olduğunu ve bu tip çalışmalarda her zaman işbirliği yapmaya açık olduğumuzu bildirir, başarılarınızın devamını dilerim.

Dr. Fethi Toker
Başkan

06538, ANKARA Telefon: 266 46 50 - 266 46 60 (10'ar Hat) Fax: 266 43 30 Telgraf: ÖSYM

Figure 1: Response letter from leadership at ÖSYM, declining my proposal to reform the mechanism that assigns high school graduates to colleges in Turkey.