Market Design in Education

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Outline

School Choice

- US: *Brown vs. Board* (1954): "separate educational facilities are inherently unequal"
- Many urban areas have abandoned solely residential based systems in favor of open enrollment or school choice
  - ✓ People already have school choices because they can "vote with their feet"
  - ✓ Alternative schooling models: charters, vouchers, theme oriented small schools
    - Difficulty of clearing supply and demand via residential assignment
- Why?
  - ✓ Desire to break link between housing market and school options (equity)
  - ✓ Introduce quasi-market forces into education (dates from Milton Friedman)
- Expansion of school choice remains a priority for current US administration

Recent literature thinking about the problem of assigning students to schools in public school choice plans in the US.

2003: New York City adopts a new centralized mechanism

2005: Boston changes the rules of their existing centralized mechanism

2007: England bans class of 'First Preference First' mechanisms nationwide

2009: Chicago abandons mechanism midstream

2012: Denver and NOLA adopt new mechanisms

2013: Boston adopts Home-Based Plan

2014: Washington DC and Newark adopt new mechanisms

2018: Chicago and Indianapolis adopt new mechanisms

Experience with mechanisms in the field has inspired new theoretical and empirical questions

From theory to practice

A few weeks after Abdulkadiroğlu and Sönmez (2003) was published in the June 2003 AER, it was described in the Boston Globe

School assignment flaws detailed

Two economists study problem, offer relief

By Gareth Cook
GLOBE STAFF

Boston uses a deeply flawed system for assigning students to its public schools, pushing more students out of their top-choice schools than necessary and giving parents a reason to lie about which schools they want, according to a pair of researchers who recently published their findings in a leading economics journal.

A new system, they say, could greatly reduce the anxiety in the city's annual school-choice process, in which thousands of parents submit lists of their top choices and await the computer-generated decision that will affect the next year to five years of their child's education.

The researchers found that once the parents submit their lists, they are subject to a poorly designed method of allocating spots in the top schools. By using a different technique, they say, the city could get more students into one of their top-choice schools while also making the system fairer. The alternate technique, which the researchers outline in the paper, could be put in place with relatively simple, inexpensive changes and would not require the city to change any of its broader policies, according to the researchers and other academics who have seen the paper.

"Once all this is known, I don't see how they can keep the Boston mechanism," said Turkish economist Tayfun Sonmez, one of the researchers who studied Boston's system.

For more than two decades, policymakers have devoted enormous amounts of attention to various ways to assign students to schools, sparking philosophical debates, charges of racial and economic discrimination, and tangled court battles — all of which have played out with particular drama in Boston. But the authors say their work, which also examined districts in Columbus, Minneapolis, and Seattle, is the first rigorous examination of how best to do the actual matching once the policy is decided.

The research has broader implications as well. If more parents were happier with their school assignments, it would help keep them from fleeing for the suburbs and bolster the fortunes of the school district — and the city.

Officials with the Boston public schools and the Boston School Committee readily acknowledge that parents are frustrated with

Boston Globe, September 12, 2003

Gale and Shapley go to school

- Gale and Shapley (1962) Deferred Acceptance is most popular proposal
- Each student applies to his or her most preferred school.
  - Each school ranks its initial applicants (those who've ranked it first) by priority then by lottery number within priority groups, *tentatively* admitting the highest-ranked applicants up to its capacity
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  - Each school ranks these new applicants *together with applicants tentatively admitted in the previous round*, first by priority and then by lottery number
  - From this pool, schools again tentatively admit those it's ranked highest, up to capacity, rejecting the rest

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  - Each school ranks these new applicants *together with applicants tentatively admitted in the previous round*, first by priority and then by lottery number
  - From this pool, schools again tentatively admit those it's ranked highest, up to capacity, rejecting the rest
- DA terminates when there are no new applications or each applicant has exhausted the schools he or she has ranked
  - Some students may remain unassigned
- Properties: strategy-proof, stable, constrained efficient

Outline

Student Assignment in Boston

- Over 60,000 students from grades K-12 in almost 140 schools, divided into three zones: East, West, and North.
- Main new school entry points are K2, 6th and 9th grade: about 3,300 entering Kindergarten, 5,400 entering grade 6, and about 6,300 entering grade 9.
- In January, students asked to rank at least three schools in order of preference.
- For elementary and middle school, parents are asked to consider schools in their zone plus five schools open to all neighborhoods. High school admissions are citywide.

- ✓ For each school a priority ordering is determined according to the following hierarchy:
  1) First priority: sibling and walk zone
  2) Second priority: sibling
  3) Third priority: walk zone
  4) Fourth priority: other students

  Students in the same priority group are ordered based on an even lottery.
- ✓ Each student submits a preference ranking of the schools (with no constraint)
- ✓ The final phase is the student assignment based on preferences and priorities:

Round 1: In Round 1 only the first choices of the students are considered. For each school, consider the students who have listed it as their first choice and assign seats of the school to these students one at a time following their priority order until either there are no seats left or there is no student left who has listed it as her first choice.

In general, at

Round k: Consider the remaining students. In Round k only the k^{th} choices of these students are considered. For each school with still available seats, consider the students who have listed it as their k^{th} choice and assign the remaining seats to these students one at a time following their priority order until either there are no seats left or there is no student left who has listed it as her k^{th} choice.

Cambridge mechanism: Advice for participants

Question: How would you participate if you were in this system?

"Strategies for Getting Your First Choice" (2007)

> *Because assignments are made randomly by a computer, the only way to strategize is to look at supply and demand for seats and try to predict human behavior. One way to do this is to obtain a list of estimated kindergarten seats.*
>
> ...
>
> *Nowadays, parents who might prefer Graham & Parks sometimes don't choose it at all for fear of wasting their top choice.*

These types of anecdotes can be found in nearly every city using this type of mechanism

Burden of Strategizing

- *Evidence from West Zone Parents Group*:

  Date: Fri, 28 Jan 2005
  Subject: Re: Philbrick School

  Have you gotten any sense if a lot of people are choosing Philbrick as a 1st choice? We really like Philbrick (love the K2 teacher) but are not in the walk zone. We are putting Manning 1st since we're in the walk zone and Philbrick 2nd but I'm getting very nervous that Philbrick has gotten so popular that it might only be a good #1 selection. We're also looking for a good safety for 4th place, perhaps Hale or Mendell.

Difficulty Interpreting Choice Data

- **From the Education Literature**:

  Glenn [Public Interest 1991] states

  > *As an example of how school selections change, analysis of first-place preferences in Boston for sixth-grade enrollment in 1989 (the first year of controlled choice in Boston) and 1990 shows that the number of relatively popular schools doubled in only the second year of controlled choice. The strong lead of few schools was reduced as others "tried harder."*

Policy Debate in Boston

- Nov 2003-June 2005: Ongoing discussion in Boston about school choice, one aspect was assignment mechanism
- July 2005: Boston School Committee voted to change their student assignment mechanism to the student-optimal stable mechanism
  - First time strategy-proofness played direct role in major public policy debate
- Superintendent Thomas Payzant's Report to School Committee (5/11/2005): "A strategy-proof algorithm levels the playing field by diminishing the harm done to parents who do not strategize or do not strategize well."
- Formal investigation of this argument in Pathak and Sönmez (2008)

What do people understand?

- BPS School Guide (2004, p3, quotes in original):

  For a better chance of your "first choice" school... consider choosing less popular schools.

- *Advice from the West Zone Parent's Group*:
  Introductory meeting minutes, 10/27/03

  One school choice strategy is to find a school you like that is undersubscribed and put it as a top choice, OR, find a school that you like that is popular and put it as a first choice and find a school that is less popular for a "safe" second choice.

⇒ Evidence of sophisticated behavior among some players, unsophisticated behavior by others.

Model: Sincere and Sophisticated Students

Empirical and experimental work has documented existence of heterogenous levels of sophistication

$\mathcal{N}$: Sincere students

$\mathcal{M}$: Sophisticated students

For each $i \in \mathcal{N}$, restrict the strategy space to be a singleton, corresponding to truthful preference revelation.

Focus on the Nash equilibria of the preference revelation game induced by the Boston mechanism.

Example: There are three schools a, b, c each of which has one seat, two strategic students i_1, i_2 and one sincere student i_3.

Utilities:

	a	b	c
u_{i1}	1	2	0
u_{i2}	0	2	1
u_{i3}	2	1	0

Priorities:

$$\pi_a : i_2 - i_1 - i_3$$
$$\pi_b : i_3 - i_2 - i_1$$
$$\pi_c : i_1 - i_3 - i_2$$

Game payoffs

	abc	*acb*	*bac*	*bca*	*cab*	*cba*
abc	(0,0,1)	(0,0,1)	**(1,2,0)**	**(1,2,0)**	(1,1,1)	(1,1,1)
acb	(0,0,1)	(0,0,1)	**(1,2,0)**	**(1,2,0)**	(1,1,1)	(1,1,1)
bac	(2,0,0)	(2,0,0)	(0,2,2)	(0,2,2)	(2,1,2)	(2,1,2)
bca	(2,0,0)	(2,0,0)	(0,2,2)	(0,2,2)	(2,1,2)	(2,1,2)
cab	(0,0,1)	(0,0,1)	(0,2,2)	(0,2,2)	(0,2,2)	(0,2,2)
cba	(0,0,1)	(0,0,1)	(0,2,2)	(0,2,2)	(0,2,2)	(0,2,2)

There is only one Nash equilibrium outcome:

$$\mu = \begin{pmatrix} i_1 & i_2 & i_3 \\ a & b & c \end{pmatrix}$$

Observations:

1. Truthful revelation is not a Nash equilibrium.

2. The sincere player i_3 is assigned a seat at school c and received a utility of 0 at all equilibria although she had the highest priority at school b where her utility is 1.

3. No reason to expect that the equilibrium outcome will be a stable matching. This is indeed the case here since (i_3, b) is a blocking pair.

Augmented Priorities

Given an economy (P, π) and a school s, partition the set of students I into m sets as follows

I_1: Sophisticated students and sincere students who rank s as their first choices under P,

I_2: sincere students who rank s as their second choices under P,

I_3: sincere students who rank s as their third choices under P,

$\vdots$ $\vdots$

I_m: sincere students who rank s as their last choices under P.

Given an economy (P, π) and a school s, construct an **augmented priority ordering** $\tilde{\pi}_s$ as follows:

- each student in I_1 has higher priority than each student in I_2, each student in I_2 has higher priority than each student in I_3, ..., each student in I_{m-1} has higher priority than each student in I_m, and
- for any $k \leq m$, priority among students in I_k is based on π_s.

Define $\tilde{\pi} = (\tilde{\pi}_s)_{s \in S}$.

Let $(P, \tilde{\pi}_s)$ be the **augmented economy**.

Example (continued): Only student i_3 is sincere. So $\tilde{\pi}$ is constructed from π by pushing student i_3 to the end of the priority ordering at each school except his top choice a (where he has the lowest priority anyways):

$$\begin{array}{lcl} \pi_a : i_2 - i_1 - i_3 & \Rightarrow & \tilde{\pi}_a : i_2 - i_1 - i_3 \\ \pi_b : i_3 - i_2 - i_1 & \Rightarrow & \tilde{\pi}_b : i_2 - i_1 - i_3 \\ \pi_c : i_1 - i_3 - i_2 & \Rightarrow & \tilde{\pi}_c : i_1 - i_2 - i_3 \end{array}$$

In this example the unique Nash equilibrium outcome μ of the preference revelation game induced by the Boston mechanism is the unique stable matching for the augmented economy $(P, \tilde{\pi})$.

Characterizing Nash Equilibrium Outcomes

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- Sincere students **lose their priority** to sophisticated students.
- Set of Nash equilibrium outcomes inherits the same properties as set of stable matchings for $(P, \tilde{\pi})$: Set of students who are single is the same in all equilibrium outcomes, set of occupied seats always the same, lattice structure, Pareto-dominant equilibrium allocation, etc.

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Example (continued): The outcome of SOSM is the following:

$$\begin{pmatrix} i_1 & i_2 & i_3 \\ a & c & b \end{pmatrix}$$

- Sincere student i_3 improves and obtains a seat at school b.
- Sophisticated student i_1 receives a seat at school a under both mechanisms.
- Strategic student i_2 suffers a loss under SOSM and receives a seat at her second choice school c.

Comparing Mechanisms for Sincere Students

Is a sincere student always better off under the SOSM? NO.

A sincere student can prefer the Boston mechanism since

- she gains priority at her second choice school over sincere students who rank it third or lower,
- she gains priority at her third choice school over sincere students who rank it fourth or lower, etc.

In a way an sincere student may luck out (at the expense of another sincere student) under the Boston mechanism!

Comparing Mechanisms for Sophisticated Students

Proposition 3: Fix an economy (P, π) and a sophisticated student $i \in \mathcal{M}$. The assignment of student i under the Pareto-dominant Nash equilibrium outcome of the Boston mechanism is at least as good as her assignment under the dominant strategy equilibrium outcome of the SOSM.

- Sophisticated players could be worse off in other Nash equilibrium outcomes of the Boston mechanism.
- Coordination at Pareto dominant Nash equilibrium may be difficult.

Political Economy of Mechanism Choice

June 8th, 2005: Community testimony from WZPG leader

"There are obviously issues with the current system. If you get a low lottery number and don't strategize or don't do it well, then you are penalized. But this can be easily fixed. When you go to register after you show you are a resident, you go to table B and the person looks at your choices and lets you know if you are choosing a risky strategy or how to re-order it.

Don't change the algorithm, but give us more resources so that parents can make an informed choice."

Outline

Condemnation of certain assignment mechanisms

- In Boston, economists were heavily involved in policy discussion
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    - ✓ Public discussion resembles academic arguments made in Boston against "gaming"

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  - ✓ Public discussion resembles academic arguments made in Boston against "gaming"
- Like another prominent "natural experiment" in mechanism design: US Medical Match (NRMP)
  - ✓ Participants (<u>not</u> game-theorists) organized rules, mostly still in place since 1952
  - ✓ Seen as support for positive interpretation of game-theoretic idea of *stability*

Chicago Sun-Times November 12, 2009
8th-graders' shot at elite high schools better

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.

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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.

Previously, some eighth-graders were listing the most competitive college preps as their top choice, forgoing their chances of getting into other schools that would have accepted them if they had ranked those schools higher, an official said.

Under the new policy, Huberman said, a computer will assign applicants to the highest-ranked school they quality for on their list.

"It's the fairest way to do it." Huberman told Sun-Times.

Chicago Public Schools

9 selective high schools

Applicants: Any current 8th grader in Chicago

Composite test score: entrance exam + 7th grade scores

Up to Fall 2009, system worked as follows:

- Take admissions test
- Rank up to 4 schools

Chicago Mechanism is Simple Version of Boston

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In general, for $k = 2, ..., 4$

Round k: For the remaining students, only the k^{th} choices are considered. For each school with still available seats, consider the students who have listed it as their k^{th} choice. Assign the remaining school seats to these students following their composite test score until either there are no seats left or there is no student left listing it as her k^{th} choice.

- New Chicago mechanism (SD^4)
  - ✓ Rank up to 4 schools
  - ✓ Students ordered by composite score
  - ✓ First student obtains her top choice, the second student obtains her top choice among remaining, and so on.
- Somewhat surprising midstream change, especially given that both mechanisms are manipulable...

Comparing Mechanisms

- Mechanism ψ is **manipulable** by player i at problem R if there exists a type R_i' such that
$$\psi(R_i', R_{-i}) P_i \psi(R).$$
- Mechanism ψ is **at least as manipulable as** mechanism φ if for any problem where mechanism φ is manipulable, mechanism ψ is also manipulable.

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- Mechanism ψ is **more manipulable than** mechanism φ if
  - ✓ ψ is at least as manipulable as φ,
  - ✓ there is at least one problem where ψ is manipulable though φ is not.

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  suggests that the old mechanism was quite undesirable.

- We'd like to compare it to a larger class of mechanisms

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Admissions Reform in Chicago

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Theorem. *The old Chicago mechanism ($\textsc{Chi}^k$) is at least as manipulable as any weakly stable mechanism.*

Chicago in 2010-11

- Based on the last two results, the new mechanism in Chicago is an improvement in terms of our criteria
- However, 2009 mechanism is not Pareto efficient
- Possible to have a completely non-manipulable mechanism by considering all choices...so why not?

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- However, 2009 mechanism is not Pareto efficient
- Possible to have a completely non-manipulable mechanism by considering all choices...so why not?
- In 2010-11 school year, Chicago decided to consider 6 out of 9 choices, so the mechanism is still manipulable; this remains true this past spring

Constrained School Choice

- Consider more general environment where students may be ordered in different ways across schools
- Vulnerability of school choice mechanisms to manipulation played a role in NYC's adaptation of a version of the student-proposing deferred acceptance, where students can rank up to 12 choices

> NYC DOE press release on change: "to reduce the amount of gaming families had to undertake to navigate a system with a shortage of good schools" (New York Times, 2003)

- Based on the strategy-proofness of DA, the following advice was given to students:

You must now rank your **12** choices according to your true preferences.

Next result formalizes the idea that the greater the number of choices students can make, the less vulnerable this mechanism is to manipulation:

Theorem: *Let $\ell > k > 0$ and suppose there are at least ℓ schools. The student-optimal stable mechanism where students can rank k schools is more manipulable than the student-optimal stable mechanism where students can rank ℓ schools.*

Corollary: The 2009 Chicago mechanism (SD^4) is more manipulable than the newly adopted 2010 Chicago mechanism (SD^6).

England: Coordinating admissions

- Forms of school choice for decades
- 2003 School Admissions Code
  - "National Offer Day": coordinated admissions nationwide, under authority of Local Education Authority; 800,000 students given offer
- 2007 School Admissions Code
  - Strengthened enforcement of admissions rules

Section 2.13: In setting oversubscription criteria the admission authorities for all maintained schools must not:

give priority to children according to the order of other schools named as preferences by their parents, including 'first preference first' arrangements.

First preference first (FPF) mechanism: definition

- A school is either a **first-preference-first school** or an **equal preference school**
- At each first-preference-first school, priorities modified:
  - ✓ any student who ranks school s as his first choice has higher priority than any student who ranks school s as his second choice,
  - ✓ any student who ranks school s as his second choice has higher priority than any student who ranks school s as his third choice,
  - ✓ . . .
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  - ✓ ...
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✓ FPF mechanism is a hybrid between Boston and the student-optimal stable mechanism

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- Pan London Admissions Authority adopted an 'equal preference' system in 2005 (=student-optimal stable mechanism)

  designed to "eliminate the need for tactical preferences and make the admissions system fairer"; it will "create a level playing field for school admissions"

- Rationale given by Dept. for Ed & Skills (2007):

  "'first preference first' criterion made the system unnecessarily complex to parents who had to play an 'admissions game' with their children's future"

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- In 2006, Coldron report: 101 LEAs used equal preference, 47 used first preference first, nearly all with constraints on rank order list length

Theorem: *Suppose there are more than k schools where* $k > 1$*.* FPF^k *is more manipulable than the student-optimal stable mechanism where students can rank k schools*.

- ◇ **Corollary**: *The old abandoned Chicago Selective Enrollment mechanism is more manipulable than the new 2009 mechanism.*

Outline

Beyond Assignment to Evaluation

- DA has seen growing use in assignment
- A broader question: does it matter where someone is assigned?
  - ✓ e.g., Children attending selective (testing) schools clearly out-perform those who do not... but is that a consequence of selection?
- A recent literature has used data from DA-like systems to study education reforms
  - ✓ Knowledge of assignment process lets researchers devise empirical strategies to obtain credible causal estimates

Schools and achievement

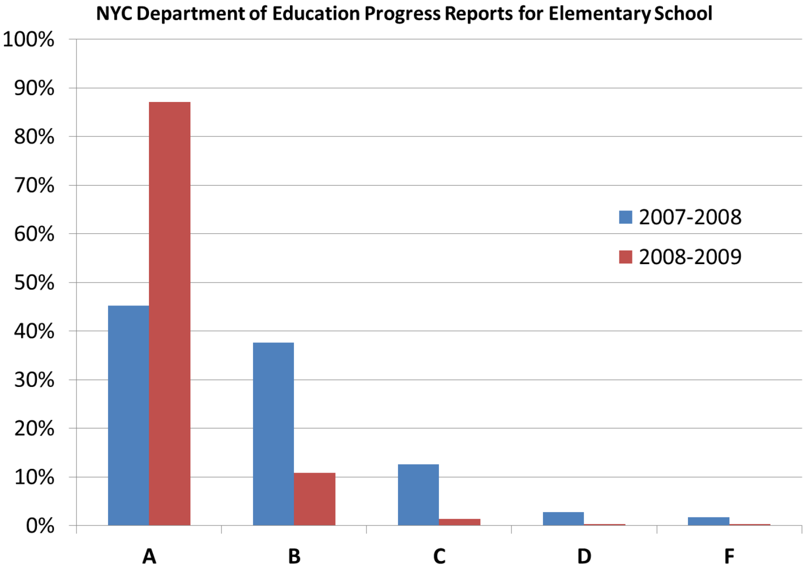
- 1966 Coleman Report: "Equality of Educational Opportunity"
  - Student family background and socioeconomic status are a much more important determinant of educational outcomes than measured differences in schools
- Is this an unfortunate fact of American life?
  - Whatever pathology may exist in Negro families is far exceeded by this social pathology in the school system that refuses to accept a responsibility that no one else can bear and then scapegoats Negro families for failing to do the job . . . The job of the school is to teach so well that family background is no longer an issue. - Martin Luther King (1968)
- Can schools alone ever close achievement gaps?

What Makes a Good School?

- We'd like to know what matters . . .
  - ✓ Teachers
  - ✓ Principals
  - ✓ Peers
  - ✓ Resources (class size, textbooks, computers)
  - ✓ School organization
  - ✓ Instructional philosophies

- We must first quantify effectiveness and its determinants before we can hope to boost it

- In practice, measurement of school effectiveness challenges and confounds policy-makers


NYC Department of Education Progress Reports for Elementary School
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
2007-2008
2008-2009
A
B
C
D
F

Finding apples-to-apples comparisons

- Look for natural experiments that result in well controlled comparisons
  - ✓ Experiments provide leverage in dealing with selection bias

- DA and other assignment mechanisms satisfy the **equal treatment of equals** property: applicants with the same preferences and priorities (or "type") have the same probability distribution over assignments

- Embedded in DA, therefore, is a stratified randomized trial

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- DA and other assignment mechanisms satisfy the **equal treatment of equals** property: applicants with the same preferences and priorities (or "type") have the same probability distribution over assignments
- Embedded in DA, therefore, is a stratified randomized trial
- We'll next show how to exploit the randomized research designs in these market designs
- We'll evaluate school sectors in the Denver's unified match
  - ✓ We use DA-generated offers of seats at charter schools to estimates the causal effects of charter school attendance
  - ✓ Charters are publicly funded school with enhanced autonomy; 6% of US school children attend

Research Design: Extracting Ignorable Assignment

- Let $D_i(s)$ indicate whether student i is offered a seat at school s
  - Applicants are characterized by prefs and priorities, their type, θ
  - Type affects assignment and is correlated w/outcomes, hence a powerful source of omitted variables bias (OVB)

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  - Applicants are characterized by prefs and priorities, their type, θ
  - Type affects assignment and is correlated w/outcomes, hence a powerful source of omitted variables bias (OVB)
- DA induces a stratified RCT
  - Let W_i be any r.v. independent of lottery numbers

$$Pr[D_i(s) = 1|W_i, \theta_i = \theta] = Pr[D_i(s) = 1|\theta_i = \theta] \tag{1}$$

  - W_i includes potential outcomes and student characteristics like sibling and free lunch status
  - Conditioning on type therefore eliminates any OVB in comparisons by offer status

Research Design: Extracting Ignorable Assignment

- Let $D_i(s)$ indicate whether student i is offered a seat at school s
  - Applicants are characterized by prefs and priorities, their type, θ
  - Type affects assignment and is correlated w/outcomes, hence a powerful source of omitted variables bias (OVB)
- DA induces a stratified RCT
  - Let W_i be any r.v. independent of lottery numbers

$$Pr[D_i(s) = 1|W_i, \theta_i = \theta] = Pr[D_i(s) = 1|\theta_i = \theta] \quad (1)$$

  - W_i includes potential outcomes and student characteristics like sibling and free lunch status
  - Conditioning on type therefore eliminates any OVB in comparisons by offer status
- But full type conditioning is **impractical**: it eliminates many students and schools from statistical analyses
  - Denver's 5,000 charter applicants include 4,300 types

Propensity Score

We condition instead on the **propensity score**, the probability of assignment to school s for a given type:

$$p_s(\theta) = Pr[D_i(s) = 1|\theta_i = \theta]$$

Theorem (Rosenbaum & Rubin 1983)

Conditional independence property (1) *implies that for any* W_i *that is independent of lottery numbers,*

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$$P[D_i(s) = 1|W_i, p_s(\theta_i)] = P[D_i(s) = 1|p_s(\theta_i)] = p_s(\theta_i)$$

- Why is this useful?
  - The score is much coarser than θ: many types share a score
  - The score identifies the maximal set of applicants for whom we have a randomized school-assignment experiment
  - The score reveals the experimental design embedded in DA: we know (and will show) its structure

Example 1: The Score Pools Types

- Five students $\{1, 2, 3, 4, 5\}$; three schools $\{a, b, c\}$, each with one seat
  - student preferences

$$
\begin{aligned}
1 &: a \succ b \\
2 &: a \succ b \\
3 &: a \\
4 &: c \succ a \\
5 &: c
\end{aligned}
$$

  - school priorities
    - 2 has priority at b
    - 5 has priority at c

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- Types are unique, ruling out research with full-type conditioning
- The score pools: DA assigns students 1, 2, 3, and 4 to school a each with probability 0.25
  - 5 beats 4 at c by virtue of priority; this leaves 1, 2, 3, and 4 all applying to a in the second round and no one advantaged there

Example 2: Further Pooling in Large Markets

- Four students $\{1, 2, 3, 4\}$; three schools $\{a, b, c\}$, each with one seat and no priorities
  - student preferences

$$1 : c$$
$$2 : c \succ b \succ a$$
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Types are again unique

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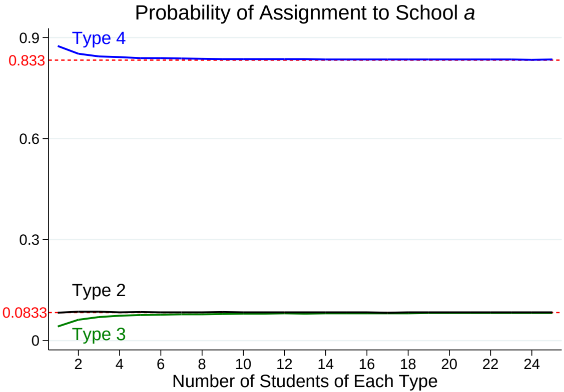
$$2 : c \succ b \succ a$$
$$3 : b \succ a$$
$$4 : a$$

  Types are again unique

- There are $4! = 24$ possible assignments. Enumerating these, we find
  - $p_a(1) = 0$, since 1 doesn't rank a
  - $p_a(2) = 2/24 = 1/12$
  - $p_a(3) = 1/24$
  - $p_a(4) = 1 - p_a(1) - p_a(2) = 21/24$
- No pooling

The Large-Market P-Score

- An $n-$ *scaled* version of Example 2:
  - n each of types 1-4 apply to 3 schools, each with n seats
  - Enumeration with large n is a chore, but repeating lottery draws reveals a common score for types 2 and 3 for n more than a few:



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- That is 26,000! lotteries for DPS... I'll get back to you...
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  - Sim scores are a black box; sample-based $\hat{p}_s(\theta)$ must be smoothed

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- Is there a formula?
  - Except for special cases, $p_s(\theta)$ as no closed form
- Our large market continuum model provides the formula we need
  - The DA score for a continuum market approximates the score as a function of a few easily-computed sufficient statistics
  - The DA score is automatically coarse: no simulation, smoothing or rounding required
  - The DA score reveals the nature of the stratified trial embedded in DA: which schools have random assignment and why

DA Formalities

- I students with preferences $\succ_i$ and priorities for school s given by $\rho_{is} \in \{1, ..., K, \infty\}$
- Student i's type is $\theta_i = (\succ_i, \rho_i)$, where ρ_i is the vector of i's ρ_{is}
- $s = 1, ..., S$ schools, with capacity vector $\mathbf{q} = (q_1, ..., q_S)$
  - In the continuum (large market), $I = [0, 1]$ and q_s is the proportion of I that can be seated at s
- Student i's lottery number, r_i, is i.i.d. uniform $[0, 1]$
- Student i's rank at school s is

$$\pi_{is} = \rho_{is} + r_i$$

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- DA assignment is determined by a vector of cutoffs, c_s: applicants to s with $\pi_{is} \leq c_s$ and $\pi_{i\tilde{s}} > c_{\tilde{s}}$ $\forall \tilde{s}$ they prefer to s, are seated at s
  - Lottery numbers matter for assignment to s only in the marginal priority group

Illustrating Cutoffs and Marginal Priorities

Rank	Priority	Lottery No.	Offer	
1.13	1	.13	1	
1.99	1	.99	1	
2.05	2	.05	1	
2.35	2	.35	1	c_s=2.35
2.57	2	.57	0	
2.61	2	.61	0	
3.12	3	.12	0	
3.32	3	.32	0	

- Marginal priority, denoted ρ_s, is the integer part of c_s; here, $\rho_s = 2$
- The lottery cutoff, denoted τ_s, is the decimal part of c_s; here, $\tau_s = .35$

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  - Θ_s^c, defined by $\rho_{\theta s} = \rho_s$
    - These **conditionally seated** applicants have marginal priority at s
    - Members of this group are seated at s when not seated at a school in $B_{\theta s}$ and they clear the lottery cutoff at s

Assignment Risk: Most Informative Disqualification

- Define

$$\text{MID}_{\theta s} = \begin{cases} 0 & \text{if } \rho_{\theta \tilde{s}} > \rho_{\tilde{s}} \text{ for all } \tilde{s} \in B_{\theta s} \\ 1 & \text{if } \rho_{\theta \tilde{s}} < \rho_{\tilde{s}} \text{ for some } \tilde{s} \in B_{\theta s} \\ \max\{\tau_{\tilde{s}} \mid \rho_{\theta \tilde{s}} = \rho_{\tilde{s}}, \tilde{s} \in B_{\theta s}\} & \text{if } \rho_{\theta \tilde{s}} \geq \rho_{\tilde{s}} \text{ for all } \tilde{s} \in B_{\theta s} \end{cases}$$

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- MID tells us how the lottery number distribution for applicants to s is truncated by qualification at more preferred schools
  - MID is 0 when priority status is worse-than-marginal at all higher ranked schools (no truncation)
  - MID is 1 if $B_{\theta s}$ includes a school where θ is seated with certainty (complete truncation)
  - For those who are marginal or worse at all schools they prefer to s, and marginal somewhere, MID is the most forgiving cutoff in the set of schools at which they're marginal
    - Applicants who clear $\max\{\tau_{\tilde{s}} \mid \rho_{\theta\tilde{s}} = \rho_{\tilde{s}}, \tilde{s} \in B_{\theta s}\}$ are seated in $B_{\theta s}$, and so not at risk for a seat at s

Theorem

In a continuum economy, $\Pr[D_i(s) = 1|\theta_i = \theta] = \varphi_s(\theta) \equiv$

$$\begin{cases} 0 & \textit{if } \theta \in \Theta_s^n \\ (1 - MID_{\theta s}) & \textit{if } \theta \in \Theta_s^a \\ (1 - MID_{\theta s}) \times \max\left\{0, \dfrac{\tau_s - MID_{\theta s}}{1 - MID_{\theta s}}\right\} & \textit{if } \theta \in \Theta_s^c \end{cases}$$

where we set $\varphi_s(\theta) = 0$ *when* $MID_{\theta s} = 1$ *and* $\theta \in \Theta_s^c$

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- $\mathrm{MID}_{\theta s}$, τ_s, and Θ are population quantities, fixed in the continuum
  - Our second theorem shows that the sample analog of $\varphi_s(\theta)$ converges uniformly to the finite market score as market size grows

DA Econometrics

- DPS has a large charter sector, part of the SchoolChoice match.
- Impact evaluation for the charter sector
  - An any-charter offer dummy, D_i, is the sum of all individual charter offers (our instrument)
  - The any-charter p-score (our key control) is the sum of the scores for each charter that type θ ranks
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- 2SLS First and Second stages

$$C_i = \sum_x \gamma(x) d_i(x) + \delta D_i + \nu_i$$
$$Y_i = \sum_x \alpha(x) d_i(x) + \beta C_i + \epsilon_i$$

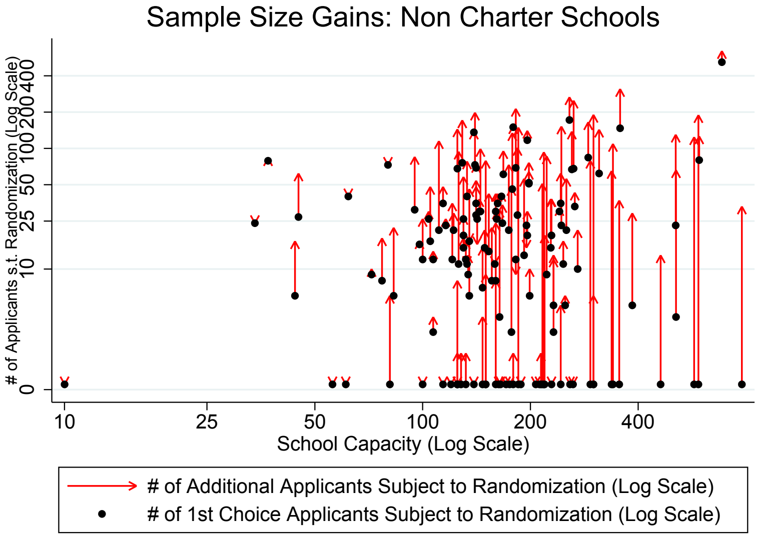
  - $d_i(x)$: dummies for propensity score values (cells), indexed by x
  - $\gamma(x)$ and $\alpha(x)$: associated "score effects"

Table 1: DPS charter schools

School	Total applicants	Applicants offered seats	Propensity score in (0,1): DA score (frequency)	DA score (formula)	Simulated score	Simulated score (first choice)
	(1)	(2)	(3)	(4)	(5)	(6)
Elementary and middle schools						
Cesar Chavez Academy Denver	62	9	7	9	8	3
Denver Language School	4	0	0	0	0	0
DSST: Cole	281	129	31	40	44	0
DSST: College View	299	130	47	67	68	0
DSST: Green Valley Ranch	1014	146	324	344	357	291
DSST: Stapleton	849	156	180	189	221	137
Girls Athletic Leadership School	221	86	18	40	48	0
Highline Academy Charter School	159	26	69	78	84	50
KIPP Montbello College Prep	211	39	36	48	55	20
KIPP Sunshine Peak Academy	389	83	41	42	44	36
Odyssey Charter Elementary	215	6	20	21	22	14
Omar D. Blair Charter School	385	114	135	141	182	99
Pioneer Charter School	25	5	0	2	2	0
SIMS Fayola International Academy Denver	86	37	7	18	20	0
SOAR at Green Valley Ranch	85	9	41	42	43	37
SOAR Oakland	40	4	0	9	7	2
STRIVE Prep - Federal	621	138	170	172	175	131
STRIVE Prep - GVR	324	112	104	116	118	0
STRIVE Prep - Highland	263	112	2	21	18	0
STRIVE Prep - Lake	320	126	18	26	26	0
STRIVE Prep - Montbello	188	37	16	31	35	0
STRIVE Prep - Westwood	535	141	235	238	239	141
Venture Prep	100	50	12	17	17	0
Wyatt Edison Charter Elementary	48	4	0	3	2	0
High schools						
DSST: Green Valley Ranch	806	173	290	343	330	263
DSST: Stapleton	522	27	116	117	139	96
Southwest Early College	265	76	34	47	55	0
Venture Prep	140	39	28	42	45	0
KIPP Denver Collegiate High School	268	60	29	37	40	24
SIMS Fayola International Academy Denver	71	15	6	22	22	0
STRIVE Prep - SMART	383	160	175	175	175	175

Notes: This table describes DPS charter applications. Column 1 reports the number of applicants ranking each school. Columns 3-6 count applicants with propensity score values strictly between zero and one according to different score computation methods. Column 6 shows the subset of applicants from column 5 who rank each school as their first choice.

Gains Over First Choice



Score Anatomy at STRIVE Prep

Table 2: DA Score anatomy

Campus	Eligible applicants (1)	Capacity (2)	Offers (3)	DA Score = 0: Θ_s^n $0 \le MID \le 1$ (4)	DA Score = 0: Θ_s^c $MID \ge \tau_s$ (5)	DA Score = 0: Θ_s^a $MID = 1$ (6)	DA Score in (0,1): Θ_s^c $MID < \tau_s$ (7)	DA Score in (0,1): Θ_s^a $0 < MID < 1$ (8)	DA Score = 1: Θ_s^a $MID = 0$ (9)
GVR	324	147	112	0	0	159	0	116	49
Lake	274	147	126	0	0	132	0	26	116
Highland	244	147	112	0	0	121	0	21	102
Montbello	188	147	37	0	0	128	0	31	29
Federal	574	138	138	78	284	3	171	1	37
Westwood	494	141	141	53	181	4	238	0	18

Notes: This table shows how formula scores are determined for STRIVE school seats in grade 6 (all 6th grade seats at these schools are assigned in a single bucket; ineligible applicants, who have a score of zero, are omitted). Column 3 records offers made to these applicants. Columns 4-6 show the number of applicants in partitions with a score of zero. Columns 7 and 8 show the number of applicants subject to random assignment. Column 9 shows the number of applicants with certain offers.

Every STRIVE campus has random assignment, though many are undersubscribed and only two have have first-choice applicants at risk

Demographic Characteristics

Table 3: DPS student characteristics

	Denver students	SchoolChoice applicants	Charter applicants	Propensity score in (0,1): DA score (frequency): Charter applicants	Propensity score in (0,1): DA score (frequency): Charter students	Propensity score in (0,1): Simulated score: Charter applicants	Propensity score in (0,1): Simulated score: Charter students
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Origin school is charter	0.133	0.080	0.130	0.259	0.371	0.230	0.357
Female	0.495	0.502	0.518	0.488	0.496	0.506	0.511
Race							
Hispanic	0.594	0.593	0.633	0.667	0.713	0.636	0.711
Black	0.141	0.143	0.169	0.181	0.161	0.192	0.168
White	0.192	0.187	0.124	0.084	0.062	0.098	0.059
Asian	0.034	0.034	0.032	0.032	0.039	0.033	0.037
Gifted	0.171	0.213	0.192	0.159	0.152	0.165	0.149
Bilingual	0.039	0.026	0.033	0.038	0.042	0.032	0.037
Subsidized lunch	0.753	0.756	0.797	0.813	0.818	0.800	0.823
Limited English proficient	0.285	0.290	0.324	0.343	0.378	0.337	0.380
Special education	0.119	0.114	0.085	0.079	0.068	0.083	0.070
Baseline scores							
Math	0.000	0.015	0.021	0.037	0.089	0.037	0.062
Reading	0.000	0.016	0.005	-0.011	0.007	0.008	-0.002
Writing	0.000	0.010	0.006	0.001	0.039	0.016	0.035
N	40,143	10,898	4,964	1,436	828	1,523	781

Notes: This table decribes the population of Denver 3rd-9th graders in 2011-2012, the baseline and application year. Statistics in column 1 are for charter and non-charter students. Column 2 describes the subset that submitted an application to the SchoolChoice system for a seat in grades 4-10 at another DPS school in 2012-2013. Column 3 reports values for applicants ranking any charter school. Columns 4-7 show statistics for charter applicants with propensity score values strictly between zero and one. Test scores are standardized to the population in column 1.

Balance: Traditional Tests

Table 5a: Statistical tests for balance in application covariates

		Propensity score controls						
		DA score (frequency)			Simulated score			
			Nonparametric			Nonparametric		
	No controls	Linear control	Rounded (hundredths)	Saturated	Linear control	Rounded (hundredths)	Rounded (ten thousandths)	Full applicant type controls
Application variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Number of schools ranked	-0.341***	0.097	0.059	0.028	0.014	0.001	-0.061	-0.015
	(0.046)	(0.103)	(0.095)	(0.094)	(0.102)	(0.095)	(0.125)	(0.042)
Number of charter schools ranked	0.476***	0.143***	0.100**	0.074	0.020	-0.017	0.009	0.007
	(0.024)	(0.052)	(0.047)	(0.047)	(0.048)	(0.043)	(0.061)	(0.010)
First school ranked is charter	0.612***	0.012	0.002	-0.001	-0.030	-0.042*	0.012	0.000
	(0.011)	(0.025)	(0.022)	(0.020)	(0.027)	(0.022)	(0.027)	(0.000)
N	4,964	1,436	1,289	1,247	1,523	1,290	681	301
Risk set points of support		88	40	47	1,148	51	126	61
Robust F-test for joint significance	1190	2.70	1.70	1.09	0.49	1.26	0.31	0.34
p-value	0.000	0.044	0.165	0.352	0.688	0.287	0.817	0.710

Notes: This table reports coefficients from regressions of the application variables in each row on a dummy for charter offers. The sample includes applicants for 2012-13 charter seats in grades 4-10 who were enrolled in Denver at baseline. Columns 1-7 are from regressions like those used to construct expected balance in Table 4, except that the tests reported here use realized DA offers, with test statistics and standard errors computed in the usual way. Column 8 reports the balance test generated by a regression with saturated controls for applicant type (that is, unique combinations of applicant preferences over school programs and school priorities in those programs). Robust standard errors are reported in parentheses. P-values for robust joint significance tests are estimated by stacking outcomes and clustering at the student level.
*significant at 10%; **significant at 5%; ***significant at 1%

Imbalance too small to detect under saturated DA score control

2SLS Estimates of Charter Effects

Table 7: Comparison of 2SLS and OLS estimates of charter attendance effects

	2SLS estimates					
	DA score					
	Frequency (saturated)	Formula (saturated)	Simulated score rounded (hundredths)	No score controls	OLS	OLS with score controls
	(1)	(2)	(3)	(4)	(5)	(6)
First stage	0.410***	0.389***	0.377***	0.683***		
	(0.031)	(0.032)	(0.032)	(0.012)		
Math	0.496***	0.524***	0.543***	0.306***	0.304***	0.386***
	(0.071)	(0.076)	(0.079)	(0.021)	(0.015)	(0.034)
Reading	0.127**	0.120*	0.106	0.093***	0.103***	0.093***
	(0.065)	(0.069)	(0.071)	(0.020)	(0.014)	(0.029)
Writing	0.325***	0.356***	0.324***	0.183***	0.180***	0.202***
	(0.077)	(0.080)	(0.080)	(0.023)	(0.015)	(0.036)
N	1,102	1,083	1,137	4,317	4,317	1,102

Notes: This table compares 2SLS and OLS estimates of charter attendance effects using the same sample and instruments as for Table 6. The OLS estimates in column 6 are from a model that includes saturated control for frequency estimates of the DA score. In addition to score variables, all models include controls for grade tested, gender, origin school charter status, race, gifted status, bilingual status, subsidized price lunch eligibility, special education, limited English proficient status, and baseline test scores. Robust standard errors are reported in parentheses.
*significant at 10%; **significant at 5%; ***significant at 1%

School FX: Brief Summary

- Urban high expectations / "no excuses" charters show promise
  - Schools emphasize traditional reading and math instruction, longer school days and years, strict discipline, young teaching staff
  - Effects seen on wide range of outcomes beyond just standardized tests
  - In different settings: our work in Boston, Chicago, Denver, and New Orleans (available at seii.mit.edu)

- Mixed evidence for other types of charters

- Selective/exam schools have been studied using RD designs; consistent zero effects (across a range of cutoffs)
  - See our paper, Abdulkadiroglu, Angrist, and Pathak (2014), "The Elite Illusion"
  - High performance is driven by selection process

- Evidence on vouchers is similarly mixed and even some large negatives
  - Negative effects undermine narrative that choice is inherently good

- Large positives and negatives are contrary Coleman view that schools can't do much

What Else? What Next?

- Non-lottery tie-breaking case: Abdulkadiroğlu, Angrist, Narita, Pathak (2017)
- We can use centralized assignment for individual-school effects; Ideally, we'd use DA for both assignment and accountability
  - To boost power, can combine with observational estimates: Angrist, Hull, Pathak, Walters (2016)
- Evaluation of other education reforms: Angrist, Pathak, Rokkanen, Zarate (2018)
- Choice markets: relationship between choices, value added, and productivity (see Abdulkadiroğlu, Pathak, Walters (2017))
- Further theoretical research on assignment algorithms and their properties: Abdulkadiroğlu, Che, Pathak, Roth, Tercieux (2017); Dur, Pathak, Sönmez (2016)