Matching “versus” Mechanism Design

Eric Budish
University of Chicago, Booth School of Business

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Mechanism design approach

- Max objective s.t. constraints (technology, incentives)
- Vickrey auction
- Myerson auction
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Matching approach
- Seek a mechanism that satisfies "good properties"
- Gale-Shapley deferred acceptance algorithm
- Gale’s Top Trading Cycles algorithm
Matching “versus” mechanism design

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  - unique mechanism that is Pareto efficient and strategyproof
- Deferred acceptance can be formulated as a constrained optimization problem
  - Maximize proposer-side welfare s.t. stability constraints
  - G-S have a section in their paper on "optimality" that explicitly makes this point
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But, of course, often times these approaches end up looking quite different. (Else, Rakesh wouldn’t have suggested this topic!)
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For all of these reasons it can be useful to find one or more good solutions to the problem, rather than pursue the optimal solution.

Keep in mind: Myerson, Vickrey ... these are the ones that worked!

▶ If only all problems had such elegant and compelling solutions.
Matching “versus” mechanism design: plan of talk

1. Introductory Example: School Choice
   ▶ Simple for the good properties approach

2. Main example: Course Allocation (aka combinatorial assignment)
   ▶ Paints a more complicated picture

3. A few methodological observations

4. From theory to practice: course allocation at Wharton
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Introductory example: school choice

In a seminal paper, Abdulkadiroglu and Sonmez (2003) initiate the market design literature on the school choice problem. They propose two mechanisms that satisfy attractive properties:

1. Gale-Shapley variant, adapted for school choice
   - Stable (i.e. no justified envy)
   - Strategy proof for students

2. Gale Top Trading Cycles variant
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- In some applications, policy makers may rank complete elimination of justified envy before full [student] efficiency, and the Gale-Shapley student optimal stable mechanism can be used in those cases.

- In other applications, the top trading cycles mechanism may be more appealing.

- In other cases the choice between the two mechanisms may be less clear and it depends on the policy priorities of the policy makers.
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But a hugely important paper, with big policy successes associated with it.
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▶ "Boston" mechanism (incentive problems)
▶ "Non mechanisms"

The fact that we don't know the "optimal" school choice mechanism doesn't mean that we shouldn't discuss "good" school choice mechanisms!
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Moreover, subsequent empirical work on NYC suggests that the good properties approach was a reliable guide to welfare

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Main example: course allocation
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Specific instance: course allocation at universities

- The indivisible objects are seats in courses
- Each student requires a bundle of courses
- Exogenous restriction against monetary transfers (even at Chicago!)
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Other examples: assigning interchangeable workers to tasks or shifts; leads to salespeople; takeoff and landing slots to airlines; shared scientific resources amongst scientists; players to teams
Environment

- Set of $N$ students $S(s_i)$
- Set of $M$ courses $C(c_j)$ with integral capacities $q = (q_1, \ldots, q_M)$
- No other goods in the economy.

- Each student $s_i$ has a set of permissible schedules $\Psi_i \subseteq 2^C$, and a utility function $u_i : 2^C \to \mathbb{R}^+$
- Impermissible schedules have utility of zero.
- No peer effects.
- Will sometimes make additional assumptions about preferences (e.g., responsiveness)

- An allocation $x = (x_i)_{i=1}^N$ is feasible if each $x_i \in 2^C$ and $\sum_{i=1}^N x_{ij} \leq q_j$ for each $j$. 
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Efficiency Criteria

Three notions of efficiency

1. Ex-post Pareto efficiency
   
   A feasible allocation is ex-post Pareto efficient if there is no other such allocation weakly preferred by all, strictly preferred by some.

2. Ex-ante Pareto efficiency
   
   A lottery over feasible allocations is ex-ante efficient if there is no other such lottery weakly preferred by all, strictly preferred by some.
   
   Note: ex-ante implies ex-post, converse false.

3. Max social welfare.
   
   Allocation $x$ maximizes $\sum_{i=1}^{N} u_i(x_i)$ subject to feasibility.
   
   Requires interpersonal comparability, and taking a stand on welfare weights/utility normalization.

In NTU assignment: Max social welfare $\subseteq$ Ex-ante Pareto efficient $\subseteq$ Ex-post Pareto efficient.

By contrast, in TU settings the three concepts tend to exactly coincide (e.g. Vickrey auction).
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Imp possibility Theorems

Ex-ante Pareto efficiency. There is no symmetric mechanism that is ex-ante Pareto efficient and strategy proof (Zhou, 1990)

Note contrast to setting with monetary transfers; VCG maximizes social welfare and is strategy proof

Ex-post Pareto efficiency. Essentially, the only mechanisms that are ex-post Pareto efficient and strategy proof are serial/sequential dictatorships (Papai (2001), Ehlers and Klaus (2003), Hateld (2009))

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What should we make of this?

In a sense, we are in a position that is similar to school choice after AS (2003). We have a mechanism that is SP + ex-post Pareto efficient, don't know much about ex-ante efficiency, and don't know much about Max SWF s.t. constraints.

▶ Papai (2001, p. 270): “[t]he implications are clear (...) if strategic manipulation is an issue, one should seriously consider using a serial dictatorship, however restrictive it may seem.”

▶ Ehlers and Klaus (2003, p. 266): “[a] practical advantage of dictatorships is that they are simple and can be implemented easily. Furthermore, they are efficient, strategy proof (...). They can be considered to be ‘fair’ if the ordering of the agents is fairly determined; for instance by queuing, seniority, or randomization.”

▶ Hateld (2009, p. 514): “[the] results have shown that the only acceptable mechanisms for allocation problems of this sort is a sequential dictatorship, even when we restrict preferences to be responsive (...). Although unfortunate, it seems that in many of these applications, the best procedure (...) may well be a random serial dictatorship.”
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A Worry

Strategyness and ex-post Pareto efficiency are certainly attractive properties. But does the dictatorship stray too far from the underlying problem of maximizing social welfare subject to constraints? That is, does it stray too far from the problem that we would like to solve, but don’t know how to solve?

In NTU assignment there are a lot of ex-post Pareto efficient allocations, some of which seem quite different from Max SWF. Example:

▶ 2 students who require 10 courses each.
▶ 20 course seats: 10 have “good” professors, 10 have “bad” professors
▶ Both students agree that any “good” class is better than any “bad” class, and have responsive preferences
▶ Among the many ex-post Pareto efficient allocations are those in which one student gets all 10 good courses, while the other gets all 10 bad courses.
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A mechanism from practice: the “draft”

Budish and Cantillon: "The Multi-Unit Assignment Problem: Theory and Evidence from Course Allocation at Harvard" (AER, 2012)
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  3. Students are allocated courses one at a time, based on their reported preferences and remaining availability.
     - Rounds 1, 3, 5, ...: ascending priority order
     - Rounds 2, 4, 6, ...: descending priority order
A mechanism from practice: the “draft”

It is easy to show that the draft is not strategy-proof.

▶ Incentive to overreport “popular courses”, underreport “unpopular courses”

▶ Intuition: don’t waste early round draft picks on courses that will sell out much later

It is also straightforward to show that the draft is not ex-post Pareto efficient in Nash equilibrium.

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We ask a different question about efficiency: how well does the draft address the problem of maximizing ex-ante social welfare?

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▶ And we know that RSD doesn’t achieve the unconstrained maximum either, from Hylland and Zeckhauser (1979).

Data (from 2005-2006 academic year)

▶ Students’ actual submitted ROLs (potentially strategic)

▶ Students’ underlying truthful ROLs, from an administration survey (caveats/robustness in paper)
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- Implication: social planner prefers HBS to RSD if students have average-rank preferences and are weakly risk-averse
Why is RSD so unattractive ex-ante? Example

Suppose there are 4 courses with capacity of $\frac{1}{2}N$ seats each. Students require 2 courses each. Preferences are as follows:

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But ex-ante, this behavior is bad for welfare:

- Benefit to lucky is small
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Important note: unattractiveness of RSD does not depend on risk preferences. Even risk-neutral agents regard a “win a little, lose a lot” lottery as unappealing.
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What do we learn from the HBS draft?

Lesson 2: Strategy-proofness in practical market design

- Our field data allow us to directly document that students at HBS – real-life participants in a one-shot high-stakes setting – figure out how to manipulate the non-strategyproof HBS mechanism.
- Further, we show that this manipulability harms welfare, and that the magnitudes are large.
- These findings are strongly consistent with the view that SP is an important desideratum in practical market design.
- However, constraints often have costs ...
- And we also find that the welfare costs of using a strategyproof dictatorship appear to be much larger than the welfare costs of manipulability.
- Overall, suggests a nuanced view of the role of strategyproofness in design, and the need for second-best alternatives to exact SP (eg “strategy-proofness in the large”, Azevedo and Budish, 2013).
What do we learn from the HBS draft?

Lesson 3: "Where to look" for multi-unit assignment mechanisms that are better still
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- Seek an incentives middle ground between strict strategyproofness (RSD) and simple-to-manipulate (HBS).
What do we learn from the HBS draft?

Lesson 3: "Where to look" for multi-unit assignment mechanisms that are better still

▶ Seek an incentives middle ground between strict strategyproofness (RSD) and simple-to-manipulate (HBS).
▶ Seek a mechanism that yields a relatively equal distribution of outcomes, like the draft and unlike the dictatorship
Approximate CEEI

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Approach: seek a mechanism that is attractive with respect to

- Ex-post Pareto efficiency
- Ex-post fairness
- Incentive compatibility
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No restrictions on preferences: students allowed to have arbitrary preferences over schedules. Allows for scheduling constraints, complementarities, etc.
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It is easy to see that existence is problematic.
Approximate CEEI

- I prove existence of an approximation to CEEI in which
  - Agents are given approximately equal as opposed to exactly equal budgets of an artificial currency (e.g., budgets distributed on $[1000, 1000 + \varepsilon]$)
  - The market clears approximately instead of exactly
  - Worst-case market-clearing error is "small", as measured in Euclidean distance of excess demand vector (cf. Starr, 1969)
  - Average-case performance on real data smaller still (+/- one seat in six courses, out of 4500 seats allocated)
  - Equal budgets: market-clearing error could be arbitrarily large
  - Other extreme: dictatorships can be interpreted as exact CE, but from arbitrarily unequal budgets
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- Two agents. Four objects: two valuable Diamonds (Big, Small) and two ordinary Rocks (Pretty, Ugly). At most two objects per agent.
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Properties of the Approximate CEEI Mechanism

**Efficiency**
*Ex-post efficient, but for small error*

**Fairness**
*N+1 Maximin Share Guarantee*
*Envy Bounded by a Single Good*

**Incentives**
*Strategyproof in the Large*
Approximate CEEI and Matching “versus” Mechanism Design

Two possible interpretations of the role of ex-post fairness in A-CEEI
Approximate CEEI and Matching “versus” Mechanism Design

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1. Ex-post fairness as an explicit design objective, alongside efficiency and incentive compatibility
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2. Ex-post fairness as a means to an end: ex-ante welfare.
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2. Ex-post fairness as a means to an end: ex-ante welfare.

Approximate CEEI is attractive relative to alternatives under either interpretation. (As I stated at the outset, these approaches aren’t always so different!)
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<th>Outcome Fairness (Truthful Play)</th>
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<td>Assignment messages</td>
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<td>Allocation Phase: Ordinal over Items</td>
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<td>HBS Draft Mechanism (Sec 9.2)</td>
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<td>If preferences are responsive and k=2, Maximin Share Guaranteed</td>
<td>Symmetric</td>
<td>Manipulable in the Large</td>
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<td>Bezakova and Dani (2005) Maximin Utility Algorithm</td>
<td>If preferences are additive-separable, ideal fractional allocation is Pareto efficient. Realized integer allocation is close to the fractional ideal.</td>
<td>Worst Case: Get approximately zero objects (if a hedonist and all other agents are depressives)</td>
<td>Symmetric</td>
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<td>Brams and Taylor (1996) Adjusted Winner</td>
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<td>Worst Case: Get Zero Objects</td>
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<td>Lipton et al (2004) Fair Allocation Mechanism</td>
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<td>UChicago Primal-Dual Linear Programming Mechanism (Graves et al 1993)</td>
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<td>Worst Case: Get Zero Objects</td>
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Figure 3: Ex-Ante Efficiency Comparison
Approximate CEEI Mechanism vs. HBS Draft Mechanism

Description: The Othman, Budish and Sandholm (2010) Approximate CEEI algorithm is run 100 times for each semester of the Harvard Business School course allocation data (456 students, ~50 courses, 5 courses per student). Each run uses randomly generated budgets. For each random budget ordering I also run the HBS Draft Mechanism, using the random budget order as the draft order. The HBS Draft Mechanism is run using students’ actual strategic reports under that mechanism. The Approximate CEEI algorithm is run using students’ truthful preferences. This table reports the cumulative distribution of outcomes, as measured by average rank, over the 456*100 = 45,600 student-trial pairs. Average rank is calculated based on the student’s true preferences. For instance, a student who receives her 1,2,3,4 and 5th favorite courses has an average rank of (1+2+3+4+5)/5 = 3.
Matching “versus” mechanism design: some reflections

Observation 1: new tools are needed!
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- Perhaps there is a better way?
  - Recent work by Nguyen and Vohra seems quite promising in this regard
  - Instead of IC constraints, use envy-freeness constraints, and rely on large-market relationship between EF and SP-L (cf. Azevedo and Budish, 2013)
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- Positive design should always be clear on the true objectives and the true constraints

“Mistake” in the axiomatic literature on multi-unit assignment was to conclude that, because we can’t get exact ex-ante efficiency, we should settle for exact ex-post efficiency

In school choice, ex-post efficiency was a reliable guide to welfare and good market design, but not so for course allocation

Sometimes we don’t know how to maximize the true objective subject to the true constraints because of limitations of the theory.

Such situations call for attacking the true objective using theory and either data or computational simulations (Roth, 2002)

Approximate CEEI: use theory to obtain reasonable worst-case performance guarantees efficiency and envy-freeness, use data to study average case

We still don’t know the optimal solution...
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  - We still don’t know the “optimal” solution ...
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Sometimes it is tolerable to satisfy constraints approximately instead of exactly. Such approximations represent a challenge for both methodologies.

Mechanism design approach

"Max objective s.t. constraints" treats constraints as lexicographically more important than the objective.

Good properties approach

Stated axioms / properties imposed as lexicographically more important than other properties.

E.g. tendency to impose strategy-proofness inexorably in parts of matching, social choice, algorithmic game theory.

E.g. in the dictatorship papers, getting exact ex-post Pareto efficiency was treated as more important than having even a modicum of ex-post fairness.

We know from Micro 101 that we don’t expect most preferences in the world to be lexicographic. Perhaps we need new tools to make our preferences over mechanism designs a bit less lexicographic as well.
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  - "Max objective s.t. constraints" treats constraints as lexicographically more important than the objective.
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Danger: we end up only paying attention to the problems we can solve beautifully. "Keys under the lamppost" joke. I think there is value in designing mechanisms that are "better" even if not "perfect".

Data can play an important role in theorizing to yield a sense of magnitudes (Roth, 2002)

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- Comparing the good but imperfect mechanism to a performance upper bound gives a sense of how much work there is left to do!
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