Matching Models versus Mechanism Design for Allocating Indivisible Goods

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Matching: Findings, Flaws, and Future.
Northwestern University, Feb 2011
Matching "versus" mechanism design
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Mechanism design approach

- Max objective s.t. constraints (technology, incentives)
- Vickrey auction
- Myerson auction
Matching "versus" mechanism design

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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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  - Maximize proposer-side welfare s.t. stability constraints
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(Else, Alp and Rakesh wouldn’t have suggested this topic!)
Matching "versus" mechanism design

Actually, if anything, the reverse. Of course what we want to do as economists is maximize design objectives subject to constraints. So, why don't all matching papers look like mechanism design papers? A few reasons:

1. Lack of tools. Main difficulty: all objects in the economy are indivisible, no numeraire.
2. Sometimes we don't know the objective. Can be useful to provide a range of solutions.
3. Sometimes we don't know the true constraints.

Keep in mind: Myerson, Vickrey... these are the ones that worked! If only all problems had such elegant and compelling solutions.
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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 justifiable envy)
   - Strategyproof for students

2. Gale Top Trading Cycles variant
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- “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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The fact that we don’t know the "optimal" school choice mechanism doesn’t mean that we shouldn’t discuss "good" school choice mechanisms!
Main example: course allocation

I School choice is a win for the "mechanism with good properties" approach.

I I now want to turn to a problem where the story is a bit more complicated: assignment with multi-unit demand

Speciﬁc instance: course allocation at universities

I The indivisible objects are seats in courses

I Each student requires a bundle of courses

I Exogenous restriction against monetary transfers (even at Chicago!)

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
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- Set of $M$ courses $\mathcal{C}(c_j)$ 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.
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- 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 $j$
Efficiency notions

Three notions of efficiency

1. **Max social welfare.**
   Allocation $x$ maximizes $\sum_{i=1}^{N} u_i(x_i)$ subject to feasibility.

   Could also define analogous notions of constrained efficiency.

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 by some.

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

   A lottery over feasible allocations is ex-post efficient if all realizations of the lottery are ex-post efficient.

In NTU assignment: Max social welfare, Ex-ante Pareto efficient, Ex-post Pareto efficient.

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

Ex-ante Pareto efficiency. There is no symmetric mechanism that is ex-ante Pareto efficient and strategyproof (Zhou, 1990) (Note contrast to setting with monetary transfers; VCG maximizes social welfare and is strategyproof)

Ex-post Pareto efficiency. Essentially, the only mechanisms that are ex-post Pareto efficient and strategyproof are serial/sequential dictatorships (Papai (2001), Ehlers and Klaus (2003), Hat (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, strategyproof (...). They can be considered to be ‘fair’ if the ordering of the agents is fairly determined; for instance by queuing, seniority, or randomization.”

Hatfield (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

Strategyproofness 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:

I 2 students who require 10 courses each.
I 20 course seats: 10 have "good" professors, 10 have "bad" professors
I Both students agree that any "good" class is better than any "bad" class, and have responsive preferences
I 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"
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It is easy to show that the draft is not strategyproof.

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

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

From the failure of ex-post Pareto efficiency, we know that the draft doesn't achieve the unconstrained maximum.

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)
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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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Like the HBS draft, none of these is in the "pure mechanism design" mold, nor in the "pure axiomatization" mold.
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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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1. Agents report preferences over bundles.
2. Agents are given equal budgets \( b \) of an artificial currency.
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  - 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).
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  - Set other prices such that the poorer agent can afford \{Small Diamond, Pretty Rock\}, wealthier agent gets \{Big Diamond, Ugly Rock\}
Properties of the Approximate CEEI Mechanism

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

**Fairness**
- Symmetric
- $N+1$ Maximin Share Guaranteed
- 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
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A-CEEI is attractive relative to alternatives under either interpretation
### Table 2: Comparison of Alternative Mechanisms

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<thead>
<tr>
<th>Mechanism</th>
<th>Efficiency (Truthful Play)</th>
<th>Outcome Fairness (Truthful Play)</th>
<th>Procedural Fairness</th>
<th>Incentives</th>
<th>Preference Language</th>
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<tr>
<td>Approximate CEEI Mechanism (A-CEEI)</td>
<td>Pareto Efficient w/r/t Allocated Goods</td>
<td>N+1 – Maximin Share Guaranteed</td>
<td>Symmetric</td>
<td>Strategyproof in the Large</td>
<td>Ordinal over Schedules</td>
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<tr>
<td></td>
<td>Allocation error is small for practice and goes to zero in the limit</td>
<td>Envy Bounded by a Single Good</td>
<td></td>
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<tr>
<td>A-CEEI v2: Competitive Equilibrium from Equal-as-Possible Incomes (Sec 6.1)</td>
<td>Pareto Efficient</td>
<td>Worst Case: coincides with dictatorship</td>
<td>Symmetric</td>
<td>Strategyproof in the Large</td>
<td>Ordinal over Schedules</td>
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<tr>
<td>A-CEEI v3: A-CEEI with a Pareto-Improving Secondary Market (Sec 6.1)</td>
<td>Pareto Efficient</td>
<td>A bit weaker than N+1 – Maximin Share Guarantee, because prices in the initial allocation may be outside of $P(\delta, b')$. Initial allocation is Envy Bounded by a Single Good. The Pareto-improvement stage may exacerbate envy.</td>
<td>Symmetric</td>
<td>Manipulable in the Large</td>
<td>Ordinal over Schedules</td>
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<tr>
<td>Random Serial Dictatorship (Sec 8.1)</td>
<td>Pareto Efficient</td>
<td>Worst Case: Get k worst Objects</td>
<td>Symmetric</td>
<td>Strategyproof</td>
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<tr>
<td>Multi-unit generalization of Hylland Zeckhauser Mechanism (Sec 8.2)</td>
<td>If vNM preferences are described by assignment messages, ex-ante Pareto efficient</td>
<td>If preferences are additive separable, envy bounded by the value of two goods Worst Case: Get Zero Objects</td>
<td>Symmetric</td>
<td>If vNM preferences are described by assignment messages, Strategyproof in the Large</td>
<td>Assignment messages</td>
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<td>Bidding Points Mechanism (Sec 8.3)</td>
<td>If preferences are additive-separable, Pareto Efficient but for quota issues described in Unver and Sonmez (forth.)</td>
<td>Worst Case: Get Zero Objects</td>
<td>Symmetric</td>
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<td>Sonmez-Unver (forth.) Enhancement to Bidding Points Mechanism</td>
<td>If preferences are additive-separable, Pareto Efficient</td>
<td>Worst Case: Get Zero Objects</td>
<td>Symmetric</td>
<td>Bidding Phase: Manipulable in the Large</td>
<td>Bidding Phase: Cardinal over Items</td>
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<td>Allocation Phase: Strategyproof in the Large</td>
<td>Allocation Phase: Ordinal over Items</td>
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<td>HBS Draft Mechanism (Sec 9.2)</td>
<td>If preferences are responsive, Pareto Efficient with respect to the reported information (i.e., Pareto Possible)</td>
<td>If preferences are responsive and k=2, Maximin Share Guaranteed</td>
<td>Symmetric</td>
<td>Manipulable in the Large</td>
<td>Ordinal over Items</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>Herreiner and Puppe (2002) Descending Demand Procedure</td>
<td>Pareto Efficient</td>
<td>Does not satisfy Maximin Share Guarantee or Envy Bounded by a Single Object</td>
<td>Symmetric</td>
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<td>Lipton et al (2004) Fair Allocation Mechanism</td>
<td>Algorithm ignores efficiency</td>
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<td>UChicago Primal-Dual Linear Programming Mechanism (Graves et al 1993)</td>
<td>Pareto Efficient when preference-reporting limits don’t bind</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.
Multi-unit Hylland Zeckhauser Mechanism

Budish, Che, Kojima and Milgrom: "Designing Random Allocation Mechanisms: Theory and Evidence"
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Overall approach of BCKM: see how far we can push the HZ idea in the multi-unit setting
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Basic idea of HZ: "divisibilize" the indivisible goods, and then find a CEEI in the market for "probability shares".
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Two technical issues:
1. Existence of competitive equilibrium in the pseudomarket
2. Implementation of the resulting random assignment, as a lottery over sure assignments (Birkhoff - von Neumann theorem)

BCKM generalize HZ setting to a class of multi-unit settings:
- Key requirement: agents' vNM preferences over bundles can be described by Milgrom's (2009) assignment messages
- Subset of the class of substitutable preferences.

Allows for some kinds of realistic constraints (e.g., can't take two classes that meet at the same time), and some kinds of diminishing marginal returns (e.g. second "star professor" course worth less than the first)
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- Ex-ante efficient
- Interim envy free
- Strategyproof in the large

Tradeoffs versus A-CEEI

Key advantage: exactly ex-ante efficient rather than approximately ex-post efficient

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- Reporting language more restrictive (e.g., complementarities)
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In Jan 2011 version of Budish and Cantillon

Overall approach: HBS draft is a pretty good mechanism observed in the field. Try to make a "local improvement" on it.

Basic trick: centralize strategic play. Students report their ROLs to a strategic proxy, which then plays the HBS draft on their behalf.

Also, a timing modification: Essentially, the proxy gets to act after learning where the student is in the random priority order, whereas in the HBS draft students submit strategic ROLs before learning where they are in the order.
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Theory results: in a continuum economy, the proxy draft is

- **Strategyproof**
- **Original HBS draft was “simple to manipulate”**
- Ex-post Pareto efficient “possible”. That is, no Pareto improving trades can be detected based on students’ ordinal preferences over individual courses. This is an improvement over the HBS draft, which leaves such trades on the table in eqm and in the data.
- Neither mechanism is ex-post Pareto efficient with respect to many-for-many trades.

Empirics: on essentially all measures,

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Strategyproofness is too strict a standard. Strategyproof in the large isn’t appropriate for all contexts.
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- We still don’t know how to maximize ex-ante efficiency in this problem. Budish and Cantillon (2009), Budish (2010), and BCKM (2010) show how to do better on ex-ante efficiency measures under different assumptions on preferences, but the "optimal" mechanism remains unknown.
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