Essays in Design Economics

PhD defense

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What is ‘Design Economics’?

Design economics is “the part of economics intended to further the design and maintenance of markets and other economic institutions” (Roth 2002, p. 1341).

- Both an collection of institutional design problems and an approach to solving them

Earliest noteworthy success stories are from the 1990s:

1. Federal Communication Commission’s (FCC) 1994 spectrum auctions
2. National Residency Matching Program’s (NRMP) residency matching algorithm

Pioneered the use of experimental and computational methods alongside economic theory

What is ‘Design Economics’? II

Further examples:

- Auction design (Binmore and Klemperer 2002; Alphabet 2024)
- Algorithms for matching new doctors to hospitals (Roth and Peranson 1999)
- Kidney exchanges (Roth 2007)
- Design of voting rules (Lackner and Skowron 2021)
- Allocating food to food banks (Prendergast 2022)
- Data acquisition & sampling strategies (Roth and Schoenebeck 2012)
- ...

Key idea: design the ‘rules of the game’

What is 'Design Economics'? III

Design economics is also an approach to *doing* economics:

- Computation and experiment are "natural complements" (Roth 2002, p. 1363) to theory

Parallels drawn with engineering in natural science:

> *The simple theoretical model in which the only force is gravity, and beams are perfectly rigid, is elegant and general. But bridge design also concerns metallurgy and soil mechanics, and the sideways forces of water and wind. Many questions concerning these complications can't be answered analytically but must be explored using physical or computational models. (Roth 2002, p. 1342)*

Structure: Big Picture

This thesis answers three interrelated questions:

1. *‘What is the scientific value of economic theory in design economics?’* (Chapter 2)
2. *‘What is an example of a theoretical contribution in design economics?’* (Chapter 3)
3. *‘What other problems might this body of theory help with?’* (Chapter 4)

Philosophy, Science, and Philosophy of Science

Philosophy of science and "common sense"

- (Sorry Dad)

Trade off: abstraction vs recommendation

- Ultimately, I still harbor scientific aspirations

Conclusion of Chapter 4 falls out of prior philosophical analysis!

Overview

1. Preamble
2. Economic Theory & Design Economics
3. Optimal Multidimensional Auction Design
4. Reflexive Measurement
5. Conclusion

Economic Theory & Design Economics

Optimal Multidimensional Auction Design

The Problem

Among all possible ways of selling a single good with multiple quality levels, which should a seller use if they want to maximize their profits?

- $K \geq 1$ 'quality levels'
- $N \geq 1$ bidders
- Assume: bidders are risk neutral with i.i.d. valuations

Example: a car with different possible customizations

Approach

Problem: analytically intractable setting!

Use simulations to understand the qualitative features of the optimal auction

- Adapt plane-cutting algorithm from Belloni et al. (2010) (see Appendix 7.1)

Compare approximately optimal mechanism yielded by the algorithm to prior conjecture

The *exclusive-buyer mechanism*

Key idea: despite multiple dimensions of value ('quality levels'), define multidimensional analog of single-dimensional *virtual value*

Allocate the good according to the maximum of bidders' quality grade-specific virtual values

$$q_j^i(x) = \begin{cases} \frac{1}{|M(x)|} & i \in M(x) \text{ and } \max_{j'} \beta_j^i = \beta_{j'}^i \\ 0 & \text{otherwise} \end{cases} \tag{1}$$

where $M(x)$ denotes the set of bidders with the largest β^i.

I investigate the specific case of linear virtual values $\beta_j^i = x_j^i - r_j$, where r_j is the *reserve price*

Conjectures (Auction Design)

I explore two conjectures concerning the optimality of the exclusive-buyer mechanism:

Conjecture (Revenue)

The revenue of the exclusive buyer mechanism well-approximates the revenue of the optimal mechanism.

Conjecture (Allocations)

The allocation of the exclusive buyer mechanism well-approximates the allocation of the optimal mechanism yielded by the approximation algorithm.

Conjectures (Exclusion)

I also explore two conjectures concerning the measure of the typespace excluded from the allocation:

Conjecture (Measure Zero Exclusion Region)

There exist multidimensional settings where a single good with multiple quality levels is sold to multiple bidders with a measure zero exclusion region.

Conjecture (Same Exclusion Region for all N)

The exclusion region of the optimal mechanism in the multidimensional setting of a single good with multiple quality levels remains the same for $N = 1, 2, 3, \ldots$ *bidders.*

Settings

I explore each conjecture in the following settings:

- **Symmetric, independent, uniform**: $X_1, X_2 \sim U[0,1]$ and $X_1, X_2 \sim U[2,3]$ (Pavlov 2011)
- **Symmetric, independent, non-uniform**: $X_1, X_2 \sim Beta(\alpha, \beta)$ with $\alpha = 1, \beta = 2$ (Daskalakis, Deckelbaum, and Tzamos 2017)
- **Symmetric, correlated**: $X_1 = X_2 = [0,1]$, $f(x_1, x_2) = x_1 + x_2$
- **Asymmetric, independent, uniform**: $X_1 \sim U[6,8]$, $X_2 \sim U[9,11]$, $c_1 = .9, c_2 = 5$ (Belloni, Lopomo, and Wang 2010)
- **Asymmetric, independent, non-uniform**:
  $X_1 \sim truncnorm(\mu = 2.3, \sigma = 1, \underline{x}_1 = 2, \overline{x}_1 = 3)$,
  $X_2 \sim truncnorm(\mu = 2.8, \sigma = .2, \underline{x}_1 = 2, \overline{x}_1 = 3)$

Results: Conjecture (Revenue)

This conjecture is supported in all settings

However, it is known that simple (deterministic) mechanisms can well-approximate optimal (stochastic) mechanisms up to some constant fraction of their value.

The gain from using the optimal mechanism over the best deterministic mechanism is typically $\sim$1-2% in instances where randomization is required for optimality

Surprisingly, deterministic mechanisms are sometimes optimal!

Results: Conjecture (Allocations)

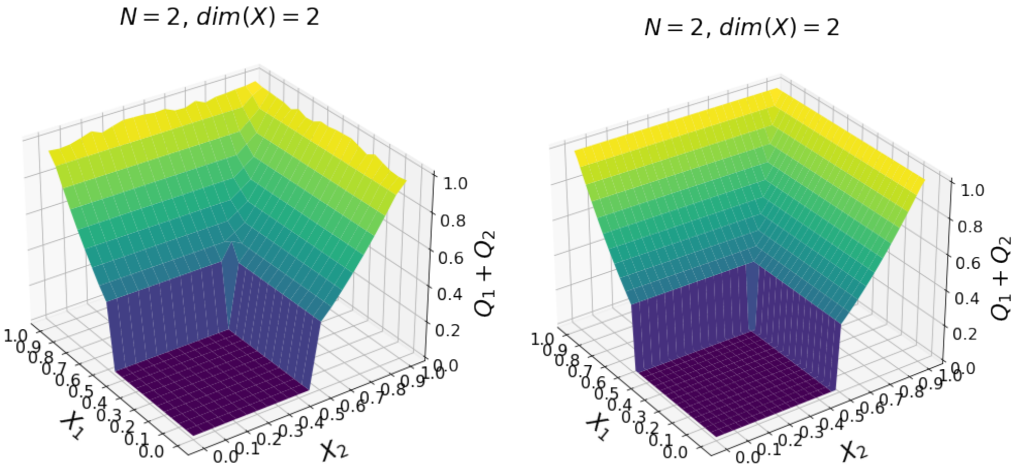

FIGURE 1: The allocations produced by the approximation algorithm (left) and exclusive buyer mechanism (right) in the **symmetric, independent, uniform** case.

Results: Conjecture (Allocations) II

This conjecture is supported when there is no evidence of randomization in the optimal mechanism

- Problem cases: symmetric, independent, uniform (Pavlov 2011) and *a*symmetric, independent, uniform (Belloni, Lopomo, and Wang 2010)

Allocations are qualitatively *very* similar in many settings

Suggests major issue lies in identifying when randomization is required; when it is not, EBM likely optimal!

Results: Conjecture (Measure Zero Exclusion Region)

This conjecture is only supported in the asymmetric, independent, uniform setting

- $X_1 \sim U[6, 8]$, $X_2 \sim U[9, 11]$, $c_1 = .9, c_2 = 5$ (Belloni, Lopomo, and Wang 2010)

This stands in contrast to theoretical work in the related multi-unit setting, which shows that it is always optimal to exclude a positive measure of buyers (Armstrong 1996; Rochet and Choné 1998)

Results: Conjecture (Same Exclusion Region for all N)

This conjecture is supported in all settings

- For cases $N = 1, 2, 3$

Suggests that $N = 1$ results can be used as 'stepping-stone' for $N > 1$ investigations, as in the case of (Pavlov 2011) (above)

Conclusion

Exclusive-buyer mechanism is often optimal!

- Depends on whether randomization is required for optimality

Future work:

- *stochastic* exclusive-buyer mechanism
- non-linear virtual values β_j^i

Reflexive Measurement

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