Essays in Design Economics

PhD defense

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Overview

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Preamble

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) 1997 residency matching algorithm

Pioneered the use of experimental and computational methods alongside economic theory

What is ‘Design Economics’? II

Further examples of success:

- Electronic marketplaces (Amazon, Uber, AirBnB, etc)
- Auction design (Binmore and Klemperer 2002; Alphabet 2024)
- Matching new doctors to hospitals (Roth and Peranson 1999)
- Kidney exchanges (Roth 2007)
- ...

Lots of different goals: revenue/welfare maximization, efficiency, stability, etc

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)*

Economic Theory & Design Economics

The Value of Economic Theory

What is the value of economic theory in design economics?

A range of possible views:

1. Economic theory is useless (a ‘collection of fables’) (Rubinstein 2006; Rubinstein 2012)
2. Economic theory sharpens the intutions of economists (Roth and Wilson 2019)
3. Economic theory has predictive value (Friedman 1953)

My argument: cannot hold (1) in light of successes of design economics

The Value of Economic Theory II

Shengwu Li
@ShengwuLi

Market design is a reminder that theory is more than fables.

Here is a model of a complex system. If you find a better policy, then fewer people die.

> **Tayfun Sönmez** @tyfn_sonmez · May 4
>
> With an idea saving countless lives since then, we published the following paper 20 years ago. Shortly after, with great personal sacrifice from my beloved late wife Banu, we moved to the US to help turn our idea into practice. Here are some resources for our story @muunver 1/4
>
> KIDNEY EXCHANGE*
>
> ALVIN E. ROTH
> TAYFUN SÖNMEZ
> M. UTKU ÜNVER

Scientific Success and Philosophy of Science

Scientific realism is the philosophical position that a science's theoretical content is 'true'

- *scientific anti-realism* is the position that theory is merely a tool

There are *lots* of ways to think about truth

Realism is most common in the natural sciences (physics)

- Argument often follows from observing "successful" scientific practices

Scientific Success and The *No-Miracles* Argument

Key idea: the more successful a science, the more likely its theory is true

Structure of the argument:

$P1$	Science X is *successful*
$P2$	Science X has theoretical content Y
$P3$	If Y weren't *true*, the successes of X would be *miraculous*
$C1$	Y is true

Realism "is the only philosophy that doesn't make the success of science a miracle" (Putnam 1975, p. 73)

The *No-Miracles* Argument and Economics

What about scientific domains where 'truth' is a "non-starter" (Alexandrova and Northcott 2009, p. 328)?

We can adapt the no-miracles argument: what explains a science's succcesses?

- $P1$ Science X is *successful*
- $P4$ Science X has common feature F
- $P5$ It would be *miraculous* if F didn't explain the success of X
- $C2$ F explains the success of X

This project loosely inspired by the idea of *local realism* (Mäki 2009)

What Explains This Success?

I consider two principal features:

1. Experiment & computation
2. Theory

Everyone (?) agrees (1) experiment and computation matter

Big disagreements about the value of economic theory

A *Minimal Non-Fable* Account of the Value of Theory

Succeses have already been established ($P1$); need to show there are common theoretical features ($P4$) that are *non-arbitrary* ($P5$)

Game theory is likely common to all the successes above (theoertical overlap)

Economic theory in design economics is *projective* (Guala 2001)

- Theory models decisions economists and policymakers subsequently take

Conclusion

Game theory is the common theoretical feature shared by the success stories of design economics

Modeling the control we exert in a model minimizes the "gap" between representation and reality

$\Longrightarrow$ Economic theory partly explains the success of 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: buying a radio spectrum license from the government (duration, coverage, use, etc)

Approach

Problem: analytically intractable setting!

Use simulations to understand the qualitative features of the optimal auction

Compare approximately optimal mechanism yielded by the algorithm to prior conjecture

- Lots of different settings!

The *exclusive-buyer mechanism*

Key idea: buyers compete for the right to be the only buyer, and then choose which quality level to purchase.

- Competition = second price or ascending-bid auction

Allocate the good according to the maximum of bidders' quality grade-specific virtual values $\beta^i = \max_{j'} \beta^i_{j'}$

I investigate the specific case of linear virtual values $\beta^i_j = x^i_j - r_j$, where r_j is the *reserve price*

Conjectures (Auction Design)

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)

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.

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)

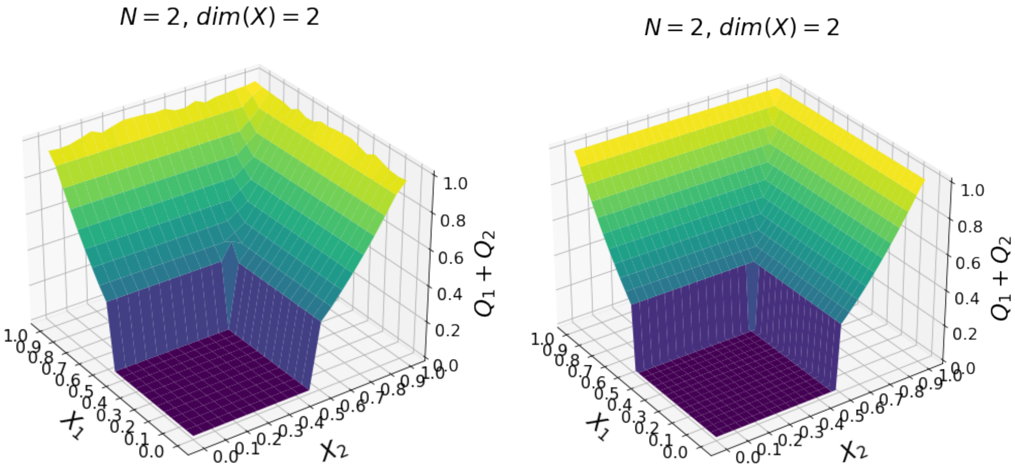

FIGURE 1: The allocations produced by the approximation algorithm (left) and exclusive buyer mechanism (right) in the **symmetric, independent, uniform** case.

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 asymmetric, 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, exclusive-buyer mechanism 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

The Causal Effects of Science Itself

Scientific practices can interfere with their targets of investigation

Example: bank runs

- Predicting a bank run can cause/exacerbate one!

Example: psychology experiments

- Study particants often guess what the experiment wants!

Goal: give a general account of this phenomenon

Jargon

Social science/philosophy

- "Self-fulfilling science" (Merton 1948) **(Sociology, Economics)**
- "Performativity" (Healy 2015) **(Sociology)**
- "Non-oxymoron criterion" (Luce 1995) **(Psychology)**
- "Reflexive prediction" (Buck 1963) **(Philosophy)**
- "Looping effects" (Hacking 1983) **(Philosophy)**
- "Reactivity" (Runhardt 2023) **(Philosophy, Sociology?)**
- "Oedipus effect" (Popper 1953) **(Philosophy)**
- "Goodhart's Law" (Goodhart 1984) **(Economics)**

Stats/CS

- "Performative prediction" (Perdomo et al. 2020) **(CS)**
- "Strategic classification" (Hardt et al. 2016) **(CS)**
- "Incentive compatible learning" (Dekel, Fischer, and Procaccia 2010) **(CS)**
- "Statistical contract theory" (Bates et al. 2022) **(CS)**

What is Reflexivity? (My Proposal)

Focus on sociological account of scientific practice

- What is it that scientists actually *do*?

Don't want to narrowly focus on prediction, measurement, etc

Consequence: broaden scope to consider *collateral effects*

- Google's 'Don't Be Evil' motto (Basu 2015)

What is Reflexivity? (My Proposal) II

What matters is people's *awareness* of their part in a *scientific investigation*

- Generalizes the notion of "partial belief" in reflexive prediction (Grunberg 1986, p. 484)

This is a broad definition!

- Avoids focus on reflexive effects (changes in outcome, changes in probability, etc)
- Relevant causal pathway for these affects is agent's awareness

This is a necessary *but not sufficient* condition

- Ask me about aliens...

Reflexive Measurement

Key idea: 'measurement as intervention' (Morgan 2001)

> *"The ways in which the economic body is investigated and data are collected, categorized, analyzed, reduced, and reassembled amount to a set of experimental interventions—not in the economic process itself, but rather in the information collected from that process." (Morgan 2001, p237)*

Helpful to consider the distinction between *data* and *phenomena* (Woodward 1989)

- Scientists can affect the underlying measurement construct (Stanford Prison Experiment)
- Or just change the incentives so people will lie (Surveys)

Reflexive Measurement & Distribution Shift

How to understand the problem of mis-aligned incentives in reflexive measurement?

De-biasing systematic component of measurement error does not work

- Narrow focus on first moment of distribution
- Assumes distribution itself doesn't change

A problem of *distribution shift*: the sample distribution no longer accurately reflects the population data model

Incentive-Compatible Measurement

Goal: design measurements that are incentive-compatible!

- Remove the incentive to lie / misreport results

It turns out there's a related literature in theoretical computer science!

- Related to work in *performative prediction* (Perdomo et al. 2020; Oesterheld et al. 2023)

Application of economic theory to measurement problems

- Arguments in Chapter 2 apply!

Conclusion

Reflexivity is general property of science

- What matters is when people are aware of their status as objects of inquiry

In the context of measurement, this is akin to the idea of 'measurement as intervention' (Morgan 2001)

This problem is best characterized as a problem of distribution shift

- Explicitly accounting for the incentives is a promising way to address this (Luce 1995)

$\Longrightarrow$ build telescopes!

Conclusion

Conclusing Remarks

Theory matters for design!

Sometimes simple mechanisms are optimal in complex settings!

Design incentive-compatible measurements!

Thank you for listening!

Bonus Slides

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**:
  $X_1 \sim truncnorm(\mu = 2.3, \sigma = 1, \underline{x}_1 = 2, \overline{x}_1 = 3)$,
  $X_2 \sim truncnorm(\mu = 2.8, \sigma = .2, \underline{x}_1 = 2, \overline{x}_1 = 3)$

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