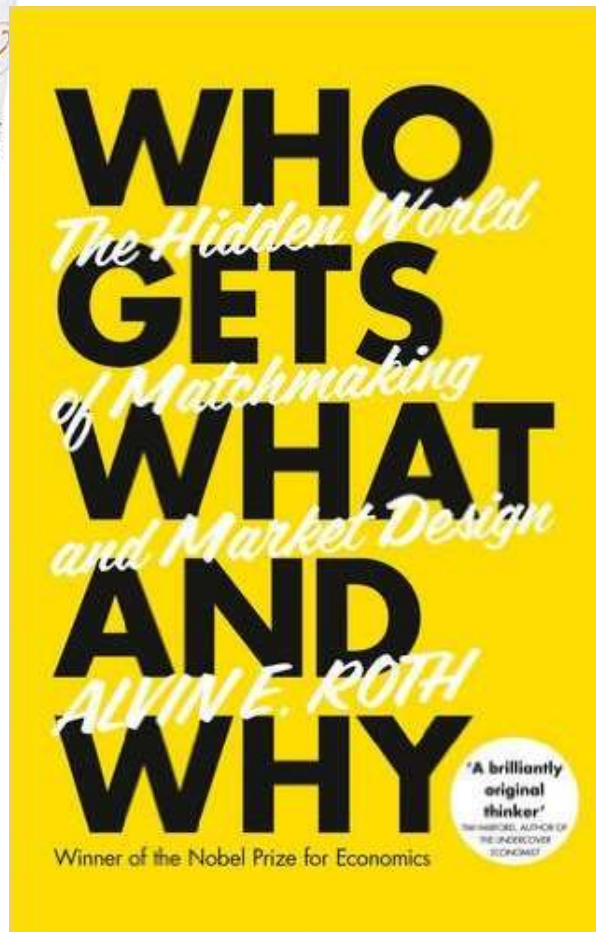
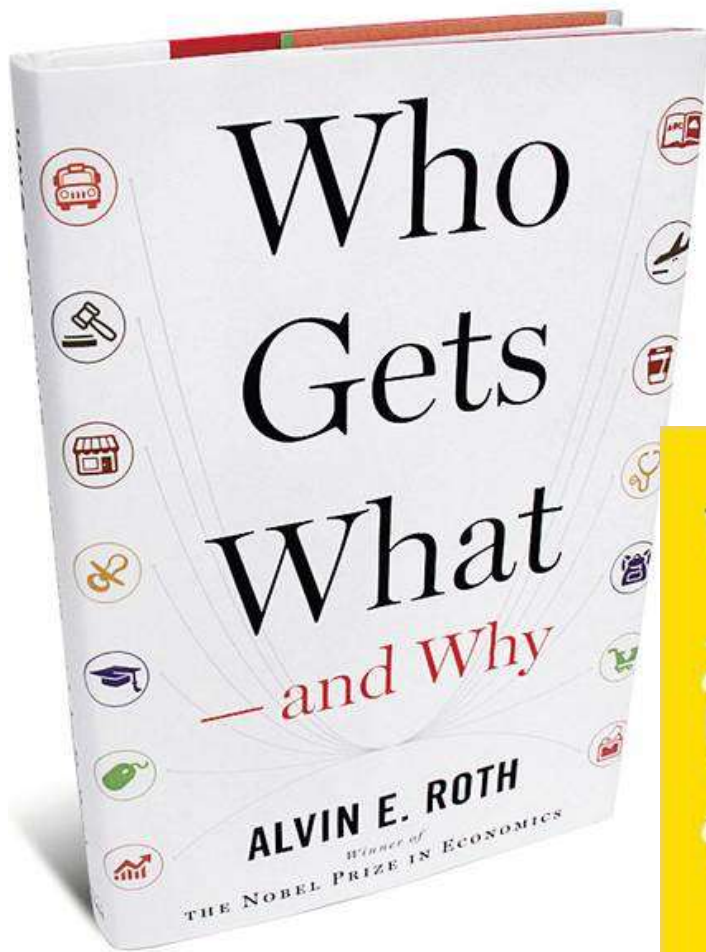


Who Gets What and Why: Matching Markets and Market Design

Alvin Roth
Stanford University

Moscow
November 2015



Markets are familiar...

I'll try to expand your idea of what is a marketplace, by telling you about some less familiar markets

Markets are a source of a lot of economic activity, and making new markets, or making existing markets work better, can be a source of growth.

Market Design and Matching Markets

- Market design is an ancient human activity
- Markets and marketplaces are human artifacts, like language
 - And just as there are many natural languages, there are many kinds of markets and marketplaces
- ***Matching markets***
 - In many markets, you care who you are dealing with, and prices don't do all the work

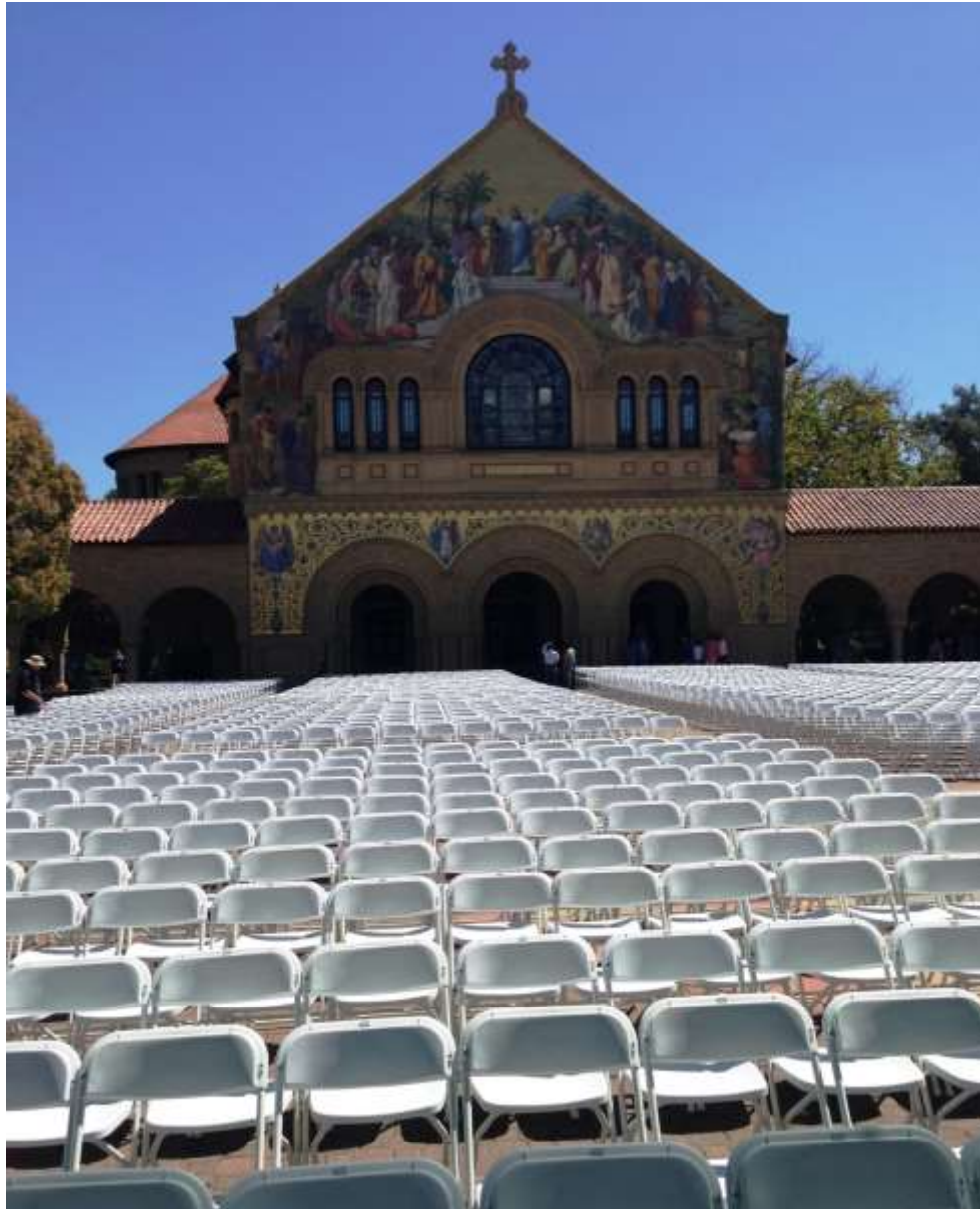
NY Stock Exchange



Stanford University



Stanford doesn't raise tuition until just enough applicants remain to fill its seats



Matching markets

- *Matching markets* are markets in which **you can't just choose what you want (even if you can afford it), you also have to be chosen.**
- Just as you can't simply inform Stanford that you're enrolling, you can't tell Google or Facebook that you're showing up for work. You also have to be *admitted* or *hired*. Neither can Stanford simply choose who will come, any more than one spouse can simply choose another: each also has to be *chosen*.
- **Labor markets and college/university admissions are more than a little like courtship and marriage:** each is a two-sided matching market that involves searching and wooing on both sides.

Design of matching markets:

- **School choice systems:**

- New York City since Sept. 2004 (high schools only)
- Boston since Sept. 2006
- Denver, New Orleans Recovery School District, Newark, Washington DC

- Kidney exchange



- Medical labor markets

- Medical Residents: in the U.S.: National Resident Matching Program (NRMP) in 1995
- Other medical markets—e.g. fellowship matches

- American labor market for new Ph.D. economists

- Scramble March 2006
- Signaling December 2007

- Teacher assignments to districts, TFA

What do marketplaces do?

Airbnb, for example

- Thickness
 - Initially, Airbnb bought competitive rival web sites to get hosts and travellers (e.g. Crashpadder in England)
 - Now competitors are e.g. Hilton Hotels
- Congestion
 - Think of how much less convenient Hilton Hotels would be if you could only inquire about what room at a time...
 - Response time of hosts
 - Communication between hosts and guests easier when both have app
 - Customer service—prioritise check in and check out
- Trust and Safety

Dates

Room Type

☒ Entire Home

☐ Private Room

☐ Shared Room

Price Range



More Filters

300+ Rentals - Moscow



\$45

Loft Studio in the Central Area

Entire home/apt • ★★★★★ • 198 reviews



\$22

Однокомнатная квартира в ...

Entire home/apt • ★★★★★ • 26 reviews



\$24

Orange Little Cozy Studio

Entire home/apt • ★★★★★ • 4 reviews



\$38

Tidy room in 1 min from subw...

Private room • ★★★★★ • 105 reviews



\$68

Art apartment in Moscow ce...

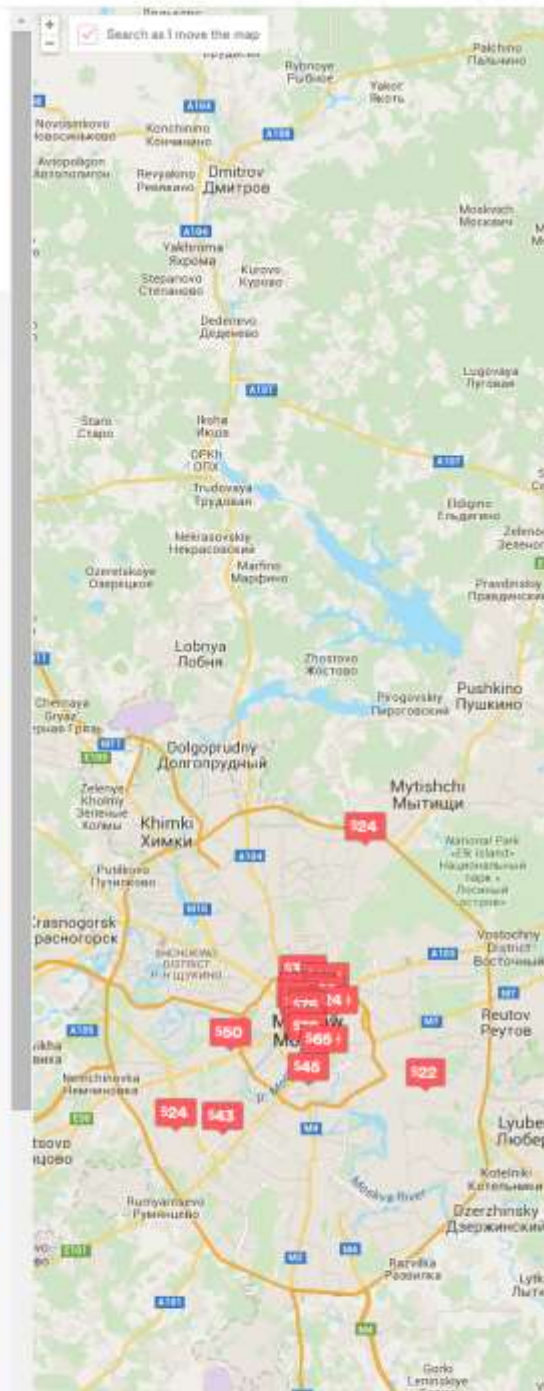
Entire home/apt • ★★★★★ • 178 reviews



\$120

Perle dans le centre de Mosc...

Entire home/apt • ★★★★★ • 16 reviews



School Choice—Bringing some market efficiency to an administrative process

- Thickness is often not an issue (school is mandatory)
- But congestion and safety can be big problems
- Parents have some information about which schools would be good for their children
 - But not every school choice system makes it safe for them to share this information

Observations on school choice

- Some school choice procedures are easy to describe but hard to navigate.
- Others may be harder to describe but easier to navigate
- Some of the ‘navigators’ may be first-timers; e.g. parents of children who are new to school choice.
- Other users of the system may be veteran, repeat users, like school principals
- **Goals: get kids into schools that are good for them, “non-wastefully,” using input from parents, while meeting various school district objectives, and gather data that helps monitor progress**

School Choice: Different in different cities

- New York City high schools, 2003
 - School principals are active participants
- Boston public schools , in 2006
 - Boston Public Schools assigns capacities to schools and priorities to students at schools: principals play no role
- 2012: Denver, Washington DC, New Orleans Recovery School District, Newark

Old NYC High School Match

(Abdulkadiroglu, Pathak, Roth 2005)

Overview: *Congestion*

- Over 90,000 students enter high school each year in NYC
- Each was invited to submit list of up to 5 choices
- Each student's choice list distributed to high schools on list, who independently make offers
- Only approx. 40% of students receive initial offers, the rest put on waiting lists—around 17,000 students received multiple offers--3 rounds to move waiting lists...
- Approx. 30,000 students assigned to schools not on their choice list, at the last minute

Issues in old (2002) system

- Schools saw rank orders
 - Some schools took students' rankings into account & considered only those that ranked their school first
- So it wasn't safe for students and families to list their true preferences
- Students needed to strategize.
 - The 2002-03 *Directory of the NYC Public High Schools* : “determine what your competition is for a seat in this program”

Issues in old (2002) system

- **Principals concealed capacities**

Deputy Chancellor (NYT 11/19/04):

“Before you might have had a situation where a school was going to take 100 new children for 9th grade, they might have declared only 40 seats and then placed the other 60 children outside the process.”

The old **Boston** school match:

- *An immediate acceptance system:*
- Students have priorities at schools set by the school district
- Students entering grades K, 6, and 9 submit (strict) preferences over schools.
- **Then as many people as possible are assigned their first choice:**
 - **In priority order, everyone who can be assigned to his first choice is. Then 2nd choices, etc.**
- **What could be wrong with a system like this??**

It wasn't safe for families to list their true preferences

- If you fail to get the school you ranked first, the school you ranked second might already be filled with people who had ranked it first.
- You wouldn't get in, even if you had the highest priority.

Advice from Boston Public Schools

- BPS School Brochure (2004, p3)
 - “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.”

But not every family is sophisticated about the choice system

- 19% of students listed two over-demanded schools as their top two choices, and about 27% of these ended up unassigned during the choice process.
 - They were assigned to a school that still had vacant places after everyone else had been assigned to one of their choices

Costs of making it unsafe to reveal true preferences:

- Many preferences are “gamed,” so the school district doesn’t know how many people are getting their real first choice, second choice etc.
 - BPS couldn’t do effective planning.
- There were real costs to strategic behavior borne by parents—e.g. West Zone Parents group.
- Those who don’t play strategically get hurt.

Objectives in NY and Boston

Redesign school choice to

- Deal with congestion
- Make it safe for families to reveal their true preferences
- Assign students to places efficiently, while meeting school district objectives
- Use the resulting data to monitor school and student performance, and inform discussions about school portfolios

Basic Deferred Acceptance Algorithm for School Assignment

- Step 0.0 Priorities of students at schools are augmented with random lottery numbers, for tie-breaking when needed.
- Step 0.1: students (and, in NY, schools) **privately** submit preferences
- Step 1: Each student “applies” to her first choice. Each school tentatively assigns its seats to its applicants one at a time in their priority order. Any remaining applicants are rejected.
- ...
- Step k: Each student who was rejected in the previous step applies to her next choice if one remains. Each school considers the students it has been holding together with its new applicants and tentatively assigns its seats to these students one at a time in priority order. Any remaining applicants are rejected.
- The algorithm terminates when no student application is rejected, and each student is assigned her final tentative assignment.

Theorems (about simple markets)

- The outcome that results from a deferred acceptance algorithm is *stable*: it is never the case that a school and student, not matched to one another, would both prefer to be. (Gale and Shapley, '62)

- The student proposing deferred acceptance algorithm makes it a **dominant strategy for students to state their true preferences.** (Roth, 1982, 1985)
 - This means it is safe for applicants to submit their true preferences: e.g. even if they don't get their true first choice, it won't hurt their chance of getting their second choice.
- In large markets, it is virtually a dominant strategy for all participants to state true preferences (Immorlica and Mahdian 2005; Kojima and Pathak 2009)

Promises you can make

- **Principals can't get better students by withholding places:** a student fails to get into a school only if it is filled with more preferred/higher priority students (Gale and Shapley, '62)
- It is safe for families to submit their true preferences: e.g. even if they don't get their true first choice, it won't hurt their chance of getting their second choice.
 - It “**levels the playing field:**” families don't have to be sophisticated.

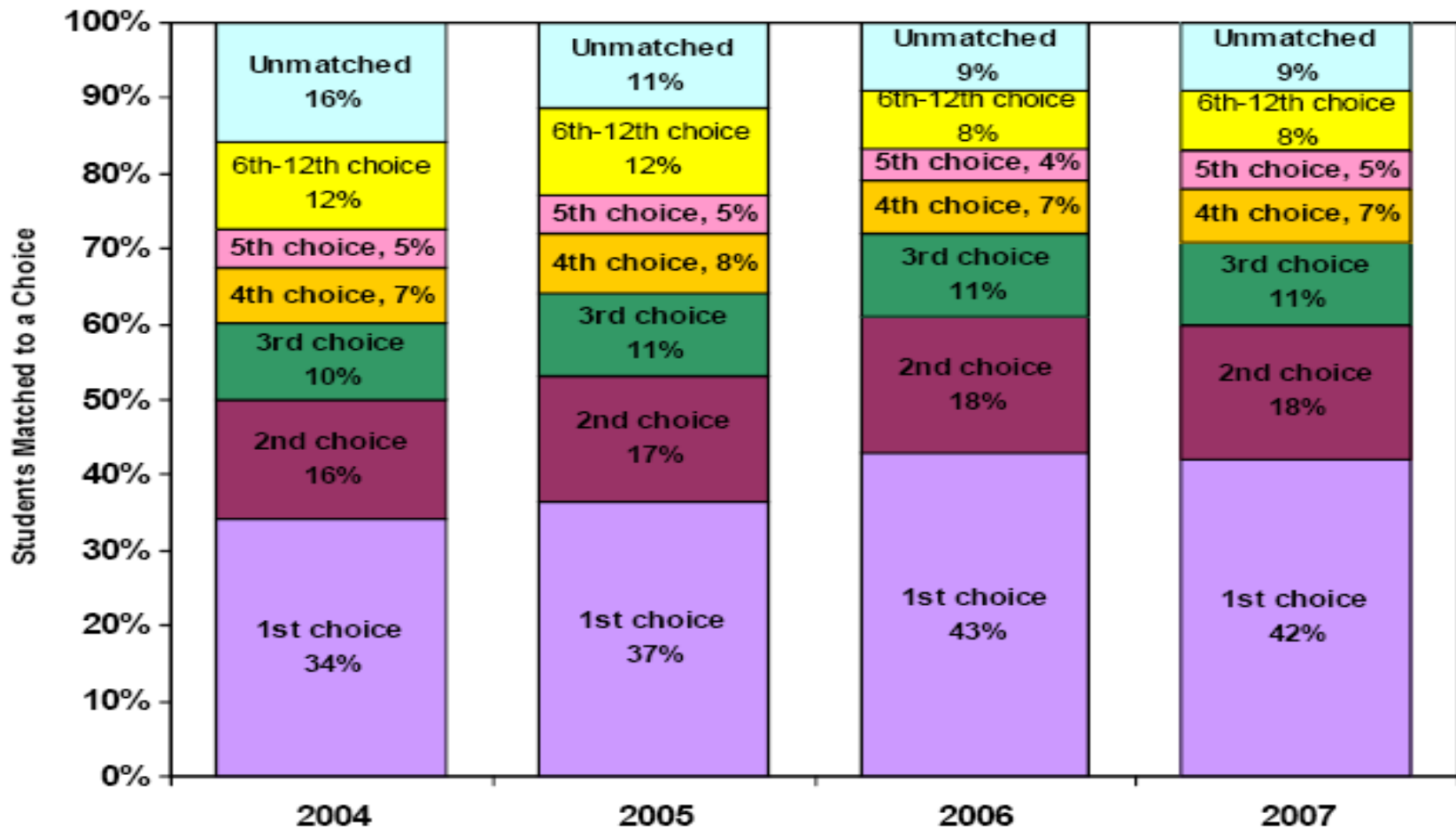
NYC: First Year of Operation

- 3,000 students did not receive any school they chose
 - Compared to 30,000 who did not receive a choice school in the previous year

First 4 years: March 23, 2007

Results at end of Round 2

(Schools have learned to change their reporting of capacities)



School places that used to be withheld by principals returned over the first three years

Other markets

- From wheat to finance to transplantation

How are commodity markets designed?

- They may start as matching markets.
- The U.S. market for wheat:
 - In the 1800's, it was a matching market, you had to know your farmer
 - “selling by sample,” since each crop was different, and there were no standards for quality, etc.

The U.S. market for wheat today

- There are eight classes of wheat: durum, hard red spring, hard red winter, soft red winter, hard white, soft white, unclassified, and mixed.
- There are grades: 1-5
- They are traded in centralized markets: the Kansas City Board of Trade, Chicago Board of Trade
- Thus you can buy a contract for 5,000 bushels of *No.2 Hard Red Winter Wheat*.
 - You don't have to sample: all offers are the same

- <http://www.wheatflourbook.org/p.aspx?tabid=1>

Do new forms of trading call for new
market designs?

Commodity markets

- NY Stock Exchange



- Chicago Board of Trade



No more 'roar' as famed trading pits come to an end



By Tribune wire reports
contact the reporter

JULY 6, 2015, 9:11 AM | NEW YORK

<http://www.chicagotribune.com/business/breaking/ct-trading-pits-cme-end-20150706-story.html>

Traders on the floor of the NY Stock Exchange



High Frequency Trading Can Make Thick Markets Thin

- The High-Frequency Trading Arms Race:
Frequent Batch Auctions as a Market Design Response, by Budish, Cramton, and Shim, QJE forthcoming.

Financial market design

- High frequency trading
- Presently both the New York Stock Exchange and the Chicago Mercantile Exchange use continuous limit order books.
 - First come first served: whoever accepts a bid or asked first gets the trade
 - This can create a race that doesn't have an economic purpose
 - It can make the market thinner in costly ways
 - It can cause breakdowns like the “flash crash” in 2010

The High-Frequency Trading Arms Race

Budish, Crampton and Shim



790 miles by road

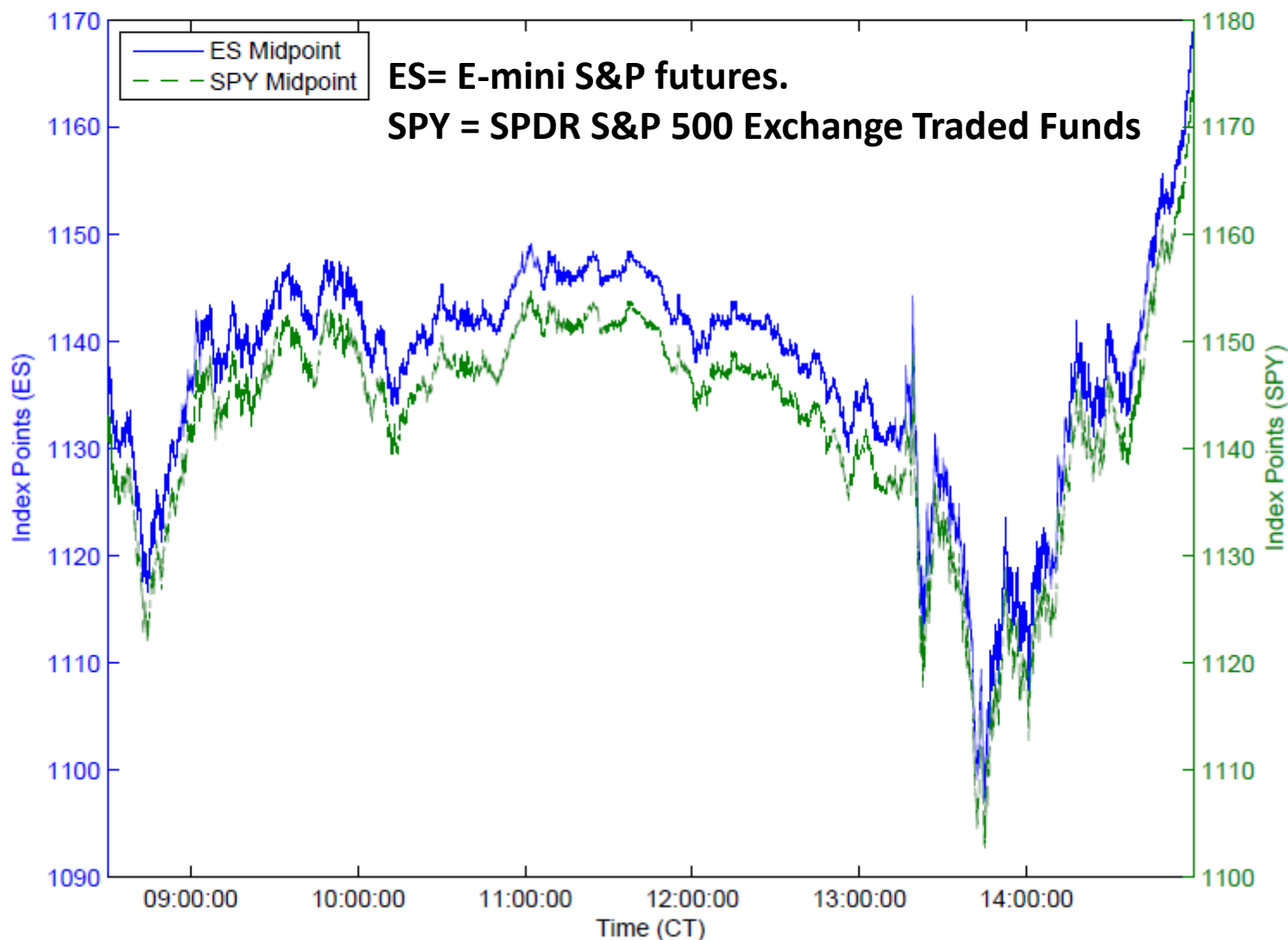
- ▶ In 2010, Spread Networks invests \$300mm to dig a high-speed fiber optic cable from NYC to Chicago.
- ▶ Shaves round-trip data transmission time ... from 16ms to 13ms
- ▶ Industry observers: 3ms is an “eternity”. “Anybody pinging both markets has to be on this line, or they’re dead” **Eyblink: 100-400ms**
- ▶ Joke at the time: next innovation will be to dig a tunnel, “avoiding the planet’s pesky curvature”
- ▶ Joke isn’t that funny ... Spread’s cable is already obsolete!
- ▶ Not tunnels, but microwaves (Initially 9ms, now down to 8.5ms).
- ▶ HFT infrastructure spending estimated as on the order of \$2bn per year by industry analysts (also substantial human capital)

Why is there demand for high frequency data and trading ability?

- Because the market is first come, first served, and sometimes there are brief opportunities for arbitrage....

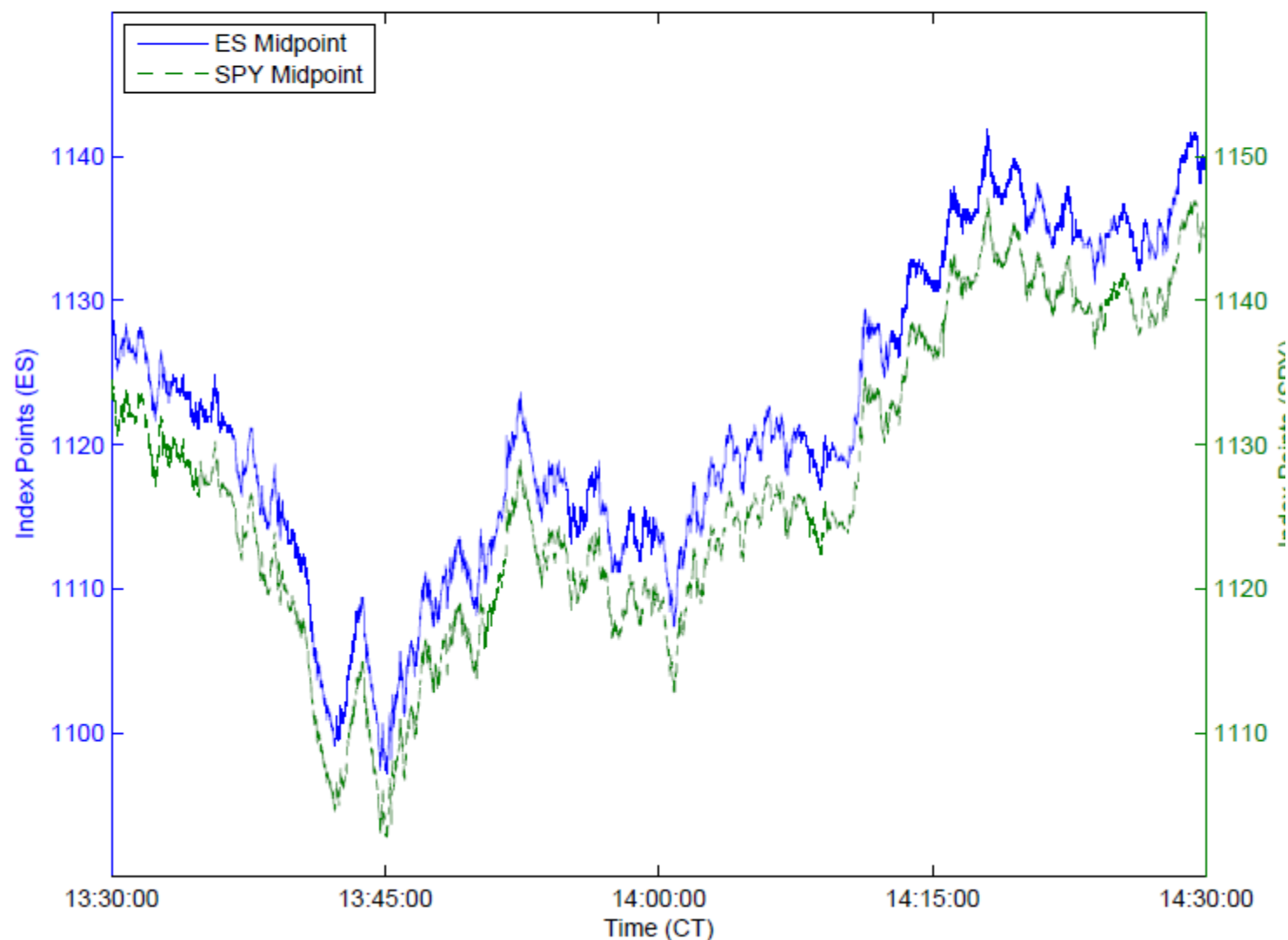
Market Correlations Break Down at High Frequency

ES vs. SPY: 1 Day



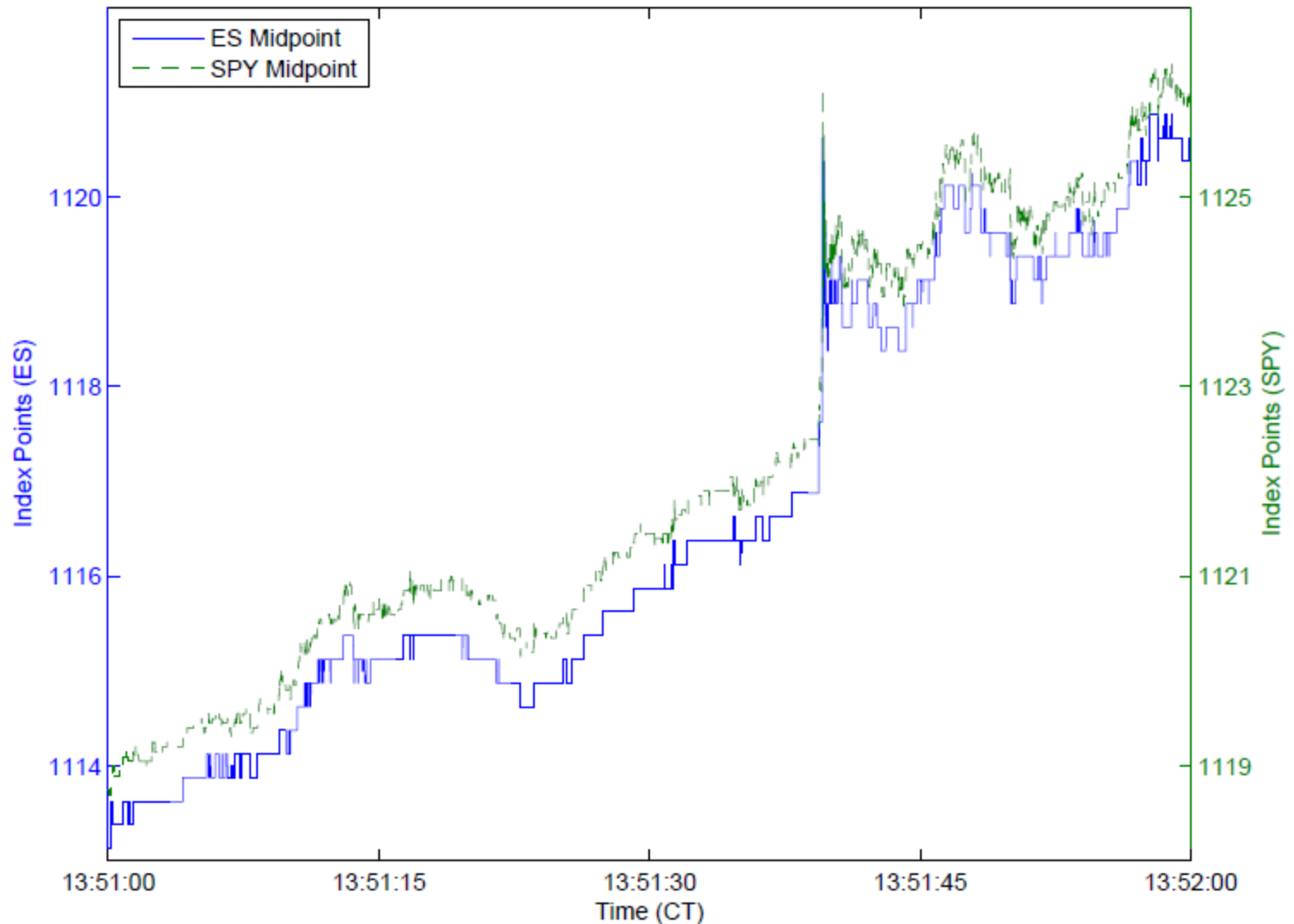
Market Correlations Break Down at High Frequency

ES vs. SPY: 1 hour



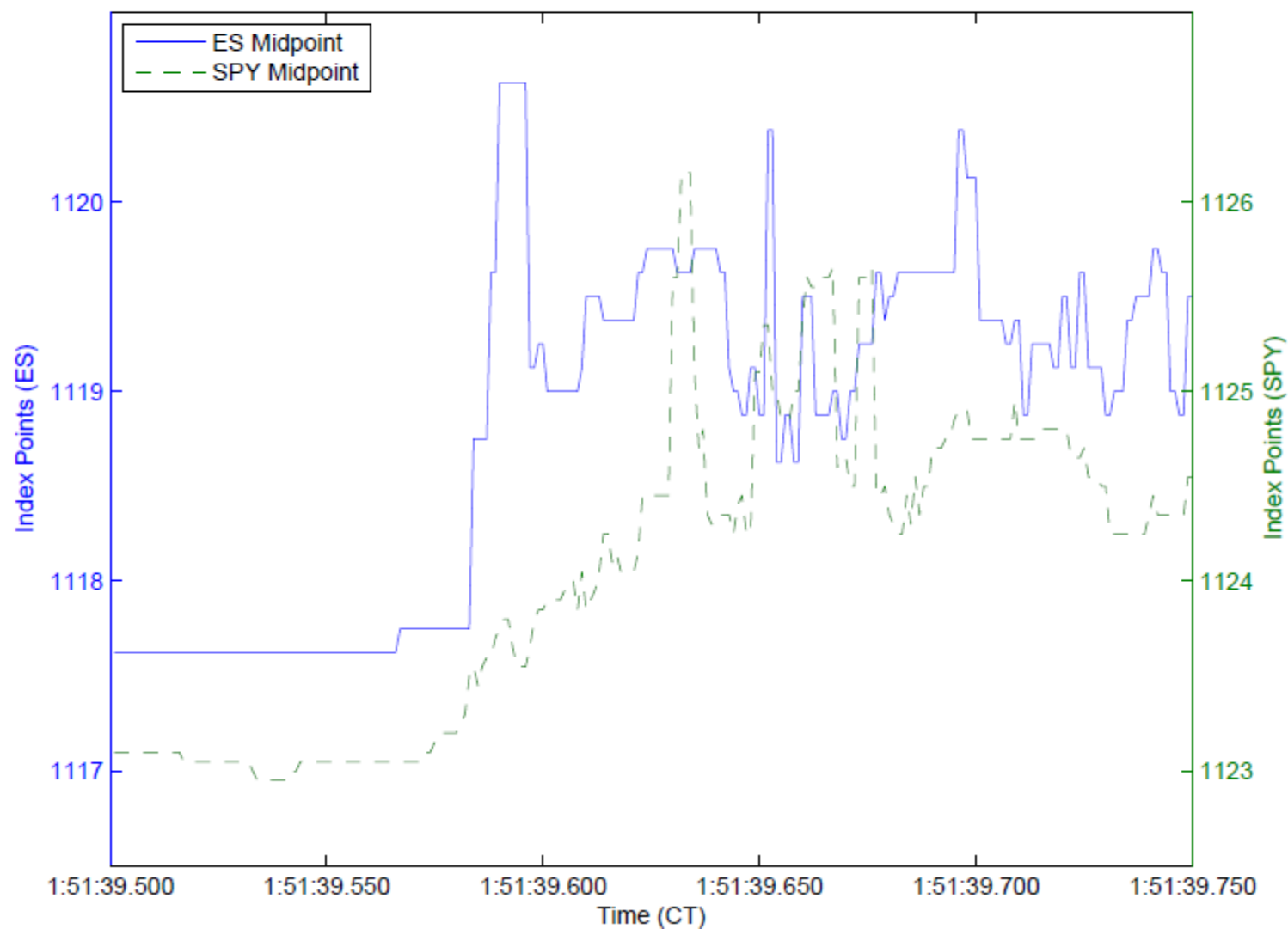
Market Correlations Break Down at High Frequency

ES vs. SPY: 1 minute

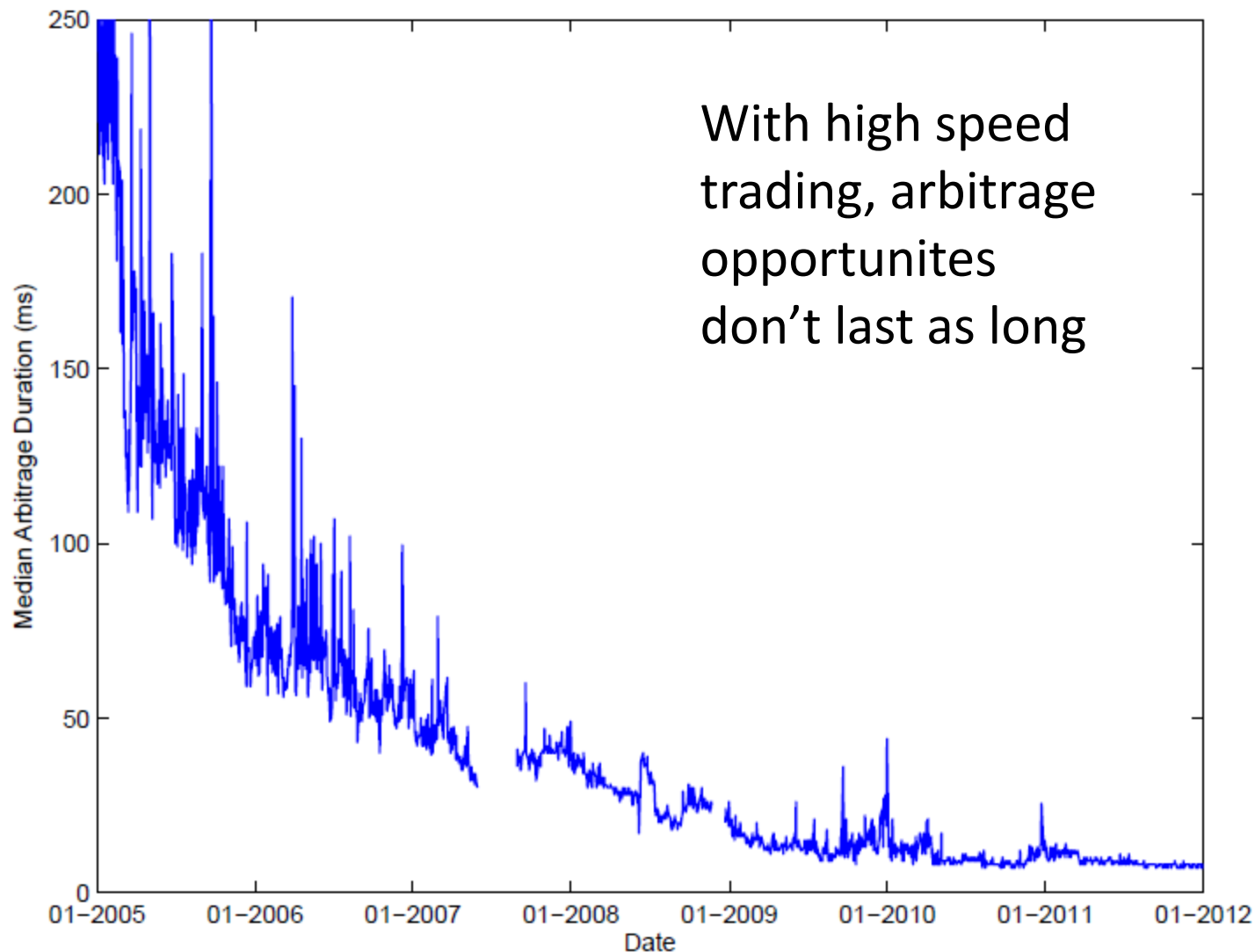


Market Correlations Break Down at High Frequency

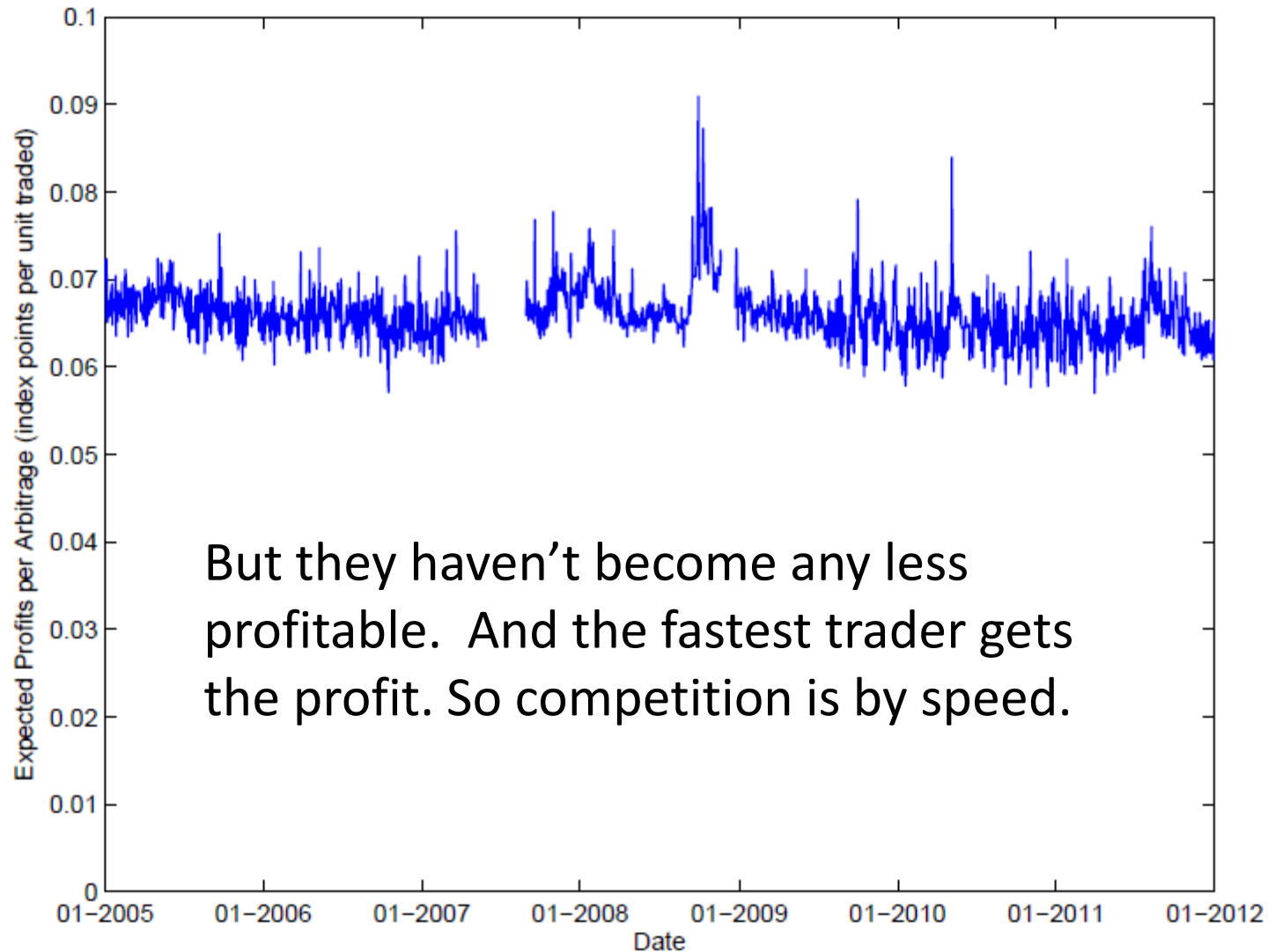
ES vs. SPY: 100 milliseconds



Technical Arbitrage: Median Arb Duration over Time



Technical Arbitrage: Per-Unit Profits over Time



Why might high speed trading be a problem?

1. Rent seeking

- a) Billions of dollars are spent on high speed lines and computers each year

2. Market inefficiencies

- a) Traders compete on speed rather than on price
- b) Bid-ask spreads become “stale” at any new news
 - a) So liquidity providers have to protect themselves by quoting higher spreads
- At very high frequencies, the market becomes thin, and unstable
 - Flash crash (May 6, 2010)

A new market design proposal

- Proposal: instead of “continuous” trading, trade once every second
 - A call market would collect the bids and asks that had come in in the last second, and produce the price at which supply equaled demand
 - In a call market run every second, the best price would make the trades.
- Compete on price rather than time
- Still provide rents for new economic information
 - A second is slow for a computer, but fast for economic news...

What has happened?

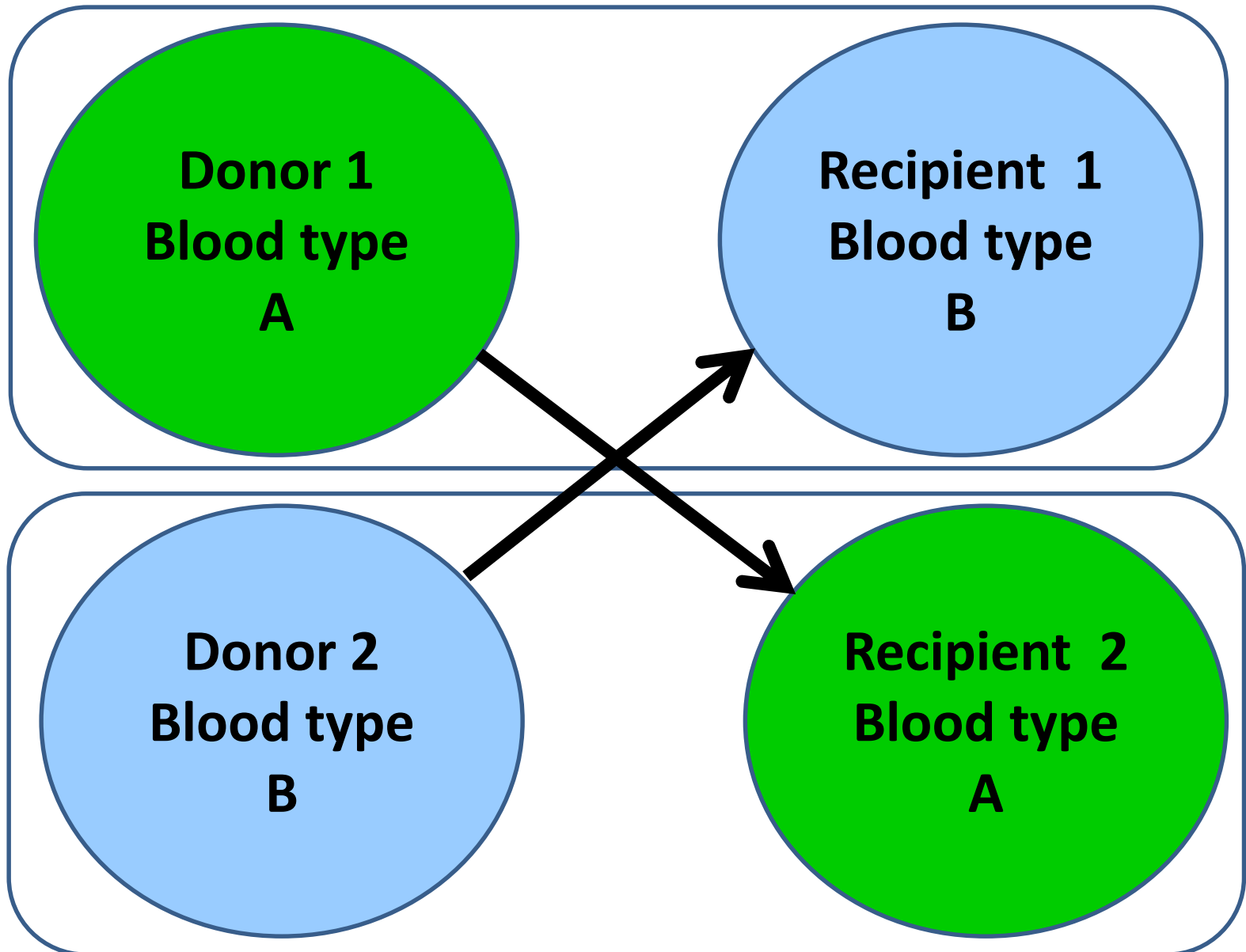
- New technology has given participants incentives for new kinds of behavior.
- These new kinds of behavior make the old market design work somewhat less well
- ...
- So new designs may be called for.

Kidney Exchange

There's a shortage of organs for transplant

- Around 100,000 people on the waiting list for deceased-donor kidneys
 - (In 2012, 4,543 died, and 2,668 became too sick to transplant...)
- Transplantable organs can come from both deceased donors and **living donors**.
 - In 2013 there were 5,732 transplants from living donors
- Sometimes **donors** are incompatible with their intended **recipient**.
- This opens the possibility of *exchange*.

Simple two-pair kidney exchange



By law, no money changes hands

Section 301, National Organ Transplant Act (NOTA),

42 U.S.C. 274e 1984:

“it shall be unlawful for any person to knowingly acquire, receive or otherwise transfer any human organ for valuable consideration for use in human transplantation”.

Charlie W. Norwood Living Organ Donation Act

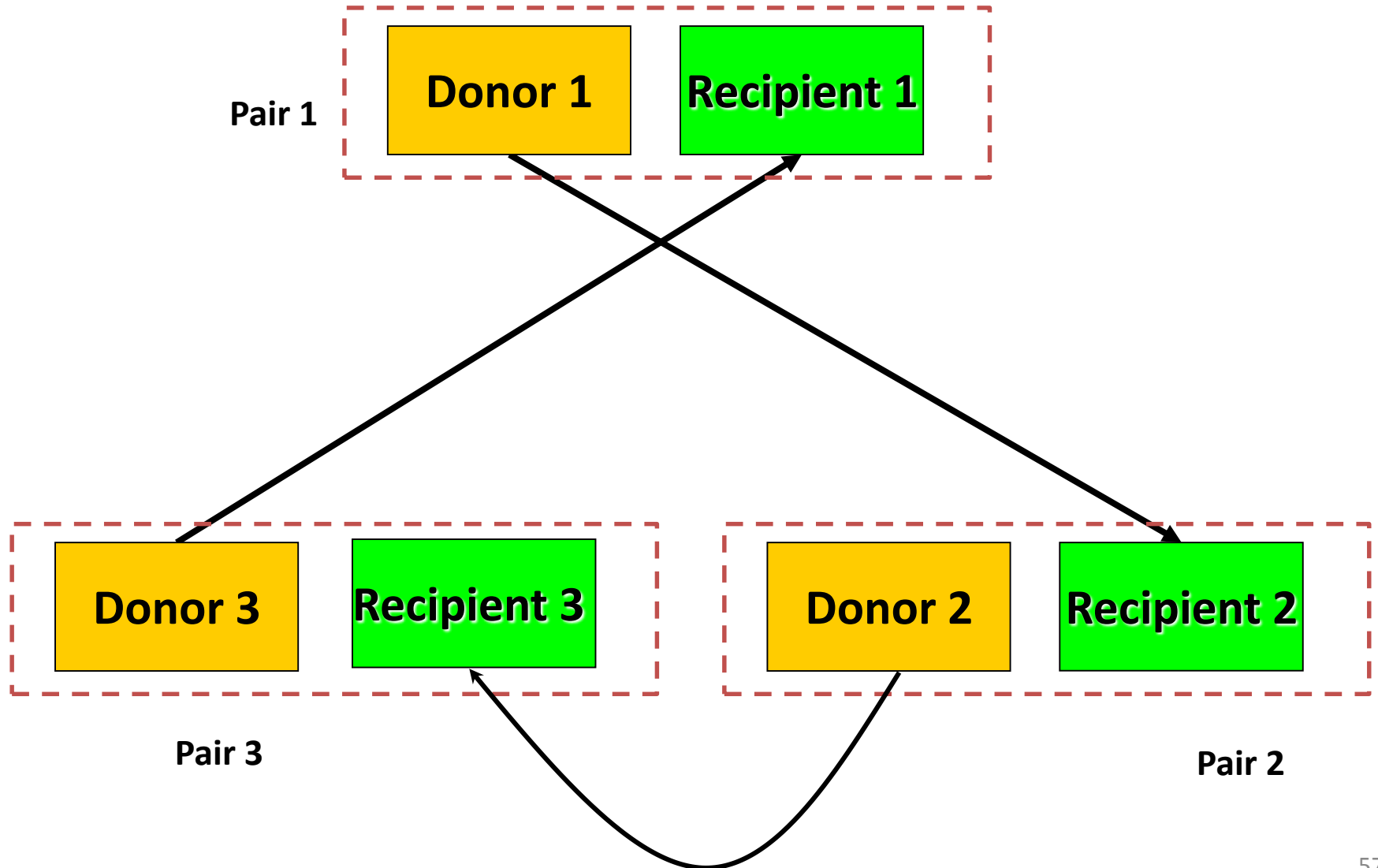
Public Law 110-144, 110th Congress, Dec. 21, **2007**

- Section 301 of the National Organ Transplant Act (42 U.S.C. 274e) is amended-- (1) in subsection (a), by adding at the end the following:
- **“The preceding sentence does not apply with respect to human organ paired donation.”**

Congestion: 2-way exchange involves 4 *simultaneous* surgeries

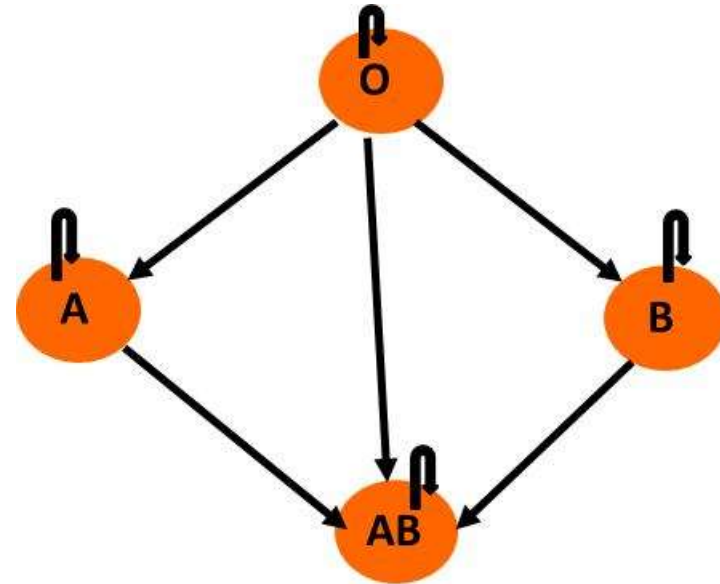


3-pair exchange (6 simultaneous surgeries)



Kidney compatibility

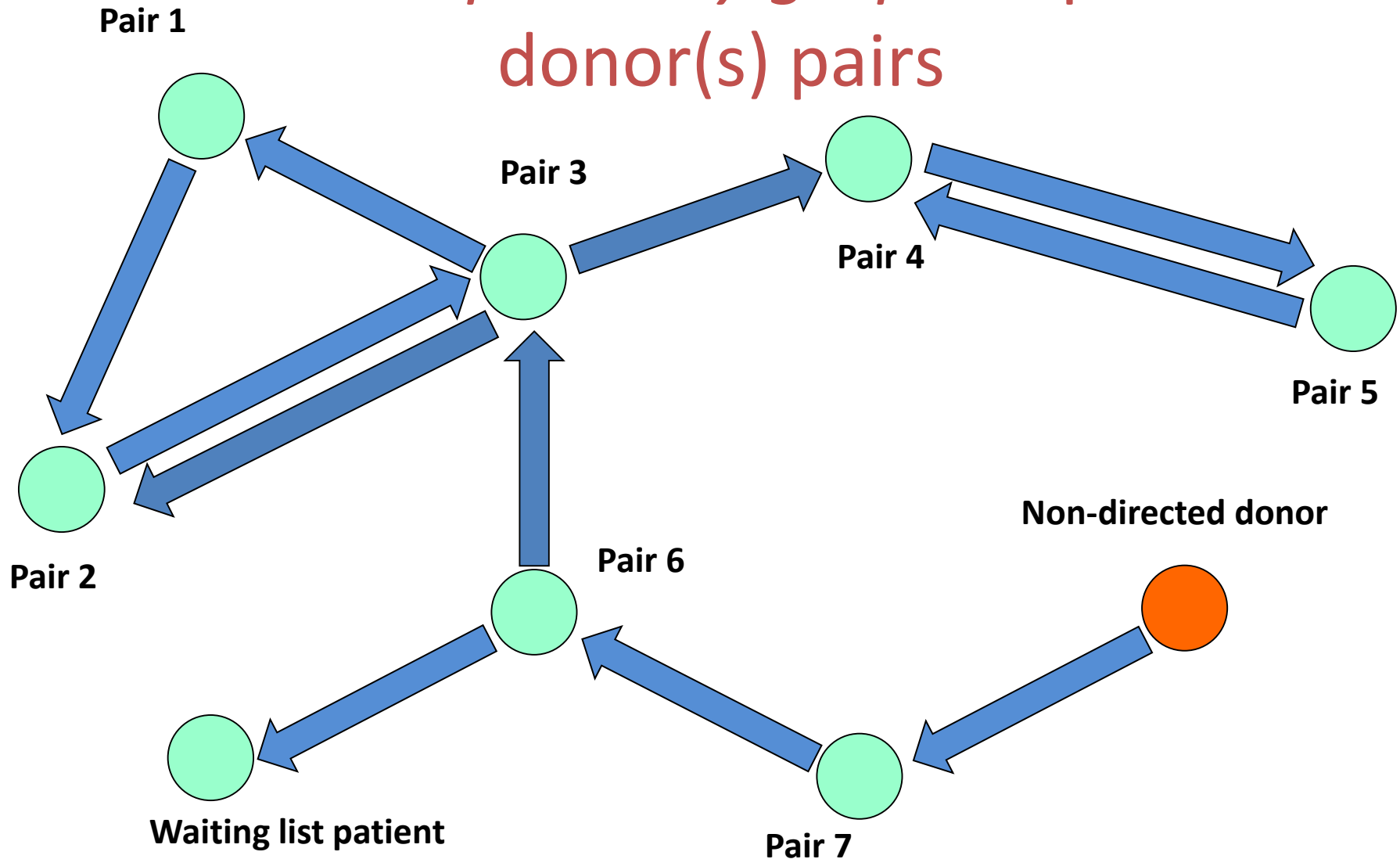
- **Blood compatibility**



- **Tissue type compatibility.** Percentage reactive antibodies (PRA)

- ❑ High sensitivity patients ($80 < \text{PRA} < 100$): **about 10% of general kidney-patient population**, somewhat higher for those incompatible with a donor

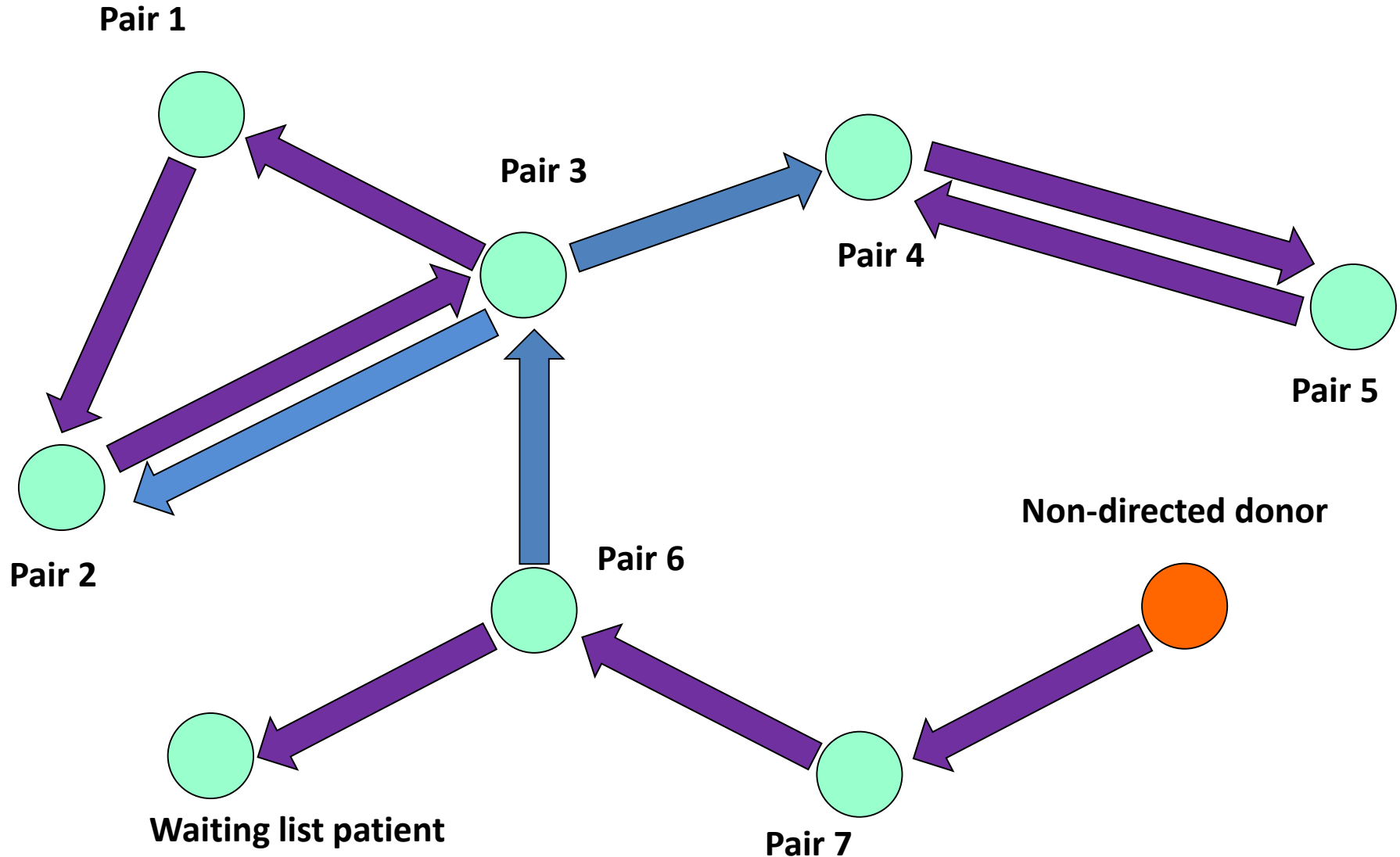
Non-directed donors: cycles plus chains in the *compatibility graph* of patient- donor(s) pairs



Making it safe to reveal information

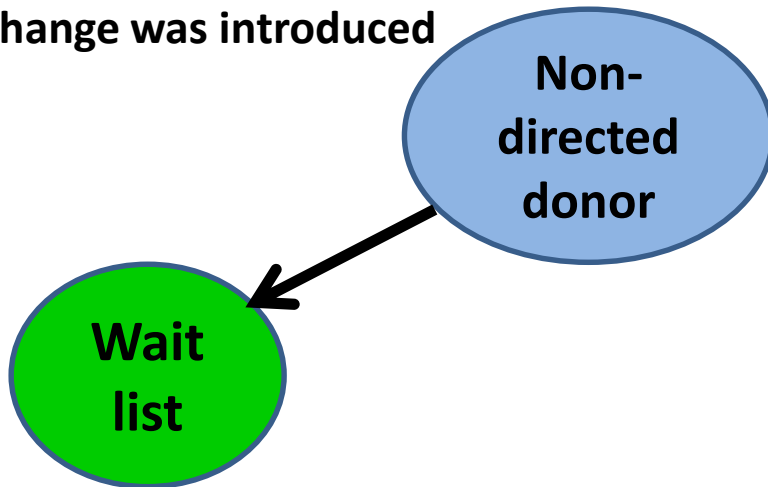
- A critical element of design is to make it *safe* for participants--patients, donors, surgeons and directors of transplant centers—to reveal the information that goes into the compatibility graph.

Optimal choice of cycles and chains



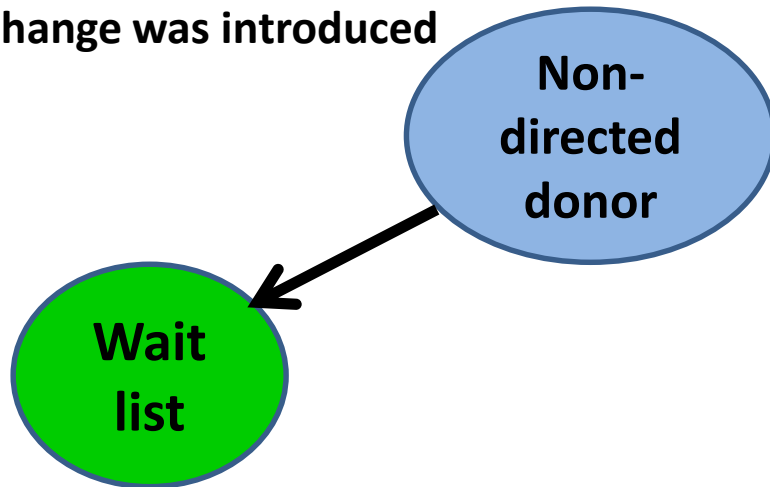
Chains initiated by non-directed (altruistic) donors

Non-directed donation before kidney exchange was introduced

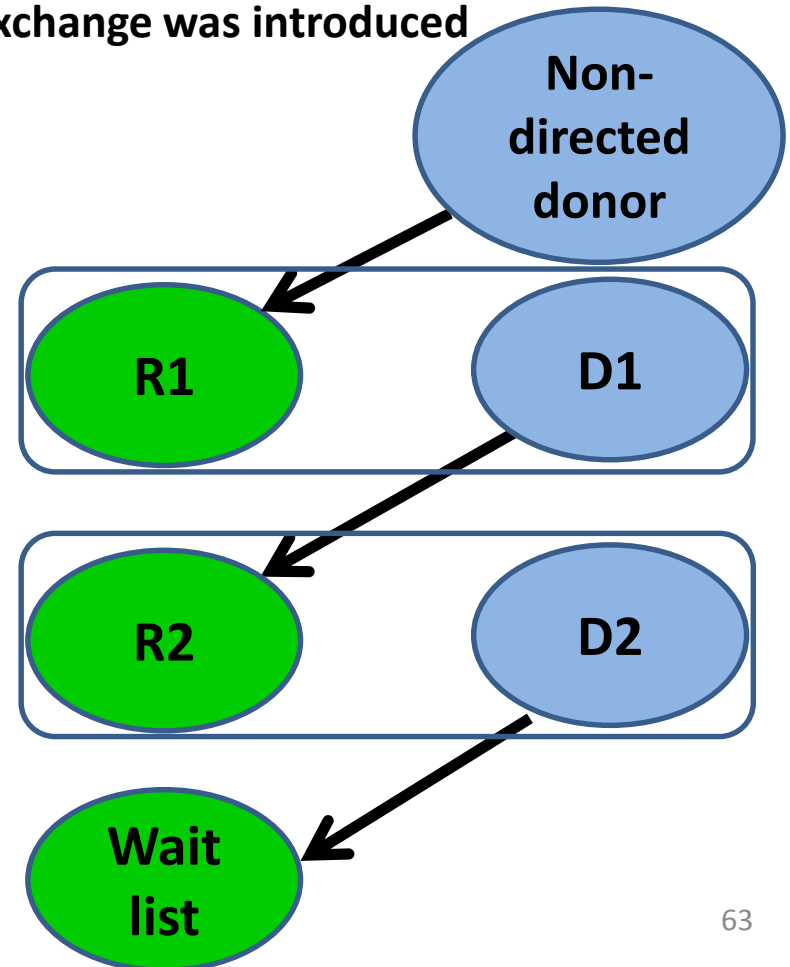


Chains initiated by non-directed (altruistic) donors

Non-directed donation before kidney exchange was introduced



Non-directed donation after kidney exchange was introduced



Here's a better picture...

Rare 6-Way Transplant Performed *Donors Meet Recipients*

March 22, 2007

BOSTON -- A rare six-way surgical transplant was a success in Boston.

NewsCenter 5's Heather Unruh reported Wednesday that three people donated their kidneys to three people they did not know. The transplants happened one month ago at Massachusetts General Hospital and Beth Israel Deaconess.

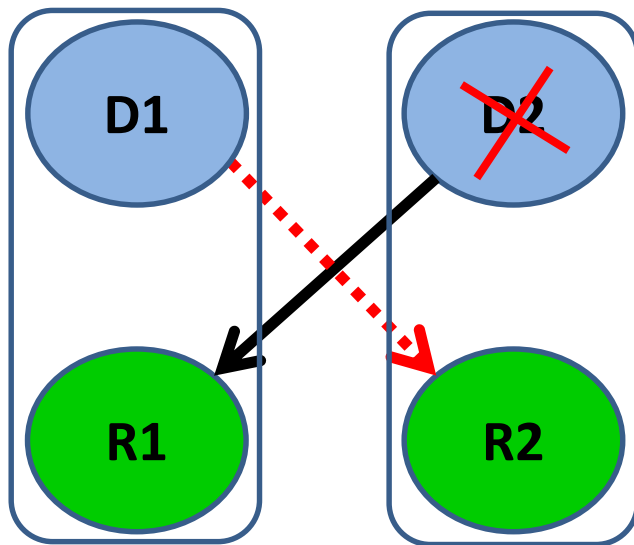
The donors and the recipients met Wednesday for the first time.



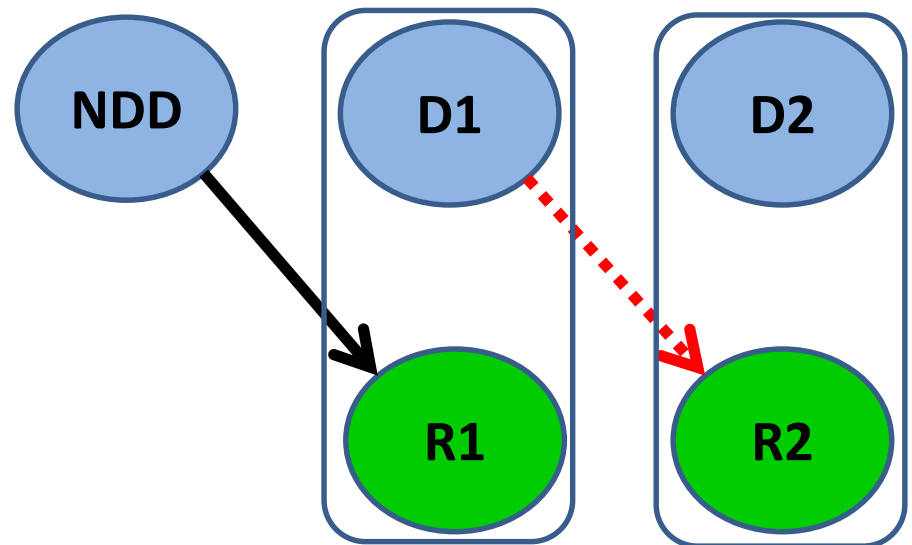
Why are there only 6 people in this picture?

Simultaneity congestion: 3 transplants + 3 nephrectomies = 6 operating rooms, 6 surgical teams...

Simultaneous cycles and Non-simultaneous extended altruistic donor (NEAD) chains



Conventional cycle



Non-simultaneous chain

Since NEAD chains can be non-simultaneous, they can be long

Roth, Alvin E., Tayfun Sönmez, M. Utku Ünver, Francis L. Delmonico, and Susan L. Saidman, "Utilizing List Exchange and Undirected Donation through "Chain" Paired Kidney Donations," *American Journal of Transplantation*, 2006

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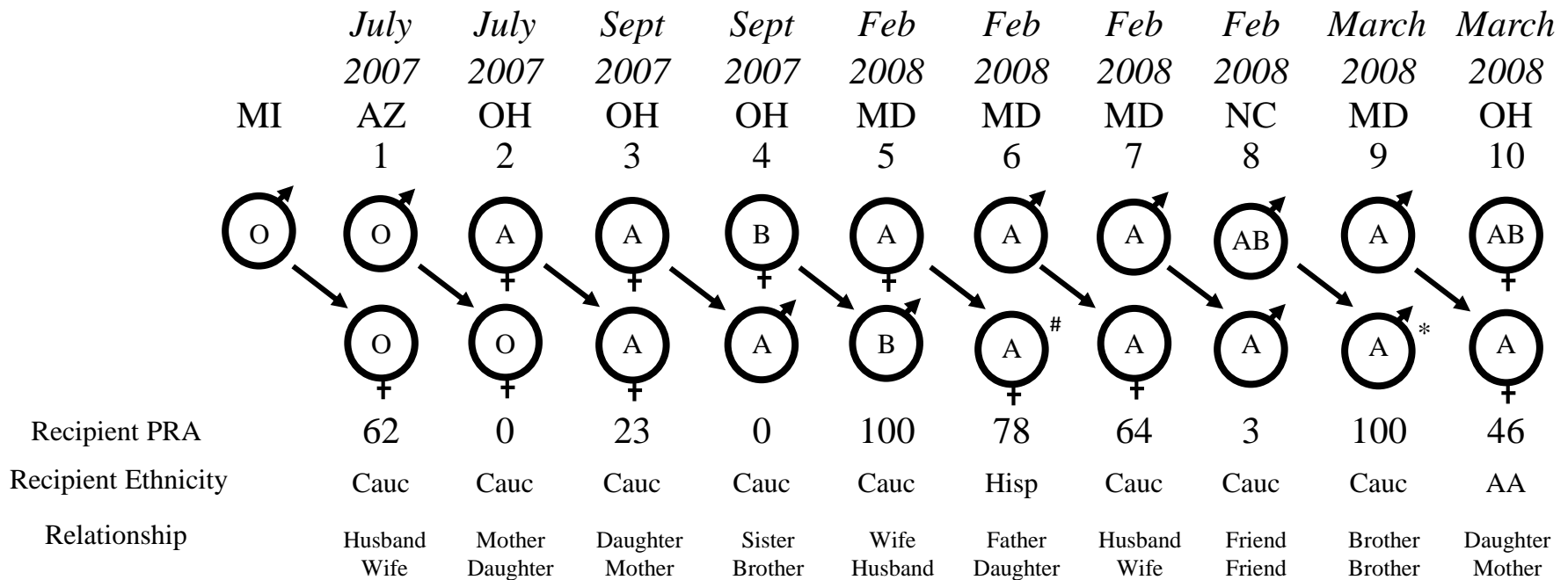
A Nonsimultaneous, Extended, Altruistic-Donor Chain

Michael A. Rees, M.D., Ph.D., Jonathan E. Kopke, B.S., Ronald P. Pelletier, M.D.,
Dorry L. Segev, M.D., Matthew E. Rutter, M.D., Alfredo J. Fabrega, M.D.,
Jeffrey Rogers, M.D., Oleh G. Pankewycz, M.D., Janet Hiller, M.S.N.,
Alvin E. Roth, Ph.D., Tuomas Sandholm, Ph.D., M. Utku Ünver, Ph.D.,
and Robert A. Montgomery, M.D., D.Phil.

SUMMARY

We report a chain of 10 kidney transplantations, initiated in July 2007 by a single altruistic donor (i.e., a donor without a designated recipient) and coordinated over a period of 8 months by two large paired-donation registries. These transplantations involved six transplantation centers in five states. In the case of five of the transplantations, the donors and their coregistered recipients underwent surgery simultaneously. In the other five cases, “bridge donors” continued the chain as many as 5 months after the coregistered recipients in their own pairs had received transplants. This report of a chain of paired kidney donations, in which the transplantations were not necessarily performed simultaneously, illustrates the potential of this strategy.

The First NEAD Chain (Rees, APD)



* This recipient required desensitization to Blood Group (AHG Titer of 1/8).

This recipient required desensitization to HLA DSA by T and B cell flow cytometry.

THE KIDNEY CHAIN

How a single organ donation changed 20 lives and created the longest-running transplant chain



Chains are important for hard to match pairs

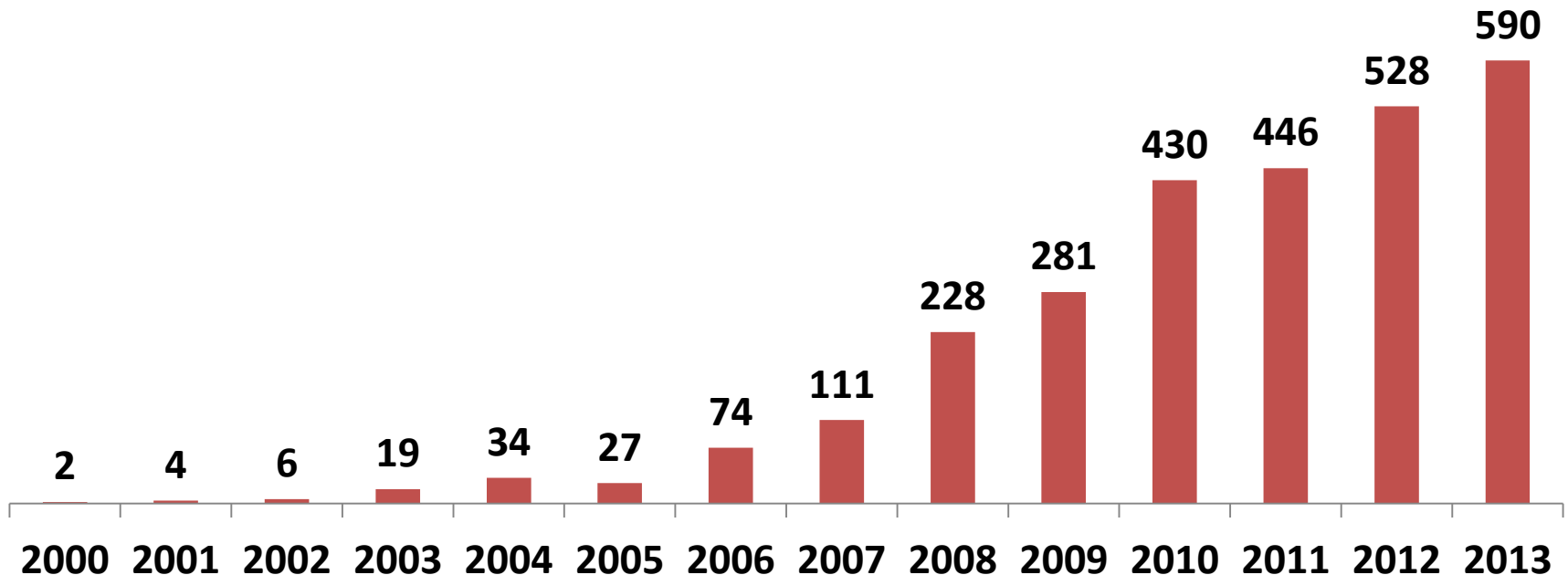
- Why are chains essential? As kidney exchange became common and transplant centers gained experience they began withholding their easy to match pairs and transplanting them internally.
- This means that the flow of new patients to kidney exchange networks contain many who are hard to match
- So chains become important: many pairs with few compatible kidneys can ***only be reached*** through chains.

Feb 2012, NKR: a NDD chain of length 60 (30 transplants)



Growth of kidney exchange in the US

Kidney exchange transplants per year

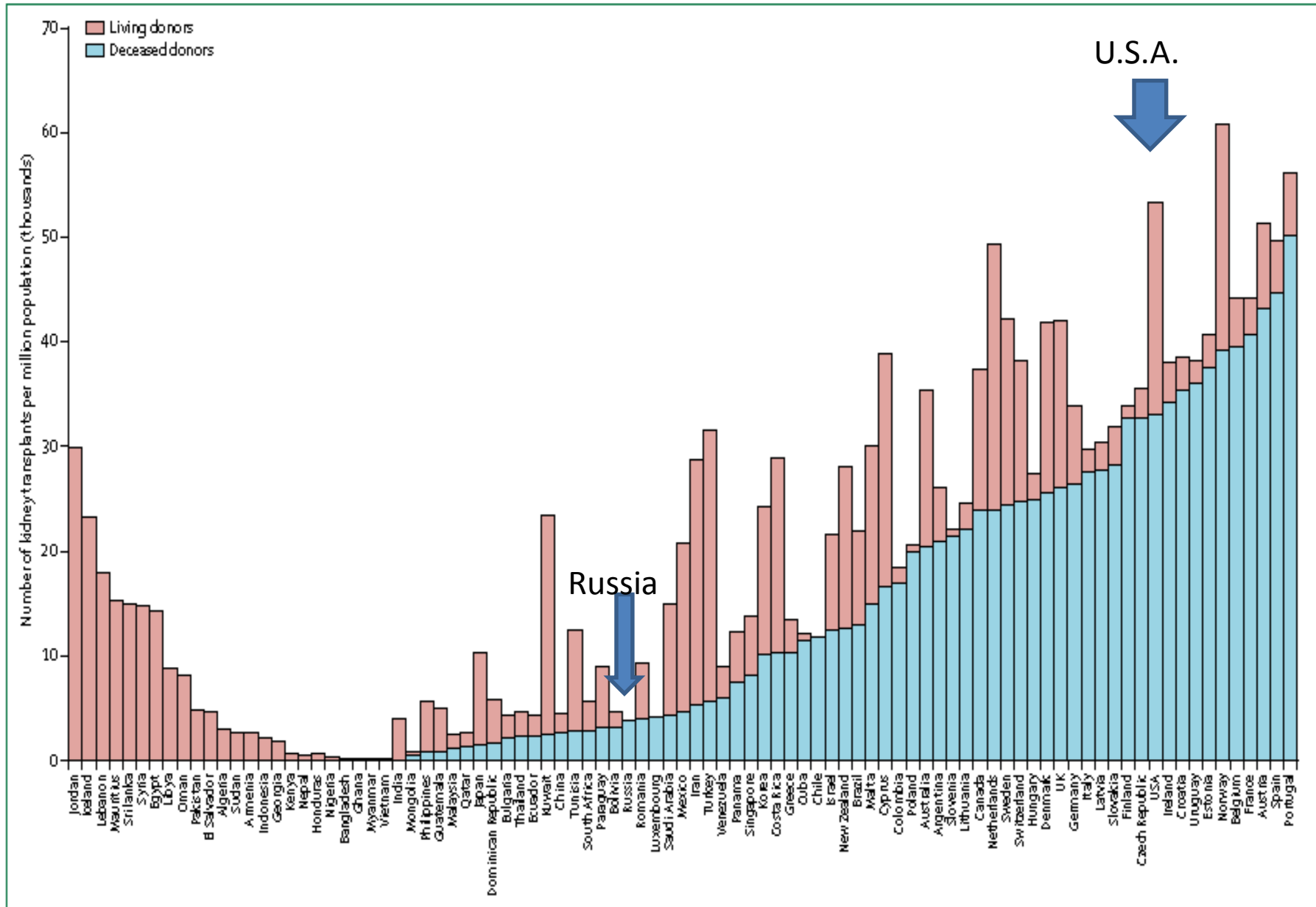


5-fold increase since 2007, majority in chains

Kidney exchange outside the U.S.

- Friday, July 24, 2015 [Kidney exchange in Turkey](#) (1st exchanges there)
- April 10, 2015 [A first non-directed donor kidney exchange chain in Italy](#)
- March 30, 2015 [A first kidney exchange in Argentina](#)
- March 5, 2015 [First kidney exchange in Poland](#)
- Friday, November 7, 2014 [Kidney exchange in Spain: now more than 100 transplants](#)
- June 7, 2014 [Kidney exchange in France](#)
- December 19, 2013 [Kidney exchange in Vienna](#)
- August 19, 2013 [Ten kidney exchange transplants on World Kidney Day in Ahmedabad, India](#)
- July 28, 2013 [First Kidney Exchange in Portugal:](#)
- July 23, 2013 [Kidney exchange chain in India](#)
- June 6, 2013 [Kidney exchange between Jewish and Arab families in Israel](#)
- December 26, 2012 [Kidney exchange in Canada](#)
- December 1, 2012 [Kidney exchange in India](#)
- June 1, 2012 [Mike Rees and Greece: an intercontinental kidney exchange](#)
- March 27, 2012 [Kidney exchange in Britain](#)
- February 5, 2012 [Kidney exchange in Australia, 2011](#)
- April 29, 2011 [First kidney exchange in Spain](#)
- December 8, 2010 [National kidney exchange in Canada](#)
- August 3, 2010 [Kidney Exchange in South Korea](#)
- Tuesday, August 3, 2010 [Kidney Exchange in South Korea](#)
- Friday, July 30, 2010 [Kidney transplantation advice from the Netherlands](#)
- March 9, 2010 [Kidney exchange news from Britain](#) (1st 3-way there)
- January 27, 2010 [The Australian paired Kidney eXchange \(AKX\) goes live](#)
- June 25, 2009 [Kidney exchange in Canada](#) (1st exchange there)
- February 27, 2009 [Kidney Exchange in Australia](#) (in Western Australia)

Kidneys Transplanted per million population



Nigeria, Philippines

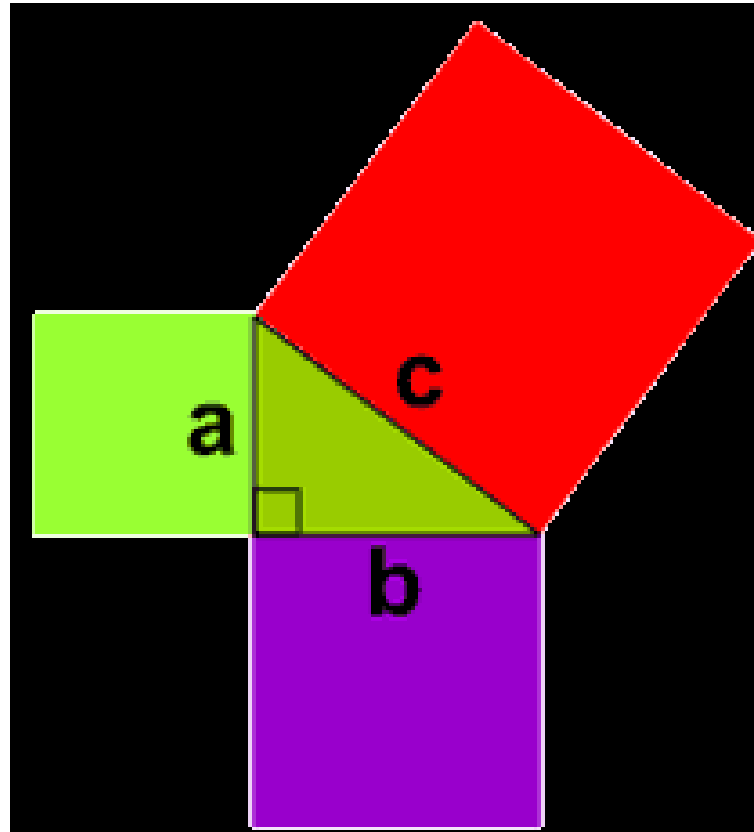
What have we learned from market design?

- To achieve efficient outcomes, marketplaces need make markets sufficiently
 - **Thick**
 - Enough potential transactions available at one time
 - **Uncongested**
 - Enough time for offers to be made, accepted, rejected, transactions carried out...
 - **Safe**
 - Safe to participate, and to reveal relevant information
- Some kinds of transactions are **repugnant**...and this can constrain market design.
 - The repugnance of some markets may give us a new viewpoint on regulation of familiar markets—markets often require a lot of social buy-in to work well.

Market design as economic engineering

- Theory and practice
- Science and engineering aren't exactly the same.
- But they complement each other—science guides the engineering, and engineering throws up new questions ahead of the science
 - They work on different time scales

Pythagoras' Theorem: then and now



Engineering: not immutable



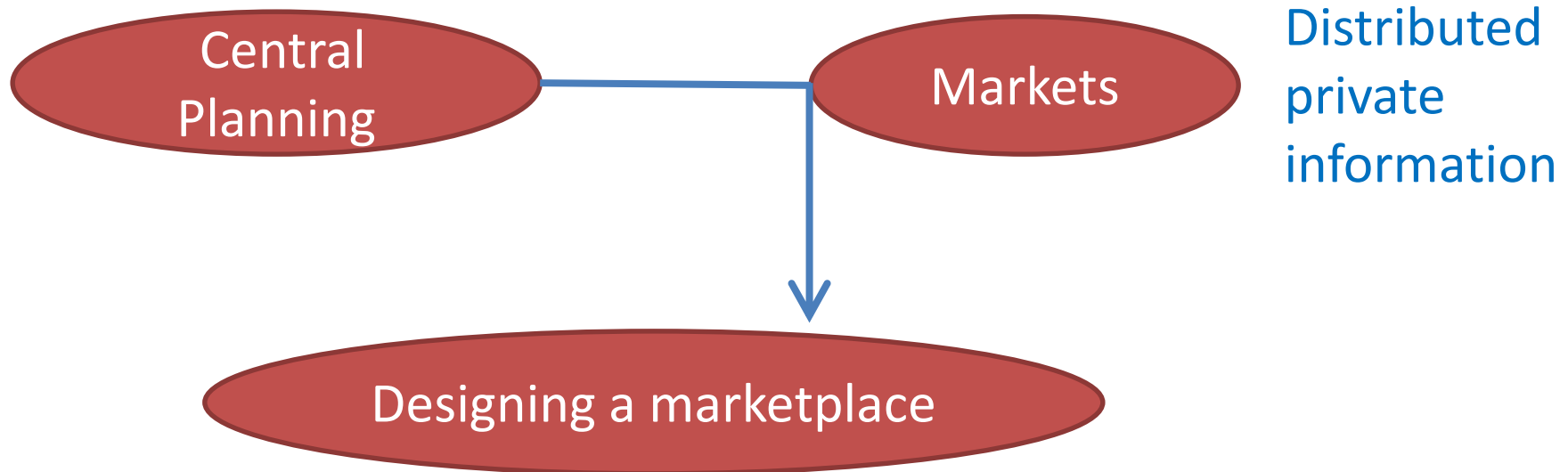
Pons Fabricius in Rome (62 BC)



Zhivopisny Bridge (2007)

Market design is an ancient human activity

How to allocate scarce resources?...and make them less scarce?



Eliciting information in a way that makes it safe for participants to reveal it

Commodity
markets
(prices do all
the work)

Matching
markets