

## Marketplaces, Markets, and Market Design<sup>†</sup>

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*Marketplaces are often small parts of large markets, and both markets and marketplaces come in many varieties. Market design seeks to understand what marketplaces must accomplish to enable different kinds of markets. Marketplaces can have varying degrees of success, and there can be marketplace failures. I'll discuss labor markets like the market for new economists, and also markets for new lawyers and doctors that have suffered from the unraveling of appointment dates to well before employment begins. Markets work best if they enjoy social support, but some markets are repugnant in the sense that some people think they should be banned, even though others want to participate in them. Laws banning such markets often contribute to the design of illegal black markets, and this raises new issues for market designers. I'll briefly discuss markets and black markets for narcotics, marijuana, sex, and surrogacy, and the design of markets for kidney transplants, in the face of widespread laws against (and broader repugnance for) compensating organ donors. I conclude with open questions and engineering challenges. (JEL A11, D40, D47, E26, J40, J44)*

*Market design* is both an ancient human activity<sup>1</sup> and the relatively new part of economics that strives to understand how the design of marketplaces influences the

\*Stanford University, 579 Serra Mall, Stanford, CA 94305 (email: [alroth@stanford.edu](mailto:alroth@stanford.edu)). Looking backward fills me with gratitude: to my family and to my teachers and advisors, to my wonderful students and coauthors, and to all of you economists, who welcomed me into economics, although economics isn't a subject in which I ever received any degree. During my professional career I have participated in at least three academic insurrections, which brought game theory into economics, and experimental and behavioral economics, and most recently market design. There have been other revolutions also, in econometrics and computation and access to large linked datasets among others. These revolutions have come about largely because economists are generally enthusiastic about finding new ways to explore the large swath of human behavior that makes up economics.

This welcoming of new ideas isn't magical, or even immediately apparent. Like raising children, it's a slow process while it's going on, but it becomes clear in retrospect how fast it actually is. Paper by paper (referee report by referee report) academic economics can feel conservative and resistant to change. But when you look at a time scale of decades, economics has opened up to new ideas very quickly.

We've also been welcoming to intellectual immigrants: to people as well as ideas. I'm hardly alone among economists of my generation who don't have degrees in economics. A bunch of us rode in on the wave that brought game theory into economics. Not every discipline is as open to new ideas or new people. This openness is something to nurture, gratefully and vigilantly.

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<sup>1</sup>The wide distribution of ancient stone tools such as ax heads, far from where they were quarried, suggests that they were traded, i.e., that markets are substantially older than recorded history (cf. Clarke 1965). Because

functioning of markets.<sup>2</sup> Armed with this understanding, economists can sometimes help build new marketplaces or repair those that are broken.

In this essay, I'll try to illustrate some principles of market design, point to some questions worth further study, and show how the study of marketplaces opens new windows through which to view markets.<sup>3</sup> Market design has also opened up new ways for economists to earn their livings.<sup>4</sup>

I want to emphasize the view that marketplaces—which consist of infrastructure, rules, and customs through which information is exchanged and transactions are made—can be relatively small parts of large markets. Participants may have large strategy sets, i.e., many options available to them, beyond those available in any particular marketplace.

Because marketplaces serve many different kinds of markets, different marketplaces have different tasks to accomplish. Practical market design that aims to design marketplaces that will be adopted, implemented, and maintained can be thought of as a kind of economic engineering, so details matter.<sup>5</sup> But, as with other kinds of engineering, although each application may demand custom design, there are common issues that many marketplaces have to deal with to be successful, and so there are also general lessons to be learned. And (also as with other kinds of engineering) sometimes these lessons are learned most clearly from marketplace failures, i.e., from marketplaces whose (poor) design impedes market efficiency. (So it isn't necessarily the most important markets that yield the most useful lessons.)

Marketplace design (or even *design economics*) might sometimes be a more descriptive name for the emerging field of market design.<sup>6</sup> However, although I didn't choose the name, I've been glad of the opportunity it has given me to defend the notion that “markets” come in many varieties, and are not only or even primarily commodity markets whose only job is price discovery.

Commodity markets are themselves a great invention, which allow trade to be conducted safely with relatively anonymous counterparties, with prices doing all

untrimmed stones to make ax heads are much heavier than the finished tools, we can conjecture that the primary marketplaces for these far-reaching markets were located near the quarries, and were marketplaces for the finished tools.

<sup>2</sup>The study of marketplaces and market design has close predecessors in parts of IO and finance, e.g., in the study of market microstructure. See, e.g., the papers presented at the recent NBER Conference on Competition and the Industrial Organization of Securities Markets (<http://papers.nber.org/sched/CIOF17>), and papers focusing on marketplaces as platforms, e.g., Rochet and Tirole (2003) or Eisenmann, Parker, and Van Alstyne (2006).

<sup>3</sup>This essay isn't meant to substitute for a survey of the fast growing field of market design. Recent overviews of market design include Biró (2017); Kominers, Teytelboym, and Crawford (2017); Ashlagi (2018); and Eisenmann and Kominers (2018). The *Handbook of Market Design* edited by Vulkan, Neeman, and Roth (2013) is aimed at an academic audience. Roth (2015b) is targeted at a general audience. Two new textbooks are Bichler (2018) and Haeringer (2018). Roth (2016) reviews some uses of laboratory and field experiments in market design. I regularly update my market design blog at <http://marketdesigner.blogspot.com/>.

<sup>4</sup>We can see this in the widening role that “chief economists” play. In the twentieth century, firms that had chief economists were mostly banks and investment firms, and those economists forecast inflation and market conditions. Today a growing number of chief economists are market designers in tech companies. For example, chief economists among those whose work is cited in this essay include Peter Coles at Airbnb, Hal Varian at Google and Michael Schwarz at Microsoft, where his predecessors with that title were Preston McAfee and Susan Athey. Preston had earlier been the chief economist at Yahoo!Research, while Michael was previously the chief economist at Google Cloud.

<sup>5</sup>Dufflo (2017) proposes plumbing as an analogy for the detailed operational issues involved in implementation and maintenance.

<sup>6</sup>The subtitle of my paper “The Economist as Engineer” was “Game Theory, Experimentation, and Computation as Tools for Design Economics” (Roth 2002).

the work of deciding who gets what. Commodity markets require design of both the marketplace procedures and the commodities themselves. The Chicago Board of Trade deals in commodities like *US soft red winter wheat*, a much more precisely defined commodity than “wheat.” In the design of commodities, there is room for both regulation by governments and standard-setting by private sector actors: see, e.g., United States Department of Agriculture (2014), and cf. Levin and Milgrom (2010). Commodities can be traded without further inspection, and without knowing one’s counterparty in any given transaction. So bids and asks can be directed to the market at large. It is practical to trade a relatively small set of commodities among a large set of potential participants, since only one price for each commodity needs to be established for a transaction. That is, a relatively small set of prices can clear the market among a large set of traders.

Note that some marketplace centralization is needed even to achieve the full benefits of commoditization, both to standardize the commodities and to allow them to be efficiently traded. Centralization of trading might involve just a central location (in space or in cyberspace), with traders coming together to trade with one another directly. Or it might also involve a centralized clearinghouse of some sort, as in a centrally administered order book that keeps track of time-stamped bids, and asks and arranges transactions according to a set of marketplace rules.

A commodity market must therefore employ particular marketplace technology and procedures, and the strategies available to participants may evolve along with the marketplace’s technologies, and their own. Open-outcry markets with gesticulating traders have largely been replaced by electronic trading, now often high speed algorithmic trading. These new technologies and the high-frequency trading strategies they enable may in turn make new market designs desirable (cf. Budish, Cramton, and Shim 2015).

Many markets that are not quite commodity markets also work through price discovery, and trade among (almost) anonymous counterparties.<sup>7</sup> Google search auctions, for example, determine which ads to show for each word that someone is searching for; i.e., they are an auction for eyeballs—for attention—with some eyeballs searching for more valuable things than others. Auctions for banner ads on websites may involve bids based on the cookies that reveal information about the previous web activity of the eyeballs being auctioned. The design of these auctions reflects that they have to be *fast*, so as not to lose the attention advertisers hope to gain with a winning bid.<sup>8</sup>

Milgrom (2017) recounts the design of the *incentive auction* through which the US government brokered the purchase and resale of spectrum licenses owned by broadcasters so that they could be repurposed. He points out that the allocation of spectrum comes with many constraints, which makes the licenses very heterogeneous

<sup>7</sup>Prendergast (2017) describes the design of a market to efficiently allocate donated food among food banks: it is close to a commodity market for trade among food banks, but doesn’t use real money. For another market design that uses “fake money” as an allocation tool, see the work on course allocation and its implementation by Budish (2011), Budish et al. (2017), and Budish and Kessler (2017). (And compare this with other course allocation mechanisms such as the ones described in Krishna and Ünver 2008, Sönmez and Ünver 2010, and Budish and Cantillon 2012. Part of market design involves examining marketplaces whose designs can be improved. In this regard, on another domain of application see, e.g., Athey and Levin 2001 on US Forest Service timber auctions.)

<sup>8</sup>For design of search auctions, see Edelman, Ostrovsky, and Schwarz (2007) and Varian (2007). For banner ads, see Balseiro, Besbes, and Weintraub (2015).

and may even preclude the existence of impersonal equilibrium prices for individual licenses. These complex auctions need to match bidders with the right units (and packages) of the licenses being auctioned.<sup>9</sup> Wilson (2002) discusses different complexities in the markets for electricity, in which the time and place of delivery face (and impose) constraints on the electricity network.

And in many markets, you care with whom you are dealing. In *matching markets*, you can't just choose what you want, even if you can afford it: you also must be chosen.<sup>10</sup> So prices don't do all the work of deciding who is matched to whom: marketplaces that serve matching markets must be able to do more than price discovery. Regulators take note: because matching marketplaces must do more than marketplaces for commodity markets, they may need to facilitate additional kinds of coordination, and so preserving competition in matching markets may involve different kinds of regulation.

Matchmaking is an old form of market making, but new technologies are making new kinds of matching markets possible. For example, Airbnb, which matches travelers and hosts, is in many ways an outgrowth of internet technology, while ride-sharing marketplaces like Uber, which match passengers with nearby drivers, depend on smartphones that know the location of the passenger and of available cars.<sup>11</sup> The ride-sharing/taxi markets will be transformed again (likely along with automobile ownership) when self-driving cars become common (cf. Ostrovsky and Schwarz 2018).

College admissions and labor markets are good examples of matching markets.<sup>12</sup> Prices—i.e., tuition and wages—are important, but they don't decide who goes to which college or works at which job. You can't just decide where to study or work, you also have to be admitted or hired. And candidates apply to particular colleges and employers, who in turn make offers to individuals, not to the market at large as when buying and selling wheat futures.<sup>13</sup>

<sup>9</sup>See McAfee and McMillan (1996) for an early account of spectrum auctions, and see Leyton-Brown, Milgrom, and Segal (2017) for the interaction between economics and computer science in the design of the incentive auction.

<sup>10</sup>In two-sided matching markets, like labor markets, both sides choose and must be chosen. But even in "one-sided" markets in which agents are matched with resources that don't themselves make any choices, agents may not be able to simply choose what they want, even if they can afford it. For example, in package auctions, the high bidder on a particular license may not win it if that license turns out to allow a more valuable allocation of all the licenses if assigned differently (see, e.g., Milgrom 2004, 2017).

<sup>11</sup>There is starting to be an Uber design literature: see, e.g., Angrist, Caldwell, and Hall (2017), Chen et al. (2017), and Nikzad (2018).

<sup>12</sup>I'll choose examples disproportionately from my own work, but the flow of market design is becoming wide and deep. For other directions than I will explore here, see, e.g., Horton (2017) on online labor markets; Cramton (2017), Cramton, Ockenfels, and Stoft (2013), and Wilson (2012) on electricity markets for energy and capacity; Resnick and Varian (1997), Resnick and Zeckhauser (2002), Bolton, Greiner, and Ockenfels (2013) on reputation and recommender systems; Ausubel and Milgrom (2002), Ausubel and Baranov (2017), Cramton, Shoham, and Steinberg (2006), and Parkes and Ungar (2000) on combinatorial auctions. See also <http://marketdesigner.blogspot.com/search/label/market%20designers>.

<sup>13</sup>Formulations exist in which matching markets can clear by prices, but many doubly personalized prices are needed, since to have a market clearing set of prices, each firm might have to offer a different wage to each worker, both those it hires at equilibrium and those it does not. See, e.g., Kelso and Crawford (1982) and Hatfield et al. (2013). So these prices don't efficiently decentralize the market in the same way that a small set of equilibrium prices can decentralize a market with many traders (cf. Segal 2007).

## I. The Market for New Economists

Consider, as a familiar example, the marketplace for interviews between employers and new PhD economists conducted at the winter meeting of the Allied Social Sciences Associations (ASSA), organized by the American Economic Association.<sup>14</sup> This marketplace facilitates many of the matches of departments and new PhDs for interviews.

The larger market for new economists extends beyond this marketplace for interviews. Not everyone chooses to participate in interviews of this sort, and even for those who do, the market extends in time and space. Earlier, there are positions to be advertised, applications to be made, and reference letters to be sent, today, often via internet clearinghouses. As interviews are being arranged, there are signals of particular interest to be transmitted, including formal signals organized by the AEA (cf. Coles et al. 2010). Later there are flyouts, and offers to be made and accepted or rejected. Later still there is a “scramble” website organized by the AEA to help organize the market for those not yet matched in the main market.<sup>15</sup> These marketplace institutions were established incrementally, over time.

Before the early 1970’s, many economics departments did not formally advertise faculty positions, even for new PhDs. Instead, positions were filled through informal, decentralized communications, with the result that there was not a clear time at which most jobs and applicants were known to be available. The AEA began publishing *Job Openings for Economists* around 1974, which helped make information about positions widely known. This made it easier for many economists to apply for each position, and for each applicant to apply to many positions. This trend toward more applications (per position and per applicant) was enhanced by changes in technology from typewriters and snail mail to word processors and the internet. These changes lowered the costs, in labor, time, and postage, of crafting and sending applications. Similar changes have lowered the costs to faculty advisors or their assistants of sending letters of reference.<sup>16</sup> A common medium on which most jobs were advertised in a relatively concentrated period, together with lowered costs of application, helped make the market *thick*, i.e., helped bring together many employers and job seekers at the same time.

Thick markets may suffer from congestion. By *congestion* I mean the accumulation of more time-consuming activities than can easily be accommodated in the time available. Evaluating many job opportunities, or many applicants, is time consuming. Organizing interviews at the ASSA meetings helps to deal with this congestion, because many interviews can be conducted in a short time once the candidates and recruiting committees are all assembled in the same place. However, as the number of applications per position has grown, many employers cannot conduct as many

<sup>14</sup>It is in fact a two-part marketplace, with many interviews, mostly by university employers, being conducted in hotel suites, while other interviews are conducted at tables under the auspices of the Illinois Department of Employment Security. Until 2001 that latter marketplace was organized around a physical bulletin board on which employers posted job openings and applicants posted their availability. That marketplace has since moved to a computerized bulletin board (see IDES 2018).

<sup>15</sup>See Roth et al. (2017a). The AEA also maintains a listing of available retired faculty who may be interested in teaching on either a part-time or temporary basis, at [https://www.aeaweb.org/joe/available\\_faculty/](https://www.aeaweb.org/joe/available_faculty/).

<sup>16</sup>See Econ Job Market, <https://www.econjobmarket.org/>; AcademicJobsOnline.org, <https://academicjobsonline.org/aj/o>; JOE Network for Reference Letter Writers, <https://www.aeaweb.org/joe/reference-letter-writers/>.

interviews as they might wish in the three days of the meeting, and must choose from hundreds of applicants those they will interview.

Many departments must therefore make strategic decisions about whom to interview. They have to consider not only which candidates they like, but also which candidates are not too likely to receive other offers they would prefer. That is, in choosing whom to interview, departments have to consider not only how likely they would want to hire the candidate, but also how likely they would succeed, since they don't have time to interview all the candidates who they might eventually be willing to hire. So the interviewing process is congested. As a step toward easing this congestion, in 2006 the AEA instituted a signaling mechanism that allows candidates to send a signal of particular interest to no more than two employers.<sup>17</sup> Because candidates can send only two signals, signals are a scarce resource that can convey serious potential interest.<sup>18</sup> And interest in signals has been steadily growing.<sup>19</sup>

Note that two very different kinds of signals are sent via various channels, throughout the courtship between candidates and employers that ultimately leads to matching applicants and jobs. On the one hand are signals about applicant quality.<sup>20</sup> Job market papers, for example, convey information about talents, accomplishments, and skills that signal why candidates should be *interesting* to employers (Spence 1973).<sup>21</sup> But congestion—e.g., the fact that many employers' interview slots are in short supply and must be carefully allocated—also makes it useful for candidates to signal that they are *interested* in particular jobs (Coles et al. 2010; Coles, Kushnir, and Niederle 2013). Because technology has made it easy to send many applications, simply sending an application is no longer a strong signal of interest.<sup>22</sup>

<sup>17</sup>I was the chair of the AEA's ad hoc committee on the job market which proposed the signaling system (and the scramble), and the whole committee published a report on the market in Coles et al. (2010).

<sup>18</sup>Lee and Niederle (2015) conducted an experiment with signaling, on a dating site that as part of its internal operation rated participants on their desirability (this rating was not visible to the participants). Participants in their experiment could send a message to any other participant, but most of them had (only) two signals—"virtual roses"—that they could attach to messages. Participants who accepted a message could then correspond with the sender. Lee and Niederle observed that messages with roses attached were more likely to be accepted. The effect of a rose was largest when the sender was ranked as more desirable than the receiver.

<sup>19</sup>3,711 signals were transmitted by the AEA in December 2017, compared to 2,144 in 2010, and 971 in 2006, the first year of operation. In December 2017, 1,916 job candidates sent a total of 3,712 signals of special interest to 706 employers who had listed job openings in JOE (120 sent just one signal). Not just new economics PhD graduates of American universities submit signals. For example, the NSF's Survey of Earned Doctorates reports that in 2016, 1,238 individuals received PhDs in economics from US universities (see <https://www.nsf.gov/statistics/2018/nsf18304/datatables/tab63.htm>). If every one of them had submitted the two signals allowed to them by the AEA signaling mechanism, the resulting signals would have fallen far short of the 3,464 signals that were actually submitted in December 2015 (for interviews at the January 2016 meetings). This suggests that the signaling service, and the market for interviews, reflects a broader market than just new US PhDs, i.e., it also includes new graduates of foreign universities, and people who received PhDs in prior years. (Finegan 2014 reports that approximately 1,000 new economics PhDs per year graduated in the decade 1997–2006, somewhat more if relevant PhDs from business schools are included.)

<sup>20</sup>Letters of reference play an important role in signaling (advisors' assessments of) applicants' quality. Some letter writers hope to send finely modulated signals with (nevertheless ambiguous) phrases such as recommending applicants to "all schools, including the top," "all schools, including the very top," "all schools interested in field XYZ," "all schools outside the top 5," etc.

<sup>21</sup>Zahavi (1975) initiated the exploration in the biology literature of costly signals of fitness, like a peacock's tail, where the impact of such signaling is sometimes referred to as the handicap principle.

<sup>22</sup>Interviews at the meetings also involve prosaic operational sources of congestion. Scheduling all the interviews can be difficult, and is done in a decentralized way between departments and candidates. Last minute communication is needed to notify candidates about where each interview will be held, as recruiting committees check into their hotels and learn which rooms they will occupy. For safety reasons, hotels decline to reveal where guests are staying, and departments don't like to broadcast their room numbers, and so, in 2000, the AEA introduced a system of codes, in which departments reveal a code to interviewees who can then match that with a room number,

As candidates and recruiting committees depart from three intense days of interviews at the ASSA meetings, the market becomes much less organized. Departments invite some candidates they interviewed to day-long “flyouts” to their campuses, to present their job talks and meet the faculty. Essentially each department operates its own marketplace where candidates come to be evaluated and compared by the faculty, and each candidate turns into a traveling salesperson, bringing his or her personal marketplace on the road. This part of the market is congested. Flyouts absorb time and other resources, so there’s a limit to how many each department can host. This happens over several months, starting immediately after the ASSA meetings.

An important part of this congestion involves the timing of offers, acceptances, and rejections. Large, highly ranked departments at wealthy universities can often schedule flyouts early and make multiple offers per position, and can thus make offers to all the candidates they wish to hire. Such offers are often effectively open-ended, allowing candidates time to see what other offers may be forthcoming. But smaller, less prosperous, and less highly ranked departments often put time limits on how long their offers will remain open. Even an offer open for two weeks (which is not too unusual), which gives the recipient some time to think and maybe to come for a second visit, may call for a decision before other offers come in, or even before other flyouts are accomplished. Congestion is one reason a department may wish to put time limits on its offers. If it expects to have to make multiple offers to fill a single position, but can only make one at a time, then making consecutive offers quickly gives it the opportunity, should the need arise, to make offers to multiple candidates before they have committed to other positions. A less beneficent reason to leave offers open for only a short time is to pressure candidates into committing before they have time to receive another offer they might prefer. For whatever reason they are made, these asynchronous offers and deadlines make the market effectively less thick, since many candidates are deprived of the opportunity to consider multiple offers. Offers with short deadlines create a negative externality not just for applicants but also for other employers, since they shorten the time during which candidates remain available.<sup>23</sup>

Although most economics departments do not make offers that candidates must accept or reject before the ASSA meetings, some potential participants choose not to participate in the ASSA marketplace for interviews. Some employers of new economics PhDs—such as marketing departments in business schools—make offers before the ASSA meetings, and by the time of the meetings have already hired, or perhaps been turned down by economists who preferred to try their

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formerly on bulletin boards near the registration desks, and now on the internet. See <https://www.aeaweb.org/conference/2018-disclosure-codes> for a description of the code system, and <https://conf.aeaweb.org/employers/codes.php> to see (in season) how codes are displayed. At the 2018 meeting in Philadelphia, an additional source of physical congestion was that, to enhance the safety of hotel guests, many elevators required a hotel key to access floors with guest rooms, and so elevator operators reemerged from elevators’ past as hotel staff ushered interview candidates on to crowded elevators.

<sup>23</sup>No formal rules describe how offers to economists should be made (and there is no rule-making body capable of enforcing rules). But there is something about the market culture in economics that seems to have restrained the extremely short “exploding” offers seen in some markets, including some contemporary markets discussed shortly (cf. Niederle and Roth 2009). Sometimes important rules of market behavior are unwritten (and sometimes written rules are not followed) so understanding how marketplaces work may require careful attention to observed behavior, to detect social norms and customs that may shape available strategies.

chances in the larger, later marketplace.<sup>24</sup> Other employers choose not to interview at the meetings, but to wait and perhaps hire some talented individual who “fell through the cracks” amidst the crowded interview schedules. So the meetings provide some services to the broader market, but the strategy sets of participants are large, and they can choose to do without those services, and not participate in that marketplace.<sup>25</sup>

Finally, note that some marketplaces in a larger market may be *repugnant*, in the sense that although they are attractive to some participants, others not only don’t wish to participate themselves but think that such marketplaces should not operate at all (Roth 2007). This kind of repugnance can occur even in the absence of easily measurable negative externalities to those who would like to eliminate such a marketplace (Ambuehl, Niederle, and Roth 2015). The kidney transplant marketplaces I’ll discuss later have been fundamentally shaped by the repugnance, enshrined in law, toward buying and selling organs.<sup>26</sup> But until recently I would have been hard pressed to name a part of the market for economists that was viewed as repugnant by other economists. Lately, however, the website Economics Job Market Rumors (EJMR<sup>27</sup>) has achieved that distinction.

The site started as an anonymous internet discussion board focused on the job market, with threads devoted to particular candidates, schools, subfields of economics, etc., including anonymously sourced rumors about which schools were interviewing, flying out, and offering jobs to which junior candidates. Over time it also featured discussions of other aspects of academic economics, and discussions of anything else someone wished to discuss. As has happened with many other anonymous and pseudonymous internet sites, the tone of the discussion sharply deteriorated, and many of the posts became attacks on particular individuals, often in misogynistic, homophobic, anti-Semitic, or racist language.<sup>28</sup> The matter became widely known among economists after an undergraduate thesis, Wu (2017), which cataloged the prevalence of misogynistic language and critical comments about individual women on the site, was discussed in a *NY Times* column.<sup>29</sup> (As of this writing it appears that

<sup>24</sup> It was not always so. “The major job market for new business-school professors of marketing is organized around the summer meetings of the American Marketing Association. The market thus occurs a little over a year in advance of the date for which the positions are to be filled. This was not always the case: in the 1950s the American Marketing Association still held its market-oriented meeting at the Allied Social Sciences meetings [then] between Christmas and New Year’s Day.” (Roth and Xing 1994, p. 1014.) Cawley (2017) also describes a small “preemptive” market in economics prior to the ASSA meetings.

<sup>25</sup> See B. Roth and Shorrer (2017) on designing centralized marketplaces—“mediators”—that interact well with preexisting decentralized markets (and cf. Ashlagi, Monderer and Tennenholtz 2007).

<sup>26</sup> Ambuehl and Ockenfels (2017) investigate how this repugnance might arise from concerns that incentives interfere with informed consent.

<sup>27</sup> <https://www.econjobrumors.com/>

<sup>28</sup> Similarly, on another internet domain entirely, Microsoft had to quickly withdraw an artificial intelligence “chatbot” designed to automatically learn how to contribute to internet conversations from those that it encountered on Twitter. See, e.g., Christopher Heine, “Microsoft’s Chatbot ‘Tay’ Just Went on a Racist, Misogynistic, Anti-Semitic Tirade,” *AdWeek*, March 24, 2016. One of the founders of Twitter, Evan Williams, was interviewed in the *New York Times*, who quote him thus: “I thought once everybody could speak freely and exchange information and ideas, the world is automatically going to be a better place,” Mr. Williams says. “I was wrong about that.” (See David Streitfeld, “The Internet Is Broken: @ev Is Trying to Salvage It,” *New York Times*, May 20, 2017.)

<sup>29</sup> See Justin Wolfers, “Evidence of a Toxic Environment for Women in Economics,” *New York Times*, August 18, 2017.



there has been increased effort by the (anonymous) proprietors of EJMR to monitor the site and remove the nastiest vocabulary, perhaps with automatic filtering.)<sup>30</sup>

Reaction included a petition addressed to the AEA by the International Association for Feminist Economics (IAFE 2017), signed by more than 1,000 economists, and a recommendation by the AEA's Committee on the Status of Women in the Economics Profession (CSWEP 2017) that the AEA set up an alternative site, to provide some of the job market information available from EJMR in a less repugnant forum. The idea was that EJMR provided information that some economists were eager to have, but in an unsafe venue for women and others, and that the AEA might provide this information in a safer way. The AEA Executive Committee responded by conducting a survey of department chairs about what kinds of in-progress job market information they might be willing to share, and at the 2018 meeting it was decided to produce some non-anonymous websites for job market information in time for the 2018–2019 job market.<sup>31,32</sup>

I'll come back to this idea of moderating the impact of repugnant markets and marketplaces by organizing competition for them via marketplaces that provide more acceptable alternatives when I speak about efforts to ban some markets, the black markets that arise in response, and the choices this raises about relaxing laws against markets that can't effectively be eliminated.

To summarize, even these familiar, prosaic institutional features of the job market for new economists illustrate some issues—like *thickness*, *congestion*, *safety*, and *repugnance*—that often arise in the study of markets through their marketplaces, and which require attention when marketplaces are designed (Roth 2008).<sup>33</sup>

<sup>30</sup> See <https://www.econjobrumors.com/topic/kirk-statement-on-recent-events-and-moderation-policy>. In the meantime, there has been an effort to organize information on twitter about the dates by which departments and other employers finish their interview and flyout calls. See the twitter hashtag #EJMINFO, <https://twitter.com/hashtag/ejminfo?lang=en>, organized for this purpose in October 2017 by Abigail Wozniak and Kasey Buckles of Notre Dame.

<sup>31</sup> See <https://www.aeaweb.org/news/statement-of-the-aea-executive-committee-oct-20-2017>.

<sup>32</sup> By late 2017 the news was also full of other kinds of sexual harassment and assault, some of it clearly criminal, followed by high profile resignations and firings in industries from movies to tech to the appellate courts. One characteristic of many of these stories is that they began with testimony by one courageous victim, and were quickly followed by many more. There is a market design issue here. If a substantial number of assaults are committed by serial predators, but if there is danger and doubt surrounding an individual report, then it may be possible to make reporting safer and more reliable by allowing reports to be aggregated without announcement until some threshold is reached. One site that attempts to use this model in schools is Callisto (<https://www.projectcallisto.org/what-we-do>), which seeks to become a clearinghouse for contingent information: "Survivors can help schools identify repeat offenders using Callisto's matching function. This option allows survivors to store information about their perpetrator under the precondition that it will only be released to the school if another student names the same perpetrator." In this connection, see also the first 2018 issue of the CSWEP News which focuses on dealing with sexual harassment (CSWEP 2018).

<sup>33</sup> Note that similar market institutions can produce different results under different market conditions such as the balance between supply and demand. The Modern Language Association hosts an annual meeting (at roughly the same time as the ASSA meetings) that serves as a marketplace for interviews between departments of languages and literature and candidates for assistant professorships in those fields. The field also has a centralized medium for job advertisements for full-time positions at 4-year colleges and universities in the Jobs Information List (<https://www.mla.org/Resources/Career/Job-Information-List>, but less so for the growing segment of part-time jobs). See MLA Office of Research (2017) and the prior annual reports (<https://www.mla.org/Resources/Career/Job-Information-List/Reports-on-the-MLA-Job-Information-List>). The computerized application processing site Interfolio (<https://www.interfolio.com/dossier/>) handles applications and letters of reference. But while the market for new economists enjoys a steadily growing number of new jobs that regularly exceeds the number of new PhDs (see Siegfried 2017), that is not the case in the markets served by the MLA. Consequently the path from PhD to tenure-track academic position is much less reliable and quick in this market (see, e.g., Ehrenberg et al 2009).

Other academic marketplaces are organized differently, and even disciplines with supply and demand more similar to economics (e.g., computer science) can therefore offer very different experiences to participants.

## II. Marketplace Failures Related to Timing

Thick marketplaces that operate at a time at which transactions can be made efficiently provide a public good to the participants, by allowing them to compare many possible transactions. But as with any public good, there is a temptation to free ride, and thus marketplaces often need to be defended in order not to lose their thickness, or their efficient timing. For example, markets can *unravel* in time, a process by which offers in a labor market gradually become earlier, shorter in duration, and diffuse in time (with the consequence that participants must make decisions before important information is available, and without knowing what other opportunities might be available in the market).<sup>34</sup> Roth and Xing (1994) describe many unraveled markets, and for many markets identified organizations that try—often with only mixed success—to regulate the time at which marketplaces operate, and often the timing and duration of offers, to prevent free riding and promote efficiency.<sup>35,36</sup>

Early offers, like exploding offers, can arise in anticipation of congestion: a firm that expects to have to make multiple offers may wish to begin early, to have more time. But it can also result from the desire to move before competitors do, and combined with exploding offers it provides a strong negative externality to those competitors (although *recipients* of early offers may or may not be glad to get them, rather than waiting for potential later offers). But there is every reason to believe that unraveling results from multiple causes, because markets are multidimensional but time is one-dimensional. Offers can be made only later or earlier, and making offers later than one's competitors does not affect them in the same way as making early offers to candidates they might have wished to hire themselves, which can lead to escalation and a race to be first.<sup>37</sup>

<sup>34</sup>The word “unraveling” is meant to bring to mind a property of some simple knitted material: if you pull on a loose thread, much of the fabric can come undone, it can unravel.

<sup>35</sup>Roth and Xing (1994, p. 996) contained the following “generic” description of unraveling (referred to there as “Stage 1,” often followed by a “Stage 2” at which some market organization tries to specify a time before which offers should not be made): “Stage 1 begins when the market comes into being (e.g., when a few hospitals begin offering internships, or when federal court clerkships are created by legislation) and the relatively few transactions are made without overt timing problems. By the middle of Stage 1, the market has grown, and some appointments are being made rather early, with some participants finding that they do not have as wide a range of choices as they would like: students have to decide whether to accept early job offers or take a chance and wait for better jobs, and some employers find that not all of the students they are interested in are available by the time they get around to making offers. The trade journals start to be full of exhortations urging employers to wait until the traditional time to make offers, or at least not to make them any earlier next year than this year. Toward the end of Stage 1, the rate of unraveling accelerates, until sometimes quite suddenly offers are being made so early that there are serious difficulties in distinguishing among the candidates. There is no uniform time for offers to be made nor is there a customary duration for them to be left open, so participants find themselves facing unnaturally thin markets, and on both sides of the market a variety of strategic behaviors emerge, many of which are regarded as unethical practices. Various organizations concerned with the market may have proposed guidelines intended to regulate it, without notable success. As Stage 1 ends, influential market participants are engaged in a vigorous debate about what can and should be done. From beginning to end, Stage 1 may have covered a period of more than 50 years, or fewer than 1.”

<sup>36</sup>The inefficiency of early matching was particularly clear when college football teams used to be matched with bowls before they had finished playing all their regular season games: this meant that some matches were made before the match quality could be determined, which had a negative effect on television viewership (Fréchette, Roth, and Ünver 2007).

<sup>37</sup>For a variety of approaches to understand particular aspects of early contracting and/or unraveling, such as its effect on thickness, on information, etc., and/or on market conditions that might promote or deter unraveling, see Roth and Xing (1994), Li and Rosen (1998), Li and Suen (2000, 2004), Kagel and Roth (2000), Suen (2000), Damiano, Li, and Suen (2005), Niederle and Roth (2009), Halaburda (2010), Fainmesser (2013), Niederle, Roth, and Ünver (2013), Du and Livne (2016), Echenique and Pereyra (2016), Ambuel and Groves (2017), Ishii, Oery, and Vigier (2018), and Pan (2018).

Consider, for example, the markets for two of the most competitive kinds of positions for new lawyers: clerkships for appellate judges (Avery et al. 2001, 2007),<sup>38</sup> and associate positions in the largest law partnerships (Roth and Xing 1994 and Roth 2012). If someone graduating from law school this year moves into one of those positions, it is very likely that the job was arranged two years in advance (formally in the case of a clerkship, somewhat informally in case of an associate position, with the formal contract being made only one year in advance).

For clerkships, the Judicial Conference of the United States has tried to change this situation, often with temporary and partial success, at least six times since 1983. In each case they have specified a date before which judges should not make offers of clerkships. The most recent and long-lasting of these attempts began in 2002 and was officially abandoned only in 2014, although by that time it was widely understood that most judges were no longer following the rules.<sup>39</sup>

The 2002 attempt at rule-making initially specified only that offers should not be made “earlier than the Fall of the third year of law school.” But by 2003, three precise dates (starting after Labor Day of students’ third year) were specified before which no applicant may submit nor judges receive applications and letters of reference; before which interviews may not be scheduled; and before which judges may not conduct interviews and (simultaneously) extend offers. This led to a very compressed market following the time of the first allowable interviews, which often ended with exploding offers. For example, Avery et al. (2007, p. 448) quote a 2005 clerkship applicant:

*I received the offer via voice mail while I was in flight to my second interview. The judge actually left three messages. First, to make the offer. Second, to tell me that I should respond soon. Third, to rescind the offer. It was a 35-minute flight.*

This compression around first interviews made some judges try to “jump the gun,” by scheduling interviews, and making offers, before the allowed time. Avery et al. (2007) report that by 2005 over one-half of the judges who responded to a survey were aware that a substantial number of judges did not adhere to the indicated dates. Nevertheless, the plan was restated each year before being officially abandoned in 2014.

During that time, a growing number of judges violated the dates by moving sometimes only a little earlier than in previous years. Moving just a little early allows a judge to free ride on the public good provided by a thick market operating in students’ third year of law school. By waiting to hire clerks until their last year of law school, judges can collect more reliable information on each student’s likely abilities.<sup>40</sup> But by moving just a little early, judges can seek to benefit from

<sup>38</sup> See also <http://marketdesigner.blogspot.com/search/label/clerks>.

<sup>39</sup> In 1983 the proposed rule was that offers should not be made until September 15 of a student’s third (final) year of law school: this attempt was formally abandoned in 1984. In 1986 the proposal was for April 2 of the second year; in 1989 for March 1, in 1990 for May 1 at 12:00 noon, and in 1993 for March 1. In each case, the proposal was abandoned due to lack of compliance, and a period of unregulated unraveling followed. Avery et al. (2001) reported on the unraveled state of the market following the formal abandonment of the 1993 plan in 1998.

<sup>40</sup> Information available by the beginning of the third year but not by the beginning of the second includes transcripts from four semesters, information on law journal selection and election to law review editorial boards, information on moot court competitions, etc.

this abundant information and to choose whom to interview from the large pool of candidates, while avoiding competition from other judges. This eventually proved to be an effective form of competition, so that more and more judges moved earlier and earlier.

The judges most inclined to move early were those who could offer good positions to the most desirable clerkship candidates, but not the very most desirable positions. In an orderly market, these candidates could expect to be able to choose among the most prestigious positions, but a judge with a slightly less attractive position might succeed in hiring top candidates—e.g., some of those who had been elected Editor in Chief of their school's law review—if the judge could deliver an exploding offer first. (See, e.g., Judge Alex Kozinski 1991, in an appropriately titled article on his recruiting practices.) Judge Kozinski was in the West Coast Ninth Circuit, the largest in the country, but less prestigious than some of the East Coast Circuits, particularly the DC Circuit.

In contrast, judges in the most prestigious circuit court of appeals have the most interest in having the market operate with lots of information, since then they can identify the best students, who they would have a good chance of hiring, in a thick market. But as other judges hired clerks earlier, via exploding offers, their opportunity to do this waned. The DC Circuit formally announced its abandonment of the plan in January 2013, saying that if other judges were going to go early then so would they,<sup>41</sup> and the plan was formally laid to rest the following year.<sup>42</sup> The market very quickly unraveled back into the summer after the first year of law school, when clerkship offers were once again mostly finalized. Judges with competitive clerkships made offers to candidates without the information about them that would have been available if the market operated later, and most applicants accepted the first offer they received.

But hope springs eternal: in February 2018 the DC Circuit announced its support of a new attempt to control the timing of clerk hires (see United States Court of Appeals District of Columbia Circuit 2018). Future law clerks already in their second or third year of law school had already been hired by this time, but the courts' plan is to defer the hiring of those who just entered law school in Fall 2017. It will have implications for hiring starting in 2019, and again in 2020, after which it will be reviewed. The plan does have a new feature: it will attempt to ban exploding offers by requiring that offers remain open for 48 hours. To my jaundiced eye it does not appear very promising—this will be the seventh such attempt to halt unraveling in this market since 1983. So I predict that either there will be more rules added in an attempt to make the market design more robust to the kinds of failures observed

<sup>41</sup>US Court of Appeals, District of Columbia Circuit (2013): "Although the judges of this circuit would uniformly prefer to continue hiring law clerks pursuant to the Federal Law Clerk Hiring Plan, it has become apparent that the plan is no longer working... We stand ready to work with the judges of the other circuits to develop an appropriate successor to the current plan. In the meantime, however, the judges of this circuit will hire law clerks at such times as each individual judge determines to be appropriate."

<sup>42</sup>January 13, 2014: "In accordance with recommendations made by the Online System for Clerkship Application and Review (OSCAR) Working Group (Working Group), I am writing to inform you that the Federal Law Clerk Hiring Plan has effectively been discontinued and no further dates are being set in connection with that plan." (Judge John D. Bates, "Law Clerk Hiring," memo to: All United States Judges, January 13, 2014, [https://oscar.uscourts.gov/assets/Federal\\_Law\\_Clerk\\_Hiring-January\\_13\\_2014.pdf](https://oscar.uscourts.gov/assets/Federal_Law_Clerk_Hiring-January_13_2014.pdf)).

in the past, or that the present plan will also fail, although perhaps only slowly as was the case with the most recent failure.<sup>43</sup>

Another very prestigious job for new lawyers is to become an associate at a large law firm. This part of the market for lawyers also presently sees a lot of action in the summer following students' first year of law school, since that is when those firms hire second-year summer associates, often with exploding offers (see Roth 2012). This is a very direct channel to full-time employment after graduation. The National Association of Law Placement (NALP) reports that almost 95 percent of the second-year summer associates of all the firms they surveyed in 2016 received offers of full-time employment for the following year (98.2 percent for firms employing more than 700 lawyers), with around 85 percent of offers accepted (NALP 2017a, Table 13, p. 29). That is, nearly all summer associates receive an offer of a full-time position, and the vast majority accept and go to work after graduation at the firm at which they summered. So the arrangement of a second-year summer associateship in the summer after the first year is very close to the same thing as being hired for a post-graduation job, two years in advance of graduation.<sup>44</sup>

Unlike judges, who have no flexibility on clerk salaries (which are set by Congress), private law firms can compete vigorously with one another, and could pay associates differently from other firms, and also pay different first-year associates of their own differently. However, neither of those things happen, and for a number of years virtually all first-year associates at large firms made the same salary, of \$160,000 (and most firms give uniform bonuses to associates of the same vintage).<sup>45</sup> Thus, it is not the salary that determines the matching between large firms and their summer associates, i.e., it doesn't determine which associates work for which firms. The matching between new lawyers and big law firms is almost entirely determined by the chaotic matching process that plays out very early in law school.

Other contemporary examples of unraveled markets include employment in private equity, recruiting for college sports (and early admissions to college more generally), Swiss apprenticeships, and some medical fellowships in specialties that have not yet adopted a centralized clearinghouse.<sup>46</sup>

The threat of unraveling sometimes prompts action, because marketplaces need to be maintained, and, when necessary, defended. Markets that have long operated at

<sup>43</sup> See also Federal Law Clerk Hiring Pilot, [https://oscar.uscourts.gov/federal\\_law\\_clerk\\_hiring\\_pilot](https://oscar.uscourts.gov/federal_law_clerk_hiring_pilot). Note that one problem documented in Avery et al. (2001, 2007) and elsewhere is that an interview with a judge is scheduled based, either implicitly or sometimes explicitly, on an understanding that the student being interviewed will accept an offer if one is made. If this feature of the market is not altered, requiring that offers remain formally open for 48 hours will not have the desired effect of allowing candidates to consider multiple offers.

<sup>44</sup> Rescinded offers are sometimes another consequence of early hiring, since law firms may not always be able to forecast their demand for new associates accurately a year or more in advance. See the NALP's attempt to make this more orderly (NALP 2001).

<sup>45</sup> NALP (2015) reports that from 2009 through 2014, "salaries of \$160,000 accounted for about  $x\%$  of reported salaries," over all firms (of different sizes) with  $x$  varying from 25 percent for the first year class of 2009 to 17 percent for the class of 2014. (The overall salary distribution is bimodal, varying by type of employment, with the other peak at about \$50,000, and showing more variance.) Current salaries are a bit higher (NALP 2017b). Medical residents at a given hospital are also often paid the same: see Niederle and Roth (2003a).

<sup>46</sup> See <http://marketdesigner.blogspot.com/search/label/unraveling>. Another example of unraveling, familiar on some American college campuses, is the recruiting activity of American college fraternities and sororities, which is called rush, in an etymology that comes from unraveling, since recruiting that years ago focused on older students moved earlier (as some recruiting was rushed...) until, for many years now, it has focused on newly arrived students: see Mongell and Roth (1991).

a given time can lose their thickness through unraveling. For example, the American Philosophical Society (APS) is attempting to preserve the marketplace for interviews provided by their Association's Eastern Division meeting, which takes place around the time of the ASSA meetings, and serves the same function as a marketplace for academic interviews. The recent growth of earlier Skype interviews has not only made that marketplace less thick, it has also moved flyouts and offers (and the time at which they must be accepted) earlier, leading to efforts by the philosophy association to stop further unraveling.<sup>47</sup>

The design of attractive marketplaces can sometimes reverse unraveling. In medicine and in some other markets, centralized clearinghouses have arisen partly in response to unraveling.

### **III. Computerized Clearinghouses for Stable Matching: Medical Labor Markets and School Choice**

#### *A. Medical Labor Markets*

The labor markets that American medical doctors navigate in their early careers have pioneered one approach to reversing unraveling and avoiding congestion. These marketplaces are centralized at a different point than the market for new economists. While economists have a centrally located marketplace for interviews, new doctors have decentralized interviews. But they have a centralized clearinghouse through which all offers, acceptances, and rejections are made quickly by a computerized algorithm that takes as input the preference orderings over jobs submitted by applicants, and over applicants submitted by employers. (Thus, as I will describe, these markets are presently experiencing congestion in the interview process, but not in the process of making offers and acceptances.)<sup>48</sup>

Almost all new American doctors go through a centralized labor market clearinghouse when seeking their first positions as medical "residents" in teaching hospitals, and many doctors go through it again as they seek more senior positions. This became a widespread form of marketplace in medicine because the market for newly graduated physicians has essentially served as a model for other parts of the medical labor market, as many of these markets for more specialized, more senior physicians recapitulated the marketplace failures that had been encountered and overcome in the market for new doctors.

Briefly, the market for new doctors unraveled, first incrementally and then by leaps and bounds, in the first half of the twentieth century, until by 1945 new doctors were customarily hired two years before they graduated from medical school. From 1945 through 1950 there were successful attempts to specify a time before which offers should not be made, but (as in the markets for lawyers some years later) this led to congestion, and exploding offers that gave applicants and employers little opportunity to consider multiple opportunities.

<sup>47</sup> See the APS "Statement on the Job Market Calendar," <http://www.apaonline.org/page/jobmarketcalendar>.

<sup>48</sup> More detailed history of the market for residents described below can be found in Roth (1984, 2003). For a first-person account from a doctor who played a role in the 1952 reorganization of the market, see Nakayama and Hendren (2017).

In the early 1950s, a collection of medical groups proposed and implemented a centralized clearinghouse. Applications and interviews would go on as before, but instead of being followed by decentralized offers and acceptances or rejections, both applicants and directors of hospital residency programs would be invited to submit a rank ordering (in order of preference) of those they had interviewed. That is, applicants would submit a rank ordering of the positions to which they still wished to apply after interviewing (i.e., a first choice, second choice, etc.), and program directors (who I will call “hospitals”) would submit a rank ordering of applicants they had interviewed and would be willing to hire.

An algorithm would process these preference lists and propose a matching of applicants to hospitals, and the matched parties were encouraged to exchange promptly a signed contract.<sup>49</sup> After a little trial and error, an algorithm was settled on that was later shown (in Roth 1984) to produce a *stable* matching, in the sense, defined by Gale and Shapley (1962), that no applicant and hospital who were not matched to one another would both prefer to be matched to the other than to their proposed match, and thus form a “blocking pair.”<sup>50</sup> The empirical evidence is that producing a matching that is stable in this way is important for the long-term success of this kind of clearinghouse (see, e.g., Roth 1991a, Kagel and Roth 2000). The importance of stable matchings for the success of a clearinghouse is closely related to the fact that market participants have large strategy sets that may involve actions taken outside of the marketplace. If a matching is not stable, then there are blocking pairs of doctors and hospitals not matched to one another who would both prefer to be, and it is often hard to prevent them from circumventing the marketplace and matching together.<sup>51</sup>

But another important feature of the computerized clearinghouse was how it eliminated congestion that arose when offers were made in a decentralized way.<sup>52</sup>

The easiest way to see this is to consider a version of the Deferred Acceptance algorithm defined by Gale and Shapley, which is the basis for the more complicated algorithm now used. It takes as input the preference lists submitted by the applicants and hospitals, and performs the following operations (phrased here as if the individuals involved were making and responding to applications, but all performed at computer speed).

- Initially, each applicant applies to his/her top choice hospital, and each hospital  $h$  with  $q$  positions holds the top  $q$  applications among the acceptable applications it receives, and rejects all others.

<sup>49</sup>Each residency program had a largely standard contract that was known at the time at which preferences were submitted.

<sup>50</sup>For applicants who are each matched to a single position, this verbal definition of stability is sufficient. For residency programs matched to multiple new doctors, a more precise statement is that the program would not prefer the applicant in question (to whom they are not matched but who prefers them) to one of those to whom they are matched, or that they would prefer the applicant to leaving a position vacant if the proposed matching did not fill all their positions. More details on the algorithms and histories can be found in Roth (2008a), and more on the mathematics of stable matchings in Roth and Sotomayor (1990). Manlove (2013) takes a computer science perspective.

<sup>51</sup>Such participants often find ways to circumvent an unstable clearinghouse so that they can be matched: see, e.g., Roth (1991a) on the experience of centralized clearinghouses in different regions of the British National Health Service, some of which produced stable matchings and some of which didn't.

<sup>52</sup>The processing of the preference lists is now computerized, but was conducted with card-sorting machinery in the 1950s.

- At each subsequent step of the algorithm, any applicant rejected at the previous step applies to his or her most preferred acceptable hospital that hasn't yet rejected him/her. (If no acceptable choices remain, he/she makes no further applications.) Each hospital holds its  $q$  most preferred acceptable applications to date, and rejects the rest.
- The algorithm stops when no further applications are made, and the resulting match is the one in which each hospital accepts the applicants (if any) whose applications it is holding.

Gale and Shapley called this a *deferred* acceptance algorithm because the determination of which applications are accepted by each hospital is deferred until the end of the application process, i.e., until no more applications are forthcoming (either because every applicant has an application being held by a hospital, or has been rejected by all hospitals on the applicant's preference list). They observed that, no matter what preference rank-orderings are submitted to the algorithm, the matching it produces is always stable with respect to those preferences, because any applicant who would prefer to be matched to a different hospital must have already applied to that hospital and been rejected because it could already fill all of its positions with applicants it preferred.

The DA algorithm organized in this way (with applicants applying rather than firms making offers) makes it safe (in fact a dominant strategy) for applicants to submit rank order lists that correspond to their true preferences. Mechanisms that make it a dominant strategy to reveal true preferences are called "strategy-proof;" because participants don't have to make strategic calculations about what others are doing, they just have to decide what they like. And although no mechanism that always produces stable matchings can be strategy-proof for hospitals employing multiple residents, this proves to be less of an issue in this market than it once seemed, because it turns out that the set of stable matchings is very small, and that this and related properties of the market limit the benefits that anyone can even hope to achieve by misrepresenting their preferences.<sup>53</sup>

In the course of the Deferred Acceptance algorithm, many offers may have to be made. But because computers are fast, and because the algorithm doesn't end until each hospital has had a chance to consider every application that it can get, this process isn't congested. In particular, every participant can submit a long preference list, and be confident that they will not be forced to make a match before exploring all available alternatives.<sup>54</sup>

<sup>53</sup> See Dubins and Freedman (1981) and Roth (1982a) on incentives in the one-to-one marriage problem, and Roth (1985) when there is many-to-one matching as in the medical match. Roth and Peranson (1999) observed the small size of the set of stable matchings, and Ashlagi, Kanoria, and Leshno (2017) have given a compelling theoretical account of why we should expect the set of stable matchings to be small in these kinds of matching models. In simple models (e.g., of one-to-one matching) this in turn implies that profitably manipulating preferences will not be a viable option for virtually all participants, because manipulation of preferences cannot move outcomes outside of the set of stable matchings (see Demange, Gale, and Sotomayor 1987; Roth 2015c). The case of many-to-one matching may sometimes introduce opportunities for firms to misrepresent their capacity (see Sönmez 1997) even when there is a unique stable matching and wages are fixed (Azevedo 2014).

<sup>54</sup> In this connection, an illuminating example is the labor market for clinical psychologists, which tried for some years to organize a marketplace by telephone, with rules that aimed to implement a decentralized deferred acceptance algorithm. This encountered significant congestion problems, studied in Roth and Xing (1997). Today



One way in which it becomes apparent that this kind of marketplace for doctors, and indeed the whole market for doctors, is part of a much larger labor market is in the changing demographics of the medical labor force. In the 1950s, almost all graduates of American medical schools were men, and today the graduates are quite equally divided between women and men. One consequence of that change has been a steadily increasing number of couples graduating from medical school together and seeking two jobs, not one. A clearinghouse in which each individual submitted a rank order list meant to represent his or her individual preferences didn't work for couples.<sup>55</sup> But in the presence of couples who submit preference lists ranking pairs of positions, stable matches are not guaranteed to always exist (Roth 1984).

It was thus apparent to me, when I agreed in 1995 to direct a redesign of the resident match, that market design was going to require answers to different questions than had so far been asked. Instead of being satisfied with theorems indicating that stable matchings always exist in simple matching problems, but might sometimes fail to exist when couples (or other instances of complementary preferences) were present, it was going to be important to know, for example, *how often* stable matchings might fail to exist when couples are in the market.<sup>56</sup> The algorithm we designed to meet the changing needs of the medical match (Roth and Peranson 1999) allowed us to show empirically not only that the set of stable matches was small, but also that it was virtually never empty. As is often the case in market design, this empirical observation, which enabled the Roth-Peranson algorithm to be implemented with confidence (albeit with a check of the final stability of the outcome), preceded and eventually inspired the theoretical work that has begun to explain why stable matchings involving couples can be found in large markets (see Kojima, Pathak, and Roth 2013, and Ashlagi, Braverman, and Hassidim 2014). Today dozens of medical and healthcare marketplaces use centralized clearinghouses that employ the Roth-Peranson algorithm, and there are a number of clearinghouses that do not deal with couples and use other variants of the deferred acceptance algorithm.<sup>57</sup>

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that market uses a centralized clearinghouse that employs the Roth-Peranson (1999) version of the deferred acceptance algorithm that also handles couples, as described next.

<sup>55</sup>The first attempt to deal with couples, in the 1970s, had them each submit an individual rank order list, and designate one member of the couple as the "leading member." That person then went through the match, after which the other couple member followed, with his or her rank order list edited to remove jobs not in the same city as the job obtained by his or her spouse. While this often produced two jobs in the same city, it was increasingly the case that couples didn't take these jobs, but found ways to arrange two jobs that they preferred, outside of the match. The issue is that couples have preferences over pairs of jobs, and the procedure above was likely to give them two jobs without regard to whether they would have preferred two different jobs. (And the iron law of marriage says that you can't be happier than your spouse, so a couple with one good job and one mediocre job has a lot of incentive to seek out two good jobs, and their strategy sets were big enough so that they could do so.)

<sup>56</sup>Kelso and Crawford (1982) were the first that I know of to emphasize the absence of complementarities (i.e., substitutability) in standard matching theory, and while preferences that don't involve complementarities are often a very useful approximation in applications, complementarities can easily arise, e.g., as a result of budget constraints (Mongell and Roth 1986).

<sup>57</sup>A high level flowchart of the Roth-Peranson algorithm is in the postscript to Roth (2013, p. 38). National Matching Services, Inc., founded by Elliott Peranson, directly runs eight matches and supports a number of others (<https://www.natmatch.com/clients.html>). In addition to the resident match (the National Resident Matching Program, <http://www.nrmp.org/>), the NRMP organization runs another 26 fellowship matches (<http://www.nrmp.org/participating-fellowships/>) as well as the Medical Specialties Matching Program (MSMP) Fellowship Match which runs another 14 subspecialty matches (<http://www.nrmp.org/fellowships/medical-specialties-matching-program/>), all using the Roth-Peranson algorithm. Another organization, the SF Match, runs another two dozen fellowship matches, as well as residency matches in ophthalmology and plastic surgery (<https://www.sfmach.org/Specialty.aspx>) and these appear to use another variant of a deferred acceptance algorithm, as do matches run in podiatry and urology. There are a number of medical matches in Britain that use deferred acceptance algorithms

Sometimes, establishing a clearinghouse to replace an unraveled decentralized market involves designing the way that offers in the larger decentralized market and in the centralized marketplace will interact.<sup>58</sup> This was an issue in the (re)establishment of a centralized clearinghouse for gastroenterology fellows, to replace a market that had unraveled steadily since a previous clearinghouse had been abandoned (Niederle and Roth 2003b). One purpose of the match was to move hiring of fellows later in the careers of internal medicine residents, who would become gastroenterology fellows only after completing their residency. But there was a concern that those fellowship programs that delayed making offers until the later time at which the clearinghouse would operate would be “scooped” by their competitors who might keep making early offers. That is, the clearinghouse was to be a marketplace in a larger market, in which early hiring might still continue, because the gastroenterology organizations did not have any ability to restrain fellowship directors from continuing to make early offers. What the professional societies could do, however, was empower students who had accepted an early offer to change their minds and later participate in the centralized marketplace. This was sufficient to get the clearinghouse off to a successful start (Niederle, Proctor, and Roth 2006, 2008).<sup>59</sup>

The problems that cause medical markets to organize centralized clearinghouses aren't a thing of the past. Several medical subspecialties have recently organized clearinghouses to combat unraveling.<sup>60</sup> But for many medical labor markets, centralized clearinghouses are a mature technology, and strategies for navigating the market have adapted.

In particular, when markets are unraveled, there isn't a lot of interviewing, because attractive applicants get early exploding offers as programs try to fill their positions before their competitors, and programs don't need to conduct further interviews once their positions are filled. But when a centralized clearinghouse allows participants to consider many alternatives, both employers and applicants are interested in gathering and transmitting information in interviews, to determine their preferences, and to impress their counterparties with how desirable they are. Consequently, residency and fellowship programs conduct many interviews. Unlike the market for new economists, there is no central national meeting at which a large proportion

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(Roth 1991a), as does a recently organized match for psychologists in Israel (Hassidim, Romm, and Shorrer 2017a). A newly organized medical match in Israel (in which hospitals are passive) has a very different organization (Bronfman et al. 2015).

<sup>58</sup>B. Roth and Shorrer (2017) examine this issue specifically in the context of stable matching, and find that it gives a new motivation for stability.

<sup>59</sup>Orthopedic surgery faced unraveling that looked quite similar to that in gastroenterology, but faced different problems in organizing a match (see Harner et al. 2008). When we suggested to our orthopedic surgery colleagues that they act to empower the students to change their minds about offers, since that had worked in gastroenterology, they told us that no young surgeon could renege on a promise made to a senior surgeon. But, unlike the gastroenterologists, they felt they could effectively prevent fellowship directors from making early exploding offers before a match, by imposing sanctions on any who did so. Eventually the various orthopedic professional societies (which largely focus on different parts of the body) organized several orthopedic surgery subspecialty matches, run by the SF Match.

<sup>60</sup>For example the match for laryngology fellowships was initiated in 2012 (Formeister, Courey, and Yung 2017), while epilepsy and clinical neurophysiology fellowship are presently unraveled (Vidaurre and Campbell 2017). An interesting case of cultural transmission of this kind of market organization is a match (using the Roth-Peranson algorithm) for PhD physicists who work in medicine, sponsored by the American Association of Physicists in Medicine (AAPM) and the Society of Directors of Academic Medical Physics Programs (SDAMPP) (see <https://natmatch.com/medphys/overview.html>).

of interviews are conducted. Programs host interviews at their own location, interviewing many candidates on the same day, and applicants travel to many interviews, paying their own way (and taking time off from medical school or from their current residency position). The increase in the number of interviews for residencies has grown in tandem with the increased number of applications, due in part to the advent of internet-based applications through the Electronic Residency Application Service (ERAS). There is increasing concern about the number of applications submitted and interviews conducted, both because of the time they take and their costs (see, e.g., Gruppuso and Adashi 2017). This concern is prompting discussions about ways to relieve congestion in the market by reducing the number of interviews.

Possible ways to address this congestion might include limiting the number of applications each individual can make through ERAS, or limiting the number of interviews each residency or fellowship program can conduct. Either of these approaches might be combined with a signaling mechanism to help guide the matching for interviews. Each of these approaches raises open questions.<sup>61</sup> Past experience suggests that addressing these practical problems will also lead to new theoretical understanding of the underlying market processes.<sup>62</sup>

### B. School Choice

Another domain in which clearinghouses organized by the deferred acceptance algorithm now play a large role is in school choice. Atila Abdulkadiroğlu, Parag Pathak, and I helped New York City organize the clearinghouse they have used for high school admissions each year since it was introduced for students entering high school in the Fall of 2004 (Abdulkadiroğlu, Pathak, and Roth 2005, 2009). It replaced a congested, decentralized process in which schools made independent admissions decisions, and many students were assigned administratively to schools over which they had expressed no preference when the process ran out of time. The NYC school choice problem resembled those facing medical labor markets, with active strategic players on both sides of the market, because school principals in

<sup>61</sup> The main issue is how any of these interventions to reduce interview congestion would impact the final match outcomes. Ashlagi, Nikzad, and Romm (2015) show how constraining applicants to submit short preference lists can have welfare improving effects when true preferences are uncorrelated. In the uncorrelated case, applicants can be advised to submit truncated preference lists that include as many of their top choices as allowed. When preferences are correlated, however, it is unclear how to advise applicants who are not likely to be highly preferred by their top choices. Ashlagi et al. (2017) point to ways in which signaling could be useful in choosing interviews, and in organizing rank order lists. And it remains to be seen how many residency and fellowship programs would be willing to limit their interviewing if their competitors did likewise, since the large strategy sets available on both sides of the market might make enforcement of interview limits difficult (e.g., “if you happen to find yourself in our city, drop by to meet us informally...”).

<sup>62</sup> A lot of matching theory has been motivated by applications. See, for example, the Rural Hospital Theorem (Roth 1986) which says that the requirement that a matching be stable essentially determines the assignment of residents to those hospitals that can't fill all their positions. (But see Agarwal 2017 for some policy options regarding rural hospitals, and Kamada and Kojima 2015 for some design issues that arise in connection with rural hospitals in Japan. See also Fragiadakis and Troyan 2017 on some properties of matchings that require certain numbers of positions to be filled.) Similarly, observations that the set of stable matchings is small in most applications have led to new theoretical understanding of why that is so (Kojima and Pathak 2009; Ashlagi et al. 2017). Extensions of the models to matching with contracts have led to connections with general equilibrium theory, and relaxation of the assumption of two-sidedness (Kelso and Crawford 1982; Hatfield and Milgrom 2005; Ostrovsky 2008), and to the observations that the set of stable matchings may often be large in matching with contracts (Hassidim, Romm, and Shorrer 2017b). The empirical study of matching markets has also led to the development of new econometric tools: see, e.g., the study of how doctors evaluate residency programs by Agarwal (2015).

NYC play an active role in admissions. So the stability of the resulting matching was an important feature of the design: there was evidence that in the prior system, which did not produce stable matchings, school principals sometimes concealed places from the NYC Department of Education, to be able to match later with students they preferred to those to whom they might otherwise have been assigned.

Data from the preferences over schools that students submit to the current clearinghouse allow Abdulkadiroğlu, Agarwal, and Pathak (2017) to compare the welfare effects of the matchings produced by the centralized school choice system to those under the old, “uncoordinated” admissions. Using the (ordinal) rank order lists submitted by students, they assess welfare by estimating a cardinal random utility model, with trade-offs among school attributes measured in terms of the additional distance a student is willing to travel to be at a more preferred school.<sup>63</sup> They find that the students placed administratively when the old congested system ran out of time were generally placed in less desirable schools than those over which they had expressed preferences. Furthermore, in the old system there was more “recontracting,” in which students ultimately entered different schools than those to which they had been assigned, than in the new system. They find that the new system improves welfare over the old by 80 percent of the gains that could be achieved by a utility-maximizing allocation made independent of stability constraints, and that changes in the algorithm (e.g., choosing a different stable matching, among the multiple that arise from random tie-breaking) would have very little additional effect on welfare.<sup>64</sup>

The biggest difference is that under the old system, only about one-half of the students were placed in the “main round” (now occupied by the deferred acceptance algorithm), whereas in the new system this number climbed to over 80 percent in the first year (with additional subsequent gains). So students who used to be assigned administratively are now largely assigned by the deferred acceptance algorithm to a school over which they have expressed a preference. That turns out to be much better for them than assignment without regard to their preferences.

<sup>63</sup>New econometric techniques have had to be developed to use the randomness involved in tie-breaking in school choice to help evaluate outcomes: see Abdulkadiroğlu et al. (2017). In analyzing NYC school choice, use was made of the fact that it is a dominant strategy for students to state their true preferences. This is of course different from an empirical statement that students’ submitted preferences always reflect their true preferences, and recently there has been a stream of work on this, much of it taking flight from Li (2017) on the distinction between strategy-proof and “obviously strategy-proof” mechanisms. Stable matching mechanisms are not obviously strategy-proof (Ashlagi and Gonczarowski 2016), and recent empirical work has focused on identifying cases in which some submitted preferences can be identified as departing from the likely underlying preferences, see, e.g., Rees-Jones (2017, 2018), Rees-Jones and Skowronek (2018), Hassidim et al. (2017), and Shorrer and Sóvágó (2017). This work supports the conclusion that the instructions that accompany a mechanism (e.g., regarding strategy-proofness) are an important part of its design, and that effective instructions may be hard to design. (An almost opposite approach looks at *relaxations* of strategy-proofness rather than refinements, see, e.g., Azevedo and Budish 2017 on strategy-proofness in the limit as markets grow large, and Kannan et al. 2015 on strategy-proofness in the limit when capacity constraints need to be respected only to a close approximation.)

<sup>64</sup>The study of tie-breaking became an important part of the design of school choice systems because schools have only coarse preferences over students, and so a school may not have capacity to admit all students in the same indifference class. Ties are typically broken by random lottery. But turning weak preferences over students into strict preferences creates the appearance of new blocking pairs, and changes the stable matching chosen by the deferred acceptance algorithm. A substantial effort has gone into understanding this and related matters connected to stable matchings, see, e.g., Erdil and Ergin (2008, 2017), Abdulkadiroğlu, Pathak, and Roth (2009), and Ashlagi, Nikzad, and Romm (2015). See Kesten (2010) for a related relaxation of stability. Motivated by school choice, Azevedo and Leshno (2016) formulate a model with a finite number of schools but a continuum of students, and characterize stable matchings simply by cutoffs for each school, that function something like prices.

School districts in other cities have since adopted similar clearinghouses. Boston Public Schools, after lengthy study, also adopted a clearinghouse based on the deferred acceptance algorithm, for students entering in Fall of 2006 (Abdulkadiroğlu and Sönmez 2003; Abdulkadiroğlu et al. 2005, 2006). An important issue in Boston was how strategy-proofness “leveled the playing field” between families that were sophisticated about the way the school choice mechanism worked, and those who might simply submit their true preferences even when this was not their best course of action (Abdulkadiroğlu et al. 2005; Pathak and Sönmez 2008).<sup>65</sup> Subsequently, my colleagues and I have collaborated on the design of school choice clearinghouses in Denver, Washington, DC, Newark, New Orleans, Camden, Indianapolis, and Chicago.<sup>66</sup> In general, our goal is to enroll both district and charter schools in a unified enrollment system that will give a single best offer to each student. This is because a big cause of congestion in school assignment occurs when some students are admitted to multiple schools and others must wait for their decision before the unused places become available, and this happens when district schools and charter schools run independent admissions.<sup>67</sup>

In many of these cities, the individual schools are not strategic players, and instead of using preference orderings of students compiled by school principals, the clearinghouse takes as input priority lists established by the school district to determine each student’s priority at each school.<sup>68</sup> These priorities, and even the menu of schools to which students living in different parts of the city may apply, are subject to changes from time to time. This reflects the fact that which children attend which schools is an intense focus of city politics, and so the priorities that different groups of children have for different schools is part of the school choice process that is perhaps inevitably subject to change over time. I think effective school choice design should seek to put in place a mechanism that allows city politics to do its work of adjusting how school places are distributed among different constituencies, but allows the information provided each year by parents to be effectively elicited and used to place children in schools that will be good for them, with as efficient allocation of school places as possible.<sup>69</sup>

<sup>65</sup>This reflects an important issue in practical market design, which distinguishes it from the theoretical literature on mechanism design that is often satisfied with an equilibrium analysis of mechanisms, without considering what might be required to reach equilibrium, or how to advise participants to choose their strategies. Strategy-proof mechanisms somewhat ease both these concerns (and make it easy to know what to advise participants, although not always how to deliver this advice effectively).

<sup>66</sup>The work on these latter cities has been organized through the nonprofit Institute for Innovation in Public School Choice (IIPSC, <http://iipsc.org/>), founded by Neil Dorosin, who was the New York City Department of Education’s Director of High School Operations when we helped organize high school choice there. Attila Abdulkadiroğlu, Parag Pathak, and I are IIPSC’s Scientific Advisory Board.

<sup>67</sup>For example, charter school applications are decentralized in Boston, but centralized and integrated with the district schools in Denver. There is some suggestive evidence that a unified enrollment system makes it easier for a broader segment of the population to apply to charter schools: charter applicants in Boston have higher average baseline tests score in comparison to the general population (Abdulkadiroğlu et al. 2011, Table II and pp. 717–18) while there is no such difference in Denver (Abdulkadiroğlu et al. 2017, p. 1381).

<sup>68</sup>In some places (and for some schools) students’ priority is determined by their score on an exam. The college admissions system in China is such a system, in which the allocation algorithms have undergone changes in recent years: see Chen and Kesten (2017).

<sup>69</sup>For example, while Boston Public Schools continue to use the deferred acceptance algorithm as originally designed, concerns arose both about the cost of transportation, and about the scattering of students from some neighborhoods among undesirably many schools. In response, they have restricted the sets of schools to which particular students can apply, and altered the priorities that each student has for each school (Shi 2015). See also Ashlagi and Shi (2016) and Pathak and Shi (2017).

Market and marketplaces of all kinds also require a certain amount of trust to gain and keep public support, and clearinghouses that operate under clear rules can make school assignment transparent even in cities in which school assignments were once widely viewed as corrupt. This role of the school choice clearinghouse in Washington, DC was emphasized by the forced resignation of the school system Chancellor in February 2018, who had earlier in the year asked a Deputy Mayor to transfer the Chancellor's daughter into a popular high school to which she could not have been assigned according to the rules. (Note again that market participants can have large strategy sets that sometimes allow marketplace rules to be circumvented.) However, the existence of formal rules made their violation apparent in this case, and the Mayor quickly demanded and received the resignation of both officials involved, in an attempt to maintain trust in the system (Stein, Jamison, and Nirappil 2018).

Because the schools are not strategic players in many cities, the case for requiring stable matchings is not as compelling as in markets in which stability helps achieve long-term orderly participation in a clearinghouse. Other strategy-proof clearinghouse mechanisms have been considered, although seldom adopted.<sup>70</sup>

The two main sources of congestion in school choice are in applications, and in offers and acceptances. When applications are decentralized, it may be hard to learn about schools and how to apply to them, and time consuming to submit many different applications. (So this is an example in which bringing applications together in a single marketplace can reduce congestion.) And when admissions and acceptances are decentralized, some students are offered multiple positions, and others must wait while they decide. In school choice, congestion can therefore be reduced by making the market thicker so that it includes all schools in a single unified admissions clearinghouse that gives each student a single offer.

Computerized clearinghouses thus help deal with school choice congestion in three ways: by bringing together the application process for many schools in a single platform, by using computer speed for processing offers, acceptances, and rejections according to the submitted preference lists, and by asking for those preference lists (and hence acceptance and rejection decisions) *in advance*, so the process is not delayed while participants decide on their preferences.<sup>71</sup>

To summarize, centrally organized computerized clearinghouses that produce stable matchings based on preference orderings submitted by market participants have succeeded as a form of market organization in a wide range of medical and

<sup>70</sup>One exception is New Orleans (Abdulkadiroğlu et al. 2018), which initially adopted a school choice system based on the top trading cycle algorithm introduced by Shapley and Scarf (1974), which also makes it a dominant strategy for students to state their true preferences (Roth 1982b), and which produces a matching which is Pareto optimal for students, and was considered for school choice in Abdulkadiroğlu and Sönmez (2003). In contrast, stable matchings are Pareto optimal only on the larger sets of students and schools, which is a less compelling criterion when stability is not required to avoid strategic play by schools. Randomization in top trading cycles has been explored in Abdulkadiroğlu and Sönmez (1998), Pathak and Sethuraman (2011), and Carroll (2014). In one-to-one matching with strict preferences, there is a unique matching produced by top trading cycles (Roth and Postlewaite 1977), but in many-to-one matching, as occurs in school choice, this is not the case. Morrill (2015) explores some refinements of top trading cycles in this case as does Abdulkadiroğlu et al. (2018).

<sup>71</sup>Recently, a number of school districts are seeking to reduce congestion in applications by adopting a common application system, after which admissions decisions will continue to be made in an uncoordinated way by individual schools. I anticipate that by making applications easier this will succeed in increasing the number of applications, but that it may also therefore increase the congestion in resolving which students will go to which schools, since without a central clearinghouse, more students will receive multiple admissions that will take time to resolve.

related labor markets, and in school choice. But they have remained a relatively rare form of marketplace in the economy at large.

One feature of the markets that have adopted these clearinghouses is that almost all the positions to be filled become vacant at the same time, and most of the applicants for these positions come from an easily identified set of candidates, who apply for very few other kinds of positions and who make up the lion's share of those hired for these positions. (Thus, most medical graduates go on to residency positions, most medical subspecialty fellowships are filled by candidates who have already become certified in the underlying specialty, most eighth graders need to be assigned to high schools, etc.) Prior to adopting a centralized clearinghouse, each of these markets also struggled with establishing and maintaining thickness and/or dealing with congestion.

Another reason we don't see so many centralized clearinghouses may be that when preference formation is very costly, eliciting preferences in advance may not be feasible. For example, in senior labor markets, preferences over possible positions may involve additional searches, for jobs for spouses and schools for children. These additional searches may often be too costly to launch over a wide range of possible positions, and so may be feasible only late in the recruiting process, or following receipt of a job offer, when the search can be focused on a small number of possibilities. Similarly, when employers consider very diverse pools of candidates, or candidates consider very diverse kinds of employment, the difficulties in organizing participation in a clearinghouse by the relevant candidates and firms may be insurmountable. As a practical matter, an existing marketplace often has to be performing very badly before a major reorganization becomes attractive to many participants, since otherwise it is difficult for a redesign to be a Pareto improvement that lifts all boats or most of them (and because some market participants may have invested in dealing with the current market environment).<sup>72</sup> So there will be markets for which this kind of centralized clearinghouse may not be feasible, as well as those for which this form of organization may not be appropriate.<sup>73</sup>

<sup>72</sup>For example, when appellate judges are hiring future clerks in their third year of law school, judges in less prestigious circuits may prefer a market in which they can go earlier than the rules permit, but when clerks are being hired in their first year of law school, all judges may prefer a system of late hiring. Similarly, when the market for gastroenterology fellowships was unraveled, it also broke into many local markets, with fellows often being hired by programs at the hospital at which they did their internal medicine residency. This could work to the advantage of a not so prestigious fellowship program at a hospital with a top residency program, so moving to a later, more national market was likely not a Pareto improvement, and faced some opposition from such programs.

<sup>73</sup>For example, new MBA's find work with a large variety of employers, whose hiring also includes many other kinds of candidates, so the problem of coordinating a centralized clearinghouse for MBA employment would be difficult. It would likely also be difficult to coordinate a clearinghouse that worked from submitted preferences for new assistant professors, because preference formation is very costly for departments (involving flyouts and seminars attended by the full faculty), so it seems likely that many departments would not prefer having to form longer lists of preferences. However admissions of students at various points in their education (undergraduates, graduate students, and students in professional schools like medicine, law, and business) all seem like candidates for a centralized match, since they all suffer to some extent from congestion. It may be, however, that the current problems are not severe enough to motivate widespread enthusiasm for changing existing admissions practices. There may also be markets in which matchings based on (prior) preferences may be considered undesirable. For this reason, Duke University decided to no longer allow first-year undergraduate students to participate in choosing their roommates, and instead now plans to match roommates randomly, to produce more diverse matchings (see <http://marketdesigner.blogspot.com/2018/03/duke-switches-to-random-roommate.html>).

There's still a lot to learn about the range of markets that could benefit from centralized clearinghouses, and, more generally, which forms of marketplaces best facilitate which kinds of markets.

But that question supposes that we want to facilitate markets. There are often markets that a substantial number of people wish to impede or prevent entirely, but that others wish to participate in. These present different kinds of market design problems.

#### IV. Repugnant Transactions, Forbidden Markets, and Black Markets

Tastes differ, so it is not surprising to find transactions that some people find appealing and others find appalling.<sup>74</sup> More puzzling are transactions that some people would like to engage in but that others would like to forbid, even when negative externalities are hard to identify or measure. I'll reserve use of the word "repugnant" for these latter kinds of transactions, as in Roth (2007).

Same-sex marriage is an example of such a transaction: two people would like to marry each other, while others don't think they should be allowed to. Laws and customs preventing same-sex marriage have been struck down around the world in recent decades, amid considerable political turmoil. In the US, these laws fell state by state through a combination of court decisions, legislation, and referenda, culminating in a Supreme Court decision in 2015 making same-sex marriage legal in every state. (This decision came a half-century after the Supreme Court decision that legalized interracial marriage in every state.)<sup>75</sup>

Laws that criminalize or strictly limit transactions sometimes contribute to the design of black markets. For example, in the United States it was illegal to sell most alcohol during Prohibition (1920–1933), and today prostitution and narcotic drugs like heroin are broadly illegal throughout the United States. But black markets for alcohol were widespread during Prohibition, and both sex and narcotics are readily found for sale in many American venues today.

Markets for drugs provide a clear example of how illegal markets can thrive. Under American law, opioids and other drugs with a high potential for abuse and addiction are legally classified as either Schedule I drugs, like heroin, which have no currently accepted medical use in the United States, or Schedule II drugs, like oxycodone and fentanyl, which are available as prescription painkillers, but cannot be sold or administered legally except when prescribed by a physician.<sup>76</sup> The law provides severe penalties for sale, resale, or inappropriate prescription of such drugs, and is vigorously enforced—often with mandatory minimum sentencing laws—so

<sup>74</sup>For example, foods made from edible insects are available for sale in the United States, but are not widely purchased: see Ambuehl (2017) for an experiment in which consumption of edible insects is explored not only as distasteful to some, but also as a potentially repugnant transaction in which some people would prevent others from participating.

<sup>75</sup>The Supreme Court decision that legalized same-sex marriage was *Obergefell et al. v. Hodges, Director, Ohio Department of Health, et al.*, which was decided June 26, 2015. The decision that struck down state laws against interracial marriage was *Loving v. Virginia*, decided June 12, 1967.

<sup>76</sup>See Title 21 Code of Federal Regulations, Part 1308—Schedules Of Controlled Substances, <https://www.dea-diversion.usdoj.gov/21cfr/cfr/2108cfr.htm>. I will concentrate here on opioids, although the drug crises in America include other classes of drugs, including stimulants like amphetamines and cocaine, and psychoactive drugs like benzodiazepines (see, e.g., Shiels et al. 2017, and Lembke, Papac, and Humphreys 2018), not to mention performance-enhancing drugs like steroids and peptides that enhance athletic endeavors.



that American prisons are filled with people convicted of drug offenses. The Federal Bureau of Prisons reports as of January 2018 that 46 percent of all inmates were convicted of drug offenses.<sup>77</sup> Yet there are over 60,000 deaths a year from opioid overdoses in the United States. And users have large strategy sets: these deaths are split between Schedule I drugs like heroin and Schedule II prescription opioids. That is, opioids can be supplied both by criminal organizations that produce the drugs, and by the diversion or misuse of legal prescription drugs.<sup>78</sup>

There is of course a simple economic model of rational crime and addiction that predicts that if the penalties are high enough, very few people will sell drugs illegally or use them, so that the prisons will be virtually empty and deaths from overdoses will be minimal. But that is not what we are seeing: there is some flaw in that market design.

Yet not every badly functioning market is ripe for redesign.<sup>79</sup> Sometimes the political and social obstacles to a good design, that historically caused a market to work poorly, persist. Thus, although there is a much bigger problem with opioids in the United States than in Europe (where there are fewer overdose deaths, and substantially less prescription of pain relief medicines), there is no clear politically feasible path forward for American policymakers who might wish, e.g., to decriminalize narcotic addiction as in Portugal (Greenwald 2009), where the legal options successfully divert customers from the illegal ones. The most likely regulatory avenues to limit legal opioids will involve changing prescription practices to treat pain much less, or very differently (as is the case in many other countries).<sup>80</sup>

Modest marketplace design changes in how we deal with the opioid crisis may be more quickly attainable (but by no means politically easy). Steps to reduce the harms of the drug markets are being explored in various venues. The most widely supported of these in the United States are needle exchanges to reduce the spread of infectious diseases among intravenous drug users (US Department of Health and Human Services 2016). More controversial are “drug checking” to allow purchasers of illegal drugs to have them tested for purity and potency (Hungerbuehler, Bhecheli, and Schaub 2011), and supervised injection facilities to promote safer drug injection practices and monitor potential overdoses (Potier et al. 2014). All of these are “harm reduction” measures intended to acknowledge the presence of active black markets, and to respond with modifications of these illegal marketplaces to give their participants access to some ancillary infrastructure and services from legal sources.<sup>81</sup>

<sup>77</sup> See [https://www.bop.gov/about/statistics/statistics\\_inmate\\_offenses.jsp](https://www.bop.gov/about/statistics/statistics_inmate_offenses.jsp). The US Drug Enforcement Administration also pursues criminal cases against physicians accused of selling or prescribing scheduled drugs outside accepted medical treatment, often resulting in prison sentences: see [https://www.dea.gov/divisions/criminal/crim\\_admin\\_actions/doctors\\_criminal\\_cases.pdf](https://www.dea.gov/divisions/criminal/crim_admin_actions/doctors_criminal_cases.pdf).

<sup>78</sup> See, e.g., Dowell, Noonan and Houry (2017) and <https://www.cdc.gov/drugoverdose/data/analysis.html>. See also Schnell (2017) and Evans, Lieber, and Power (2018) on interactions between black markets and prescription practices and drug (re)formulation in legal markets, and Schnell and Currie (2018). The negative effects of the drug crises in the US are not limited to the US: the supply chain is worldwide, and drug cartels have in some times and places assumed state-like political and even military powers.

<sup>79</sup> There are also calls, including by US President Trump, not for redesign but for increasing the penalties in the current design (Lemire and Superville 2018).

<sup>80</sup> Note that the discussion is complicated by periodic shortages of pain medicines, such as injectable opioids available to hospitals and hospices. For example, as of this writing see Morphine and some other opioids on the Food and Drug Administration’s list of drug shortages: <https://www.accessdata.fda.gov/scripts/drugshortages/>.

<sup>81</sup> None of these harm reduction ideas are uncontroversial or politically easy to implement. Many of the studies reviewed in Potier et al. (2014) come from Canada and Australia, while some reports from the United States come

Just as legal markets require social support to thrive, laws banning markets require social support to have a good chance to be effective. In the United States, marijuana is still a banned Schedule I drug under Federal law.<sup>82</sup> But after a long history as a popular illegal drug, 30 states and Washington, DC have legalized marijuana in some forms and for at least some uses, and legalization has proceeded in other countries as well.<sup>83</sup> And just as small marketplaces have to accommodate themselves to large markets, small banned markets are influenced by adjacent legal marketplaces.<sup>84</sup> For example, as of this writing, marijuana remains banned in Idaho, which shares borders with three states (Washington, Oregon, and Nevada) in which marijuana is legal for recreational use, and three more (Utah, Wyoming, and Montana) in which some uses of marijuana are legal. I anticipate that enforcement of Idaho's ban will become more difficult.<sup>85</sup> There are indications that legalization has resulted in harm reduction: it appears that competition from legal suppliers of marijuana has reduced violent crime in the United States connected with imports of marijuana by criminal organizations in Mexico (Gavrilova, Kamada, and Zoutman forthcoming).

Among the oldest repugnant markets are markets for sex.<sup>86</sup> Prostitution is called the oldest profession,<sup>87</sup> and there is a long history of largely failed attempts to eliminate it. In many countries prostitution (the selling of sex) is a criminal offense. In Iceland, Norway, and Sweden the *purchase* of sex has lately been criminalized while the *sale* has been decriminalized, and in many countries the participation of third parties ("pimps" or brothels) is outlawed even when the purchase and sale of sex is legal in at least some venues.<sup>88</sup> In the United States, prostitution is widely illegal,

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from sites that are not themselves fully legal; see, e.g., Kral and Davidson (2017) on an "Unsanctioned Supervised Injection Site in the US." But see Massachusetts Medical Society (2017) for a proposal to set up a pilot program in the United States. Opponents argue that harm reduction may make drug use more socially acceptable and widespread, or even that reducing the risk of death and disease may lessen the disincentives and lead to a growth of addiction.

<sup>82</sup>Marijuana (spelled "Marihuana" in Schedule I) seems no longer to fit the legal definition of a Schedule I drug. Although high quality clinical evidence is not yet available for many therapeutic uses, marijuana is now often prescribed by doctors for relief of pain, and of nausea accompanying chemotherapy, and for these uses the evidence of therapeutic benefits is judged to be "substantial" or "conclusive" (National Academies of Sciences, Engineering, and Medicine 2017, <https://www.nap.edu/read/24625/chapter/6>). Marijuana is even sometimes prescribed together with opioid painkillers to reduce their required dose (Cooper et al. forthcoming). The United States is not the only country with seemingly contradictory laws about marijuana. In the Netherlands, it is legal to buy and sell marijuana, but not to grow it, and so "coffeeshops" legally licensed to sell marijuana must purchase their supplies on the black market (Schuetze 2018).

<sup>83</sup>See <http://www.governing.com/gov-data/state-marijuana-laws-map-medical-recreational.html> and <https://marketdesigner.blogspot.com/search/label/marijuana>.

<sup>84</sup>Conversely, small legal markets also have to adapt to neighboring illegal markets. For example, the Netherlands, where marijuana can legally be sold, eventually restricted sales outside of Amsterdam to be only to Dutch residents, to reduce the flow of what was viewed as undesirable "drug tourism" from elsewhere in Europe, and this was eventually upheld by the courts as consistent with EU regulations (Court of Justice of the European Union 2010).

<sup>85</sup>In a similar way, states and municipalities in the United States that seek to enforce controls on the sale and possession of guns face difficulties related to the much freer availability of guns in other jurisdictions.

<sup>86</sup>Not all prostitution involves a willing seller, as markets for sex can involve human trafficking of coerced participants including children (Kotrla 2010). This is a large issue in any discussion of prostitution, often complicated, and made contentious by related issues having to do with the rights of sex workers (see, e.g., Butcher 2003; Kempadoo, Sanghere, and Pattanaik 2015). Some of the references for my discussion here can be found at <https://marketdesigner.blogspot.com/search/label/sex>.

<sup>87</sup>See, e.g., a venerable expression of this thought in Kipling's 1893 story "On the City Wall," which begins "Lalun is a member of the most ancient profession in the world."

<sup>88</sup>For a summary of international laws on the sale of sex, see <https://prostitution.procon.org/view.resource.php?resourceID=000772>. The site contains a country by country summary, with these high level summary statistics of the countries considered: Legal in 49; Limited Legality in 12; Illegal in 39; Total: 100.

with the exception of some counties in Nevada, and a period of legal indoor prostitution in Rhode Island from about 2003 to 2009, following a 2003 judicial decision involving an apparent oversight in an amended anti-prostitution law that defined prostitution as involving outdoor solicitation, which was rectified in 2009 to make both the buying and selling of sex illegal in any venue.

There is evidence that decriminalization confers some harm reduction. Cunningham and Shah (forthcoming) report that the period in which indoor prostitution thrived in Rhode Island resulted in fewer sexual crimes and lower rates of sexually transmitted disease. Similar results regarding crime in the Netherlands are reported by Bisschop, Kastoryano, and van der Klaauw (2017) following the establishment of regions (“tippelzones”) in which licensed prostitutes could legally solicit customers on the street.

The market for sex has many marketplaces.<sup>89</sup> It appears that outdoor solicitation (“streetwalking”) is the most dangerous of these for sex workers, in terms of encounters both with violent customers and with law enforcement.<sup>90</sup> Some of the more discreet markets are hard for law enforcement to successfully prosecute.

For example, Elliott Spitzer resigned as Governor of New York State after just one year, after being reported as a customer of an “escort agency” called the Emperor’s Club.<sup>91</sup> Only the organizer of that agency was convicted of a crime. But although Spitzer was never charged, the repugnance felt toward prostitution is reflected in the speed with which his political career ended. *The New York Times* broke the story on March 10, 2008 with the headline “Spitzer Is Linked to Prostitution Ring.”<sup>92</sup> Just two days later, the headline was “Spitzer Resigns, Citing Personal Failings.”<sup>93</sup>

Part of the negative reaction to Spitzer’s patronization of prostitutes was that he had prosecuted prostitution when he was Attorney General. One of the organizations Spitzer had prosecuted adopted the market design that gives rise to the expression “call girls.” It operated by phone, and customers called to arrange that sex workers would come to them.

The internet has provided the newest marketplaces for prostitution, and between 2002 and 2010 one of the most active internet marketplaces was Craigslist’s “erotic services” ads. Craigslist eventually closed this section in response to pressure from legal authorities who threatened prosecution for violating the anti-prostitution laws. However, Cunningham, DeAngelo, and Tripp (2017) use the different times at which this service was introduced in different cities to estimate that it reduced the female homicide rate by 17 percent. They attribute this to a reduction in street solicitation, as prostitutes who would formerly have tried to find clients outdoors were able to

<sup>89</sup>In addition to the marketplaces for sexual acts discussed here, there are also marketplaces for pornography, i.e., for the depiction of sexual acts (Edelman 2009).

<sup>90</sup>Potterat et al. (2004) estimate that the workplace homicide rate for female prostitutes in Colorado is 204 per 100,000.

<sup>91</sup>“Escort agency” is both a euphemism and an indication of why prostitution can sometimes be a hard market to prevent. Escort agencies purport to sell nothing more than companionship, and there are few remaining laws about what adult companions can consent to do with each other.

<sup>92</sup>Danny Hakim and William K. Rashbaum, “Spitzer Is Linked to Prostitution Ring,” *New York Times*, March 10, 2008, <http://www.nytimes.com/2008/03/10/nyregion/10cnd-spitzer.html>.

<sup>93</sup>Michael M. Grynbaum, “Spitzer Resigns, Citing Personal Failings,” *New York Times*, March 12, 2008, <http://www.nytimes.com/2008/03/12/nyregion/12cnd-resign.html>

screen them more reliably if the initial contacts were through email.<sup>94</sup> So there also seem to be some harm reduction benefits of moving marketplaces for prostitution off the street.

Another market that is repugnant and legally limited or banned in many venues, but is fully legal in others, is surrogacy, i.e., the market for someone to bear a child for someone else. The most usual form is gestational surrogacy, in which a woman agrees to be impregnated with a fertilized egg, and to bring the child to term. In this kind of surrogacy, the pregnant surrogate mother is not genetically related to the child. The surrogate parents, i.e., the parents who intend to assume parental rights and raise the child, may have contributed both sperm and egg, or just the egg, or just sperm, or have obtained the fertilized egg with the help of both a sperm and egg donor. Male couples are often clients in surrogate pregnancies, since they have no womb between them. However single parents and heterosexual couples can also be clients for a variety of medical and other reasons.<sup>95</sup>

In some jurisdictions (including much of Western Europe), surrogacy is illegal, and there are legal obstacles that may make it difficult for parents to repatriate a surrogate child born elsewhere. An extreme example comes from Italy, where the courts removed a surrogate child from the parents' custody and placed it with a social service agency for subsequent adoption. (In this case the surrogate parents were not genetically related to the child.) The European Court of Human Rights (ECHR) ruled that Italy was within its rights "to reaffirm the State's exclusive competence to recognize a legal parent-child relationship" (ECHR 2017). But the urge to have children is strong, and adoption is not a perfect substitute, so families are also willing to take extreme measures. Sweden, where surrogacy is illegal, has been a pioneer in womb transplantation, for example.

In other places, for example England and Canada and some American states, surrogacy is legal but "commercial surrogacy" is not: i.e., it is illegal to pay the surrogate mother (although some expenses may be reimbursed). This severely limits the availability of surrogates in these places, mostly to family members, so that for example a woman's mother may become her surrogate, and give birth to her own (the surrogate's) grandchild. Other limitations on surrogacy limit its reliable use in family planning: in England and Canada the birth mother (i.e., the surrogate) is the legally presumed mother of the child, and is not allowed to give up her maternal

<sup>94</sup> Unsurprisingly, shutting down Craigslist's erotic services marketplace did not shut down the internet as a marketplace for prostitution. A site called Backpage largely replaced it, and it in turn was subject to legal pressure, including arrest of its executives and several prosecutions, against which Backpage was able to successfully defend itself by invoking (among other defenses, including Constitutional protection of the press) the protections of the 1996 Communications Decency Act, which defend internet providers from liability for content posted by users. In 2018 the Senate passed (by a vote of 97 to 2) and the President signed the *Fight Online Sex Trafficking Act of 2017*, as previously passed by the House of Representatives. It amends the Communications Act of 1934, "to clarify that section 230 of such Act does not prohibit the enforcement against providers and users of interactive computer services of Federal and State criminal and civil law relating to sexual exploitation of children or sex trafficking..." (<https://www.congress.gov/115/crpt/hrpt572/CRPT-115hrpt572-pt1.pdf>). In a parallel development, on April 6, 2018 the content of the Backpage site was replaced with a notice beginning "Backpage.com and affiliated websites have been seized as part of an enforcement action by the Federal Bureau of Investigation, the US Postal Service Inspection Service, and the Internal Revenue Service Criminal Investigation Division, with analytical assistance from the Joint Regional Intelligence Center." The accompanying indictment (<https://www.justice.gov/file/1050276/download>) suggests that the proprietors of Backpage.com may have helped write the site's content, and thus may not have been protected by the Communications Decency Act.

<sup>95</sup> See <http://marketdesigner.blogspot.com/search/label/surrogacy> for a collection of articles and links that supply the background for my remarks on surrogacy.

rights until some days after the child is born. It of course happens in some cases that the surrogate chooses to retain parental rights, including custody of the child.

For these reasons and others, there is a lively market in “fertility tourism” to places where surrogacy is legal and reliable, such as California. In California there are reliable commercial contracts that permit surrogate parents to pay a surrogate, and be named as parents on the California birth certificate.<sup>96</sup>

There have also been thriving markets for surrogacy in Asia, but some of the countries that hosted many fertility tourists are now outlawing commercial surrogacy for foreign parents.

Thus, the repugnance associated with surrogacy is complex.<sup>97</sup> Some repugnance focuses on issues related to the rights of children and the regulation of family formation, while other concerns focus on the rights of surrogates, and the potential that they can be exploited. These latter concerns motivate laws against compensating surrogates. Note that in jurisdictions that permit surrogacy but forbid compensation, a transaction that is apparently not repugnant when supplied for free becomes repugnant when money is added. This isn’t such an uncommon distinction, (e.g., prostitution is banned in many places where promiscuity is allowed, and charging interest on loans was repugnant in the middle ages, although loans were allowed), and is related to concerns about exploitation and coercion.<sup>98</sup> Similar concerns arise in connection with bans against compensating kidney donors.

## V. Kidney Exchange

Kidney failure (End Stage Renal Disease, or ESRD) is a major cause of death in both the developed and developing world. Care for ESRD is a \$50 billion a year industry in the United States, and takes up about 7 percent of the Medicare budget. Transplantation is the treatment of choice: dialysis can extend a patient’s life but is hardly a cure for ESRD, while most patients can resume an essentially healthy life after receiving a transplant (Liyange et al. 2015; USRDS 2017).

Around 100,000 American patients are on the waiting list for a deceased donor transplant, but in 2017 only about 14,000 deceased donor kidneys were transplanted, while around 8,000 patients either died while waiting or were removed from the waiting list after becoming too sick to transplant. Healthy people have two kidneys and can remain healthy with one, so live donation is a very practical possibility, and in 2017 almost 6,000 living transplants were performed in the United States.<sup>99</sup>

<sup>96</sup>The typical surrogate in California is a married mother, and representative payments quoted by agencies begin around \$35,000 plus benefits to the surrogate, and additional fees for the clients. Matching of intended parents and surrogates is also involved.

<sup>97</sup>Note also that repugnance concerns can’t be simply ordered by some kind of “degree of repugnance,” since, e.g., prostitution is legal and surrogacy is illegal in Germany, while the reverse is true in California.

<sup>98</sup>The idea that high payments can be coercive (and that people can be exploited by offering them too much money) is one that often causes economists and ethicists to speak at cross purposes. Ambuehl, Niederle, and Roth (2015) find that a non-trivial minority of surveyed subjects share this intuition, a result replicated and extended by Leuker et al. (2018). Ambuehl (2017), Ambuehl and Ockenfels (2017), and Ambuehl, Ockenfels, and Stewart (2018) explore the way large payments change not only the decision but the decision processes of experimental subjects, and draw conclusions about how informed consent faces extra challenges when the payments are very salient. These papers bridge some of the gap in the discussion of “coercion” in the ethics and economics literatures.

<sup>99</sup>See <https://optn.transplant.hrsa.gov/data/view-data-reports/national-data/#>.

Two facts strike an economist looking into kidney transplantation for the first time. There is a dramatic shortage of organs compared to the need. And it is against the law almost everywhere in the world to pay a living kidney donor, or the family of a deceased donor, for a donation. By law, kidneys must be gifts, offered at a price of zero.

Becker and Elías (2007) argue that repealing the laws against paying donors could solve the organ shortage, and estimate that the market clearing price would be low. Held et al. (2016) estimate that the amount that the American healthcare system would save from each additional transplant and could therefore afford to pay for a kidney donation would be much higher than needed to end the kidney shortage, because transplantation is both much cheaper and more beneficial than the alternative treatment of dialysis. These papers are part of a large literature arguing for or against compensation for donors, not only of organs for transplant, but of other parts related to the body, like blood and blood plasma, sperm and eggs, surrogacy, etc.<sup>100</sup> However, only one country in the world, Iran, has a market in which living kidney donors can legally be paid.<sup>101</sup> Everywhere else, it is illegal to compensate donors, although there are active black markets. So buying and selling kidneys is a repugnant transaction in the sense I described earlier.

*Kidney exchange* is a way to increase the number of organs available for transplant without paying donors. Sometimes a person is healthy enough to donate a kidney, and would like to donate to a loved one but cannot, because not every kidney is compatible with every patient. In the past, a patient with a willing but incompatible living donor would have to continue to wait for a deceased donor, but the idea of kidney exchange is that two incompatible patient-donor pairs could exchange kidneys, so that each patient would receive a compatible kidney from the other patient's donor. This was first suggested by a surgeon who studied transplant incompatibility (Rapoport 1986), who proposed that an international registry of incompatible patient-donor pairs be established to facilitate kidney exchange. The first kidney exchanges were not performed until the 1990s, and interestingly the first kidney exchange in Europe was between two pairs of different nationalities: Swiss and German. When the surgeries were reported in Theil et al. (2001), some German critics compared it to organ trafficking, and indeed repugnance almost completely prevents kidney exchange in Germany up to the present time.<sup>102</sup> For the early history of kidney exchange, see Wallis et al. (2011).

<sup>100</sup>Leider and Roth (2010) note that repugnance to kidney sales is mild compared to repugnance to prostitution in a survey of a structured sample of Americans, and Elias, Lacetera, and Macis (2015) note that whether survey respondents register repugnance for donor compensation is sensitive to how the questions are framed. On blood, see Lacetera, Macis, and Slonim (2012, 2013). For other links, references, and proposals, see <http://marketdesigner.blogspot.com/search/label/compensation%20for%20donors>. One strand of the literature considers market designs that might allow donors to be paid without running into the widespread repugnance barriers that exist. See, e.g., Niederle and Roth (2014), who consider whether rewarding the heroism involved in living kidney donation might be more acceptable than paying for a kidney.

<sup>101</sup>The legal market in Iran appears to be one in which the donor/sellers nevertheless suffer from the kind of stigma that, e.g., sex workers continue to suffer in places where prostitution is legal. See Miresghhi (2016), Fry-Revere et al. (2018), and Nayebpour and Koizumi (2018) for surveys of kidney donor/sellers in Iran. See also <http://marketdesigner.blogspot.com/search/label/Iran>.

<sup>102</sup>For some of the contemporaneous press coverage, see Berndt (2001) and Ludwig (2001), and for some contemporary discussion of how German law very largely prevents kidney exchange, see <http://marketdesigner.blogspot.com/2016/03/transplants-in-germany-further.html>.

In the United States, the first kidney exchange occurred in 2000, and, soon after, Utku Ünver, Tayfun Sönmez, and I started to formulate ways in which exchanges could be organized on a larger scale (Roth, Sönmez, and Ünver 2004, 2005b, 2007, and Roth et al. 2006). We considered how to organize exchanges between different numbers of patient-donor pairs, and in potentially long non-simultaneous chains started by a non-directed donor (i.e., a donor who does not have a particular patient in mind). We helped our surgical colleagues, led by Frank Delmonico, to found the New England Program for Kidney Exchange (NEPKE) to build a database of patient donor pairs and facilitate exchange at scale among the 14 transplant centers in New England (Delmonico et al. 2004; Roth, Sönmez, and Ünver 2005b).

Today, kidney exchange has become established as a standard mode of transplantation in the United States, and is growing around the world.<sup>103</sup> But initial progress was slow. By the end of 2007, NEPKE had facilitated only 22 transplants.<sup>104</sup> It became clear that effective market designs were going to have to deal with the detailed operations of kidney exchange marketplaces, and not just with their overall architecture.

The logistics of trades among cycles of patient-donor pairs are subject to congestion (since all parts of the exchange need to be conducted simultaneously), and so there has been increased attention to the chains of transplants started by a non-directed donation, which don't have to be performed simultaneously. (Since a non-directed donor does not have a particular patient in mind, he or she can initiate a chain of transplants by donating to a patient in a pair waiting for a kidney exchange, whose donor gives to someone else and so on. Each incompatible patient-donor pair receives a kidney before they donate their own, so that no pair bears the risk that a broken link in the chain would leave them still needing a transplant but no longer having a kidney to exchange.) The first such chain was organized by the Alliance for Paired Donation (APD), and reported in Rees et al. (2009). One of the big operational issues was how to manage the sometimes long non-simultaneous chains that became possible. These chains were initially controversial, but early experience together with computational simulations from clinical data, paying careful attention to how such chains could be organized, eventually allowed them to become standard practice (Ashlagi et al. 2011a, b).<sup>105</sup>

As chains became national in scope, hospitals with different costs started shipping kidneys to each other, and there were some financial frictions (e.g., one hospital might charge much more than another for a nephrectomy, which could make

<sup>103</sup> In 2017 in the United States, 715 kidney exchange transplants were officially recorded, and these are 12 percent of the 5,811 living donor transplants, not counting the non-directed donors who begin chains of transplants. There were also 256 anonymous non-directed donations (not all of whom will have started chains of exchanges). See <https://optn.transplant.hrsa.gov/data/view-data-reports/national-data/>. Kidney exchange is becoming well established in Australia, Britain, and the Netherlands, and is growing elsewhere in Europe (see Biró et al. 2017), and in India (see Kute et al. 2017). See also <http://marketdesigner.blogspot.com/search/label/kidney%20exchange>.

<sup>104</sup> See <http://web.archive.org/web/20080206202158/http://nepke.org/>. Even by the time it ceased operation in 2011 to become part of the national kidney exchange pilot program operated by the federal Organ Procurement and Transplantation Network, NEPKE had only facilitated 83 transplants (<http://web.archive.org/web/20110905220442/http://nepke.org/>).

<sup>105</sup> Managing chains as well as exchanges in closed cycles (entirely among patient-donor pairs) also strained the integer programming solvers, and so there has been progress on that front as well, from the original formulation in Roth, Sönmez, and Ünver (2007), with advances in optimization by Abraham, Blum, and Sandholm (2007) and (as chains have become long) by Anderson et al. (2015). See also Manlove and O'Malley (2012) and Dickerson et al. (2016).

it difficult for them to bill each other for their costs). Proposals to overcome such frictions have to date been implemented only partially (see Rees et al. 2012).

Fumo et al. (2015) discuss many incremental design changes made over the years by the APD. Many of these were related to the fact that an optimized kidney exchange involves many particular proposed transplants, each of which has to be individually approved by the surgeons and patients and donors involved. It can take time to get these approvals, and there were initially many rejections of proposed transplants, which made the kidney exchange process slow, and the marketplace congested.

Some sources of congestion and declined transplants were relatively simple to fix, e.g., by promptly updating the database so that no time is wasted proposing transplants for patients who may have already received a deceased donor transplant, or died.<sup>106</sup> Other sources of delay through rejected offers were more complex. Surgeons' preferences over kidneys are not so easy to elicit, because a kidney and its donor have many properties that can interact. It is difficult to entice surgeons to review in advance potential kidneys that they may never be offered: consequently many kidneys that are medically compatible may nevertheless be rejected. We have made partial progress on this by introducing a threshold language that allows surgeons to constrain the set of compatible kidneys that they can be offered, so that offers are more likely to be accepted.<sup>107</sup>

A different set of operational problems arose as transplant centers became accustomed to kidney exchange. Directors of transplant centers have bigger strategy sets than individual surgeons, since they see multiple patient-donor pairs and can choose which ones to enroll in an interhospital exchange. Ashlagi and Roth (2014) note that transplant centers may have incentives to withhold their easy to match patient-donor pairs from the interhospital exchanges, and transplant them internally, and Agarwal et al. (2017, 2018) observe that this is in fact happening to a surprisingly large degree (they report that more than one-half of kidney exchanges are done internally).<sup>108</sup> This reduces the thickness of the inter-hospital kidney exchange marketplaces, not only because it reduces the number of pairs that they enroll, but because it means that those that do enroll may have difficulty finding donors and recipients

<sup>106</sup>This kind of congestion, involving time-consuming efforts to match with many possible partners, some of whom may no longer be available, is found in many kinds of matching markets, from dating sites to labor markets (see, e.g., Arnosti, Johari, and Kanoria 2016). Other sources of delay involved the blood and serum samples that must be exchanged to verify that a proposed transplant that looks feasible from the available data is in fact feasible, and some of these were addressed by centralizing the blood work done for the APD.

<sup>107</sup>Using thresholds in this way substantially reduces but by no means eliminates discretionary rejections of proposed transplants. For example, in an effort to be offered many possible transplants, a surgeon may indicate that kidneys for a particular patient will be considered, e.g., from donors up to age 60, and with slightly higher than optimal blood pressure or weight, and slightly suboptimal kidney function, etc., only to reject proposed transplants that meet all of those stated constraints. The reason of course is that preferences are over combinations of attributes: when the surgeon specified a 59-year-old donor would be acceptable, he or she had in mind a former Olympic athlete who had stayed in perfect shape, and for a donor with elevated blood pressure a 25-year-old is desired, etc.

<sup>108</sup>Ashlagi and Roth (2014) note that some of these disincentives can be removed by changing the allocation algorithm to give "frequent flier" priority to pairs from transplant centers that enroll easy to match pairs. NKR was the first kidney exchange network to subsequently introduce such priorities, but this is not yet widespread, except for keeping track in this way of centers that enroll non-directed donors to initiate chains of transplants. In another use of priorities, Israel has started to incentivize deceased donation by giving priority on the waiting list to people who are registered donors, and to the family members of deceased donors (see Stoler et al. 2016, 2017).



with whom to match.<sup>109</sup> This is one of the reasons that non-directed donors and potentially long chains are so useful: a high concentration of hard to match pairs means that few simple exchanges between two pairs will be feasible (and these are the exchanges that are further removed from the interhospital marketplace because they can be transplanted internally by their own transplant center).<sup>110</sup>

Throughout these developments (and unlike the situation in Germany), kidney exchange faced little repugnance in the US, although this wasn't initially obvious. The National Organ Transplant Act (NOTA) of 1984 specifies that "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." This raised a potential barrier to kidney exchange, if a kidney in return for a kidney is viewed as "valuable consideration" of the kind precluded by the NOTA. The Department of Justice initially declined to issue an opinion on the legality of kidney exchange. But as kidney exchange began to be performed, Congress was prevailed upon to amend the NOTA via the Norwood Act (Public Law 110-144, 2007), which said that the sentence about valuable consideration "does not apply" to kidney exchange.<sup>111</sup>

Kidney exchange is one of few examples that achieve the triple aim of healthcare reform: improved care, reduced cost, and increased access. There is still work to do to make kidney exchange marketplaces work better.<sup>112</sup> But if I stopped here, it could appear as if the story were a simple one, of victory after victory for market design and kidney exchange.

But these victories come in a war that we are losing: there are more people waiting for kidney transplants today than there were when I first began to think about transplants.<sup>113</sup> So it will not be enough to keep improving the current operations of

<sup>109</sup> Patients can have trouble finding a donor if they are "highly sensitized" and have lots of antibodies that would cause most donor kidneys to be rejected. Donors can have trouble finding a compatible recipient mostly if they are blood type AB (while donors with blood type O are easy to match). The easiest to match pairs are those with unsensitized patients, and blood type O donors, while the hardest to match are those with very highly sensitized patients and not-so-easy to match donors.

<sup>110</sup> A related operational issue is that because new easy to match pairs are most efficiently used to match hard to match pairs, it turns out to make sense for kidney exchanges that operate beyond a certain scale to look for matches frequently, whenever new pairs are enrolled (Ashlagi et al. 2018). That is, in the clinical environment faced by the largest kidney exchange organizations (the National Kidney Registry, the APD, and the pilot program organized through UNOS), matching infrequently does not increase the effective thickness of the market. Increasing the rate of new arrivals would do this much more effectively. These conclusions depend on some of the particular details of kidney exchange marketplaces. Akbarpour, Li, and Gharan (2017) present an abstract model that allows some of the trade-offs between frequent and infrequent matching to be analyzed. Similar issues of matching frequency arise for marketplaces for other matching markets: see, e.g., the trade-off for ride-sharing markets between frequent and infrequent matching (with a trade-off between number and quality of matches) for ride-sharing for the Chinese service Didi Chuxing (Liu, Wan, and Yang 2018).

<sup>111</sup> Regarding the absence of repugnance, note that the Norwood Act ultimately passed without any dissenting votes in either the House or the Senate (<https://www.govtrack.us/congress/bills/110/hr710>). During the process of finalizing the Norwood Act, the Department of Justice finally did issue a memorandum with the legal opinion that kidney exchange had already been legal under the NOTA, see <http://web.stanford.edu/~alroth/JusticeDeptMemo.KidneyExchange.March2007.pdf>.

<sup>112</sup> Often the need to change kidney exchange marketplaces arises from adaptations that transplant centers make when deciding how to interact with kidney exchange, which are decisions they get to revisit for every patient-donor pair, and for which they have large strategy sets.

<sup>113</sup> See [https://www.nobelprize.org/nobel\\_prizes/economic-sciences/laureates/2012/roth-bio.html](https://www.nobelprize.org/nobel_prizes/economic-sciences/laureates/2012/roth-bio.html) for some recollections of those early days. Note that the rise in the number of people waiting for kidney transplants since the 1980s is a combination of bad news, such as an increase in diabetes, with good news, such as increased success in keeping kidney patients alive, and a drop in the number of auto accident fatalities that were once a larger source of deceased donors. (The largest single cause of death for deceased donors used to be "head trauma" and today it is "anoxia": see <https://optn.transplant.hrsa.gov/data/view-data-reports/national-data/>.)

existing kidney exchange organizations around the world. The large-scale further progress that is needed (while we wait until transplants are no longer needed) will depend on increasing the scale and scope of kidney exchange.

For example, given the substantial number of transplants produced by chains begun by living non-directed donors, it would be desirable to allow some chains to be initiated by deceased donors. Presently, virtually all deceased donors are non-directed, but each deceased donor kidney results in only a single transplant. Melcher et al. (2016) propose allowing chains to be initiated by deceased donors, which would require changes in regulation that are currently under consideration in the United States.<sup>114</sup> Increasing the average number of transplants from a deceased donor kidney even from one to two would more than double the reach of kidney exchange.

The approach that I think has the greatest possibility to reduce suffering from kidney failure—both in the developed world and in the developing world, where it is also major cause of death—is to expand kidney exchange globally, including to places where transplantation is not widely available because of financial constraints.<sup>115</sup> This is feasible because in the developed world transplantation is so much cheaper than dialysis that each transplant generates savings sufficient to pay for the inclusion of a foreign pair in kidney exchange, for free, including funds to pay for their long-term post-surgical care after returning home.<sup>116</sup> Rees et al. (2017a) set forth a proposal for Global Kidney Exchange (GKE), and report on the first foreign pair included in an American chain in this way.<sup>117</sup> That patient-donor pair was a married couple from the Philippines, where national insurance does not cover treatment for ESRD, but where high quality hospitals exist that can conduct transplants and care for patients and donors post transplant.

The reaction to the GKE proposal has included both support in the US and Europe, and vigorous opposition that finds GKE repugnant and equates it with illegal organ trafficking.<sup>118</sup> A related objection is that GKE would inevitably become entangled with black markets for kidneys in poor countries. Delmonico and Ascher (2017) write that ethical GKE with patient-donor pairs from the developing world “is not feasible when the culture is so experienced with organ sales.” They argue that efforts to ban kidney sales have failed to such an extent that transplanting patients

<sup>114</sup>The proposal for deceased-donor initiated chains met with an initially enthusiastic political reception (see <https://marketdesigner.blogspot.com/2016/06/white-house-organ-summit-video-and.html>), and is now wending its way more slowly through bureaucratic channels. In 2018 a deceased-donor initiated chain was reported in Italy (<http://marketdesigner.blogspot.com/2018/04/deceased-donor-kidney-exchange-chain-in.html>). It would also be useful to increase the supply of deceased donors. Other avenues that might possibly increase the scope of exchange involve including other organs in exchanges (see Dickerson and Sandholm 2017; Sönmez and Ünver 2017; Samstein et al. 2018).

<sup>115</sup>Liyanage et al. (2015) estimate that two to seven million people die every year worldwide due to inability to pay for dialysis or kidney transplantation.

<sup>116</sup>See Nikzad et al. (2018) for discussion of costs in the steady state, if GKE were to grow to the point that waiting times and hence dialysis costs were substantially reduced.

<sup>117</sup>That first pair received a kidney from an American non-directed donor who was blood type A, and in turn donated a kidney that continued a chain that included (at the time it was reported) another ten pairs. At their third anniversary after surgery, they were in good health at home, with an escrow fund that provided continued care, including immunosuppressive drugs for the recipient that are not covered by Philippine health insurance.

<sup>118</sup>See <https://marketdesigner.blogspot.com/search/label/global%20kidney%20exchange> for a blow by blow account, and see the further discussion in Rees et al. (2017b) and Roth et al. (2017).

from poor countries would result in paid donors infiltrating American health care in contrived guises as spouses and relatives.<sup>119</sup>

So, GKE, which is still in its earliest stages (six such chains have been accomplished as of this writing), is likely to face the full set of complications that kidney exchange has faced around the world. These include not only the market design issues involved in attracting participants, eliciting their information, and resolving analytic, computational, and operational obstacles, but also in garnering social support.<sup>120</sup>

In these respects, kidney exchange and its continued development represent issues that are typical of market design.

## VI. Open Questions, Engineering Challenges, and Opportunities

Markets and marketplaces, broadly understood, are woven into the fabric of the human environment, so opportunities to build new ones are ubiquitous, and there are still many unresolved scientific and engineering questions about how they work, and what makes them work well.

I've already mentioned open questions in the context of the particular markets I've discussed. More generally, what are the roles of marketplaces in markets? What properties of transactions, in addition to prices, do marketplaces help determine? Which markets are adequately organized without a coordinated marketplace (coordinated in time, or space, or both)? For which markets is a *centralized* marketplace desirable? For which markets does a *centralized clearinghouse* (possibly computer-assisted) offer additional benefits? Understanding what well-designed centralized marketplaces can accomplish will also illuminate how *decentralized* matching markets succeed and fail, how markets mediate inequality, and other questions underlying the organization of market economies.

**Computers** have begun to play multiple roles in marketplaces, no longer just as intermediaries or record keepers. "Smart marketplaces" help markets clear in ways that parallel-processing by participants could not. For example, there are computationally difficult problems involved in determining optimal kidney matchings, or in selecting optimal combinations of bids to maximize revenue in a complex

<sup>119</sup>This brings me back to black markets and harm reduction. Black markets for kidneys, which by law must be run by criminals, provide little if any subsequent care for donors, and are widely abhorred. (The larger question of whether compensation for donors should itself be abhorred is more controversial, as discussed earlier.) But if these illegal markets continue to thrive, should we view the poor medical care that compensated donors receive as a feature of the efforts to discourage compensation, or as a bug in our efforts to save potential kidney donors from exploitation and harm? I see parallels between this objection to GKE (which might possibly result in some paid donors receiving first-world medical care) and the debate about whether drug addicts should be protected from infection and overdose by harm reduction efforts like needle exchange and safe injection facilities, or whether those harms should be regarded as part of society's efforts to discourage drug use.

<sup>120</sup>I am encouraged in this endeavor by the support GKE has received in the countries from which patient-donor pairs have come. For example, see Carillo (2017), who reports on the first Mexican GKE pair in *Newsweek en Español*, in a cover story called "Un Puente de Vida," a bridge of life. (The first sentence, translated: "At the same time that US President Donald Trump is seeking to build a wall of thousands of miles on the border with Mexico, a tireless surgeon and a renowned economist join forces to exchange organs between citizens of both countries.") GKE has also received support from the American Society of Transplant Surgeons (see <http://marketdesigner.blogspot.com/2017/10/global-kidney-exchange-endorsed-by.html>) and Italy has proposed that it be adopted by the World Health Organization (see <http://marketdesigner.blogspot.com/2018/01/italy-recommends-global-kidney-exchange.html>).

auction for radio spectrum. Computational speed also helps deal with congestion. Ads can be matched with internet users by auctions that run quickly enough to keep up with internet attention spans, and stable matchings can be determined without delay. But computerized markets can also increase congestion by easing access, e.g., by increasing the number of job applications it is easy for a job seeker to send. How will computerized speed and intelligence influence the scope and scale of marketplaces? How will artificial intelligence and machine learning techniques help automate parts of market design?<sup>121</sup> Somewhat separately, as computers become increasingly important as infrastructure for markets and capital equipment for firms, markets *for* computation, such as cloud computing, may fundamentally change some of the make or buy decisions of firms, and how computers are owned and accessed.

**Privacy** issues arise with special force when markets are computerized, because computerized markets can create “big” data of participants’ behavior, both of conventional sorts (prices, transactions, buyers, sellers) and new sorts (e.g., clickstream and cookie data on search behavior, and location and social network data). There are already markets for these data, connected not only to advertising, but to other kinds of marketing (such as marketing candidates to voters). These data can be combined with other data in ways that allow individuals to be tracked in detail. So a big question for all marketplaces, but especially those that are computerized, is: how can and should privacy be preserved? A technical literature on differential privacy addresses the extent to which privacy can be preserved by databases that employ some randomness (see, e.g., Dwork and Roth 2014). Related questions have to do with markets for individualized data (or, conversely, privacy). These present important unresolved conceptual difficulties. For example, individuals’ privacy may be correlated with their value for privacy, i.e., a marketplace that allows individuals to implicitly or explicitly express a reservation value for their data may cause individuals to reveal their data even when they decline to sell it. As Ghosh and Aaron Roth (2015) put it: “An individual’s cost for privacy may itself be private information. Suppose that Alice visits an oncologist, and subsequently is observed to significantly increase her value for privacy...”

**Rules are data** for the study of how marketplaces are designed, and the computerization of marketplaces also gives us access to data on market rules, precisely encoded in algorithms and apps. Contracts are data too, and contracts are what is for sale in many marketplaces, including computerized marketplaces. The increased availability of precisely coded rules and contracts may lead to an explosion of empirical game theory, parallel to the growth of applied microeconomic research fostered by big datasets of individual behavior.

**Repugnance** and its causes and consequences are worth much further study. Economists often shrink from having third parties prevent voluntary transactions

<sup>121</sup> Compare to Milgrom and Tadelis (2018), who reflect on machine learning in spectrum auctions, and in identifying problematic sellers in online marketplaces. The smart marketplaces I’ve discussed already take steps in the direction of helping market clearing, and market designers working with AI will also have a chance to design the agents who participate in markets.

between informed adults if no negative externalities can be identified. But notice I say “adults.”<sup>122</sup> Children, particularly when they are small, may need to be prevented from harming themselves, and paternalism (“parentalism?”) is an obligation of being a responsible parent. When might society have such responsibilities toward ordinarily competent adults? To put it another way, when does repugnance point to important issues left out of many economic models?<sup>123</sup>

**Black markets** are often the result of banned markets. If we do decide that some markets are unacceptable, we need to better understand which markets can be banned effectively (like those for ozone-depleting chlorofluorocarbons), and which must just be accommodated or contained (like those for narcotics and prostitution). Two questions of a practical engineering sort are how should we best go about banning markets we can effectively prevent, and how should we limit the damage caused by repugnant markets we can’t prevent? For markets we can’t prevent, we need to understand when we should be regulating legal markets, and when we should be engaging in harm reduction in illegal markets, and to do this we need to understand in each case what we want, and what we can get.

Aside from questions about market design generally, many particular design issues present themselves. Here are two that seem to me particularly worth mentioning.

**Refugee resettlement** and large-scale human migration present some of the most pressing engineering problems facing market design. Although recent political upheavals around the world suggest that immigration may arouse considerable repugnance among some members of host populations, it is clear that resettlement of refugees and migrants is a matching problem. Refugees can’t simply choose where they wish to go, but neither can national and international authorities simply tell them where to settle (Roth 2015b). Once refugees have been granted asylum in a particular country, we need to figure out how to settle them in cities, and housing, and jobs in ways that will allow them to effectively integrate into the host country economy and society. This has a resemblance to school choice, but the differences are as important as the similarities (cf. Delacretaz, Kominers, and Teytelboym 2016; Andersson and Ehlers 2017; Andersson, Ehlers, and Martinello 2018; Bansak et al. 2018; and Jones and Teytelboym forthcoming).<sup>124</sup> A more difficult problem may be matching refugees and migrants to host countries (cf. Moraga and Rapoport 2015a, b; and van Basshuysen 2017). What is clear is that our present methods for handling human migration leave a lot to be desired: we need to learn to do this better (especially if sea level rises in the coming century).

<sup>122</sup>Note also that who is an “adult” may be applied differently in different places and for different purposes, e.g., for driving, drinking, voting, and holding elected office.

<sup>123</sup>One cause of repugnance is “unfairness,” a powerful but hard to define concept. One reason it is hard to define is that statistical fairness to populations is not the same as fairness to individuals (cf. Kearns et al. 2018). Another cause of repugnance might be asymmetry of information, or opportunity. Economists are not the only ones interested in repugnant transactions: see, e.g., Satz (2010) and Radcliffe Richards (2012), who consider a range of views in the philosophy literature, and Fiske and Tetlock (1997) and Tetlock (2003) on sacred values and taboo trade-offs.

<sup>124</sup>Of course refugees aren’t the only people who need to be matched to social services and housing. See Leshno (2018) and Arnosti and Shi (2017) on design issues in the way public housing is allocated.

**Open science** presents a different, more open-ended kind of engineering problem. Do the incentives for scientific investigation and publication need to be modified to keep up with the changing ways science is produced and disseminated? Gall, Ioannidis, and Maniadis (2017) point out that fostering a reliable scientific literature is a market design problem. Scientific journals in particular are marketplaces for ideas that can experiment with ways of increasing the long-term reliability of reported results, for example by allowing study designs to be pre-registered, requiring data to be made widely available, encouraging replications, and generally making it easier to identify (and reward) robustly replicable findings.<sup>125</sup>

Any list of open questions is necessarily arbitrary and incomplete, but this is particularly true of engineering challenges. Some kinds of questions can (eventually) be answered definitively, but engineering isn't like that. Pythagoras's Theorem is as true today as it was when he proved it, and applies as well to modern right triangles as to ancient ones, but the bridges that were built in his time have been replaced by stronger and longer bridges, and today's bridges will be replaced by better ones in the future. The job of engineering is to use available knowledge to make things work better, and the market designs of today will be replaced by different designs as our needs change and as we understand better how to achieve our goals. Of course engineering and science progress together. Market design is going to require reliable domain knowledge about how particular markets work. And, to quote Bob Wilson: "for the theorist, the problems encountered by practitioners provide a wealth of topics."<sup>126</sup>

## VII. Concluding Remarks

Markets and marketplaces are like languages; both are ancient human artifacts. Whole languages are hard to redesign, but smaller parts, e.g., technical vocabularies, are easier. And so it is with marketplaces: a marketplace is a piece of the market, not the whole. Marketplace designers don't have control over the whole strategy space: market participants have lots of options.<sup>127</sup> And marketplace behavior evolves as participants gain experience in developing and deploying their strategies. Practical market design must often proceed in advance of reliable theory, and so market designers also need big strategy sets, that include theory, field studies, computation, and experimentation.<sup>128</sup>

<sup>125</sup> A more parochial issue in the design of the economic literature will be how to accommodate hybrid fields like market design. We value theory for being simple, elegant, and potentially general, and we value engineering for taking into account complex potential causes of failure, and these two sets of values sometimes clash. Market design is starting to include a mix of simple tractable models and more detailed models, simulations, and experiments focused on sometimes messy operational procedures.

<sup>126</sup> Wilson (1997) as quoted in Holmström, Milgrom, and Roth (2002).

<sup>127</sup> This is one of the ways in which practical market design is different from the theoretical literature on mechanism design, which often assumes that the designer has complete freedom to introduce new mechanisms, and that participants in the economy must interact through these mechanisms. In a wide-ranging Ely Lecture, Hurwicz (1973, p. 27) remarks: "The new mechanisms are somewhat like synthetic chemicals: even if not usable for practical purposes, they can be studied in a pure form and so contribute to our understanding of the difficulties and potentialities of design."

<sup>128</sup> Nevertheless, in the history of ideas, market design is rooted squarely in the tradition of game theory. Before game theory, economists focused on systems of prices in commodity-like markets. Game theory gave us tools with which to pay attention to rules. Market design also deals with behavioral economics. Game theory, experimental and behavioral economics, and market design all allow us to look at rules, and how people interact with them, understand them, circumvent them, and change them.

Note that market designers are not mostly academics: the design of marketplaces offers rich rewards to entrepreneurs, who must also experiment to develop, maintain, and defend marketplaces that attract wide and steady participation. So market design as an emerging academic discipline not only helps in the design of new markets and marketplaces, it helps us better understand a large part of the general economy. And markets may be becoming even more important as computerized markets together with mobile computing and communication make marketplaces ever more omnipresent. This is changing the boundaries of firms as more things that firms have traditionally done internally (like record keeping, computing, and logistics) become available through markets.

In conclusion, in honor of its centennial in 1990, the *Economic Journal* solicited a set of papers looking into the next 100 years of various parts of economics. I was tasked with looking into the future of game theory. Noting that game theory itself was not yet 50 years old (counting from von Neumann and Morgenstern 1944), I confined myself to looking ahead only 50 years. It seemed to me then that, looking ahead, the prospects were mixed—game theory had delivered important conceptual insights, but if we wanted it to remain a foundation of economics we would have to do more. Here is part of the final paragraph (Roth 1991b):

*in the long term, the real test of our success will be not merely how well we understand the general principles which govern economic interactions, but how well we can bring this knowledge to bear on practical questions of microeconomic engineering... Just as chemical engineers are called upon not merely to understand the principles which govern chemical plants, but to design them, and just as physicians aim not merely to understand the biological causes of disease, but their treatment and prevention, a measure of the success of microeconomics will be the extent to which it becomes the source of practical advice, solidly grounded in well tested theory, on designing the institutions through which we interact with one another.*

Rereading today what I wrote almost 30 years ago, I'm glad that we still have 20 years of running room. We've already made a little progress, and there's every reason to think we can make more. We have begun to understand better and even to play a role in how marketplaces transform markets and sometimes create whole new markets. Economics is still an early-stage science, and an even earlier-stage engineering discipline. So this is an exciting time to be an economist. There is lots of progress we still need to make, it's important for the world that we do so, and there are some indications of fruitful paths to follow. I'm looking forward with substantial optimism.

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