

WHO
The Hidden World
GETS
of Matchmaking
WHAT
and Market Design
AND
ALVIN E. ROTH
WHY

Winner of the Nobel Prize for Economics

Who Gets What — and Why

*The Hidden World of Matchmaking
and Market Design*

ALVIN E. ROTH



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Dedication

To Ben and Aaron, *Emilie*, and Ted

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PART I

Markets Are Everywhere

Introduction: Every Market Tells a Story

IT WAS 5:00 a.m. on an April morning in 2010. Eight teams of surgeons were preparing to operate on eight patients in four different cities. Four healthy people would each be donating one of their kidneys to someone they had never met, and those four recipients, each suffering from end-stage renal disease, would receive a new lease on life.

At the same time, Jerry and Pamela Green were at their kitchen table in Lincoln, Massachusetts, studying the weather. They were soon to fly as volunteers, in their own small airplane, to Lebanon, New Hampshire, to pick up one of those kidneys, take it to Philadelphia, pick up another kidney there, and take it to Boston. (Two other pilots would transport the other two kidneys.) Because they had identified their flight with the call sign “Lifeguard,” signifying medical urgency, the air traffic controllers would take them, no questions asked, right through one of the world’s busiest airspace corridors down the Hudson River and over Newark airport, on their way to Philadelphia, where they would be scheduled to land immediately. Several jetliners carrying hundreds of passengers would be briefly delayed by their passage.

Kidneys for transplantation are scarce. So is airspace: an airliner uses several hundred dollars per minute in fuel, and only one airplane can occupy a given block of airspace at a time. Passengers’ time is also costly. Who got which kidney, which operating room, and which flight path that day in April, all required an allocation of scarce resources, so it is perhaps fitting that when Jerry is not flying his small plane, he is a professor of economics at Harvard.

Economics is about the efficient allocation of scarce resources, and about making resources less scarce.

Those kidneys and flights weren’t the only scarce resources that had been allocated to bring everything together on that day when four lives were saved. Years earlier, each surgeon had been admitted to medical school and then had proceeded through surgical residencies and fellowships. At each stage, they’d competed with other aspiring physicians. Jerry himself had to go through a similar set of competitions to get his job. Before embarking on their professional training, Jerry and the other surgeons had been admitted to colleges, and before that Jerry had been admitted to Stuyvesant, New York City’s most selective public high school. Notice that none of these things — kidneys, places in competitive schools, sought-after jobs — can be acquired by the person willing to pay the most and work for the lowest wage. In each case, a match must be made.

Matchmaking

The Talmud tells of a rabbi who is asked what the Creator of the universe has been doing since the creation. The rabbi answers, “He has been making matches.” The story goes on to make clear why making matches — in this case, successful marriages — is not only important but also difficult, “as hard as dividing the Red Sea.”

Matching is economist-speak for how we get the many things we choose in life that also must choose us. You can’t just inform Yale University that you’re enrolling or Google that you’re showing up for work. You also have to be admitted or hired. Neither can Yale or Google dictate who will come to them, any more than one spouse can simply choose another: each also has to be chosen.

Often there is a structured matchmaking environment — some kind of application and selection process — through which that courtship and choosing takes place. Those matching processes, and how well we navigate them, determine some of the most important turning points in our lives, and many smaller ones, too. Matching dictates not only who gets admitted to the best colleges but also which students get into the most popular courses and which ones live in the best dorms. After college, matching determines who lands the best jobs and who has the best opportunities for advancement. Matching sometimes is the gatekeeper of life itself, as when it determines which desperately ill patients receive scarce organs for transplant.

Even if matches are made in heaven, they are found in marketplaces. And markets, like love stories, begin with desires. Marketplaces help shape and satisfy those desires, bringing together buyers and sellers, students and teachers, job seekers and those looking to hire, and even sometimes those looking for love.

Until recently, economists often passed quickly over matching and focused primarily on commodity markets, in which prices alone determine who gets what. In a commodity market, you decide what you want, and if you can afford it, you get it. When buying one hundred shares of AT&T on the New York Stock Exchange, you needn’t worry about whether the seller will pick you. You don’t have to submit an application or engage in any kind of courtship. Likewise, the seller doesn’t have to pitch himself to you. The price does all the work, bringing the two of you together at the price at which supply equals demand. On the NYSE, the price decides who gets what.

But in *matching markets*, prices don’t work that way. Going to college can be costly, and not everyone can afford it. But that isn’t because colleges raise tuition until only as many students can afford to attend as the college can accommodate — that is, until demand equals supply. On the contrary, selective colleges, high priced as they are, try to keep the tuition low enough so that many students would like to attend, and then they admit a fraction of those who apply. And colleges can’t just choose their students; they have to woo them, too, offering tours, fancy facilities, financial aid, and scholarships, since many students are admitted to more than one school. Similarly, many employers don’t reduce wages until just enough desperate job hunters remain to fill their ranks. They want the most qualified and committed employees, not the cheapest ones. In the working world, courtship often goes both ways, with employers offering good salaries, perks, and prospects for advancement, and applicants signaling their passion, credentials, and drive. College admissions and labor markets are more than a little like courtship and marriage: each is a two-sided matching market that involves searching and wooing on both sides. A market involves matching whenever price isn’t the only determinant of who gets what.

Some matches don’t use money at all. Kidney transplants cost a lot, but cash doesn’t decide who gets a kidney. In fact, it’s illegal to buy or sell kidneys for transplantation. Similarly, airport landing slots involve fees, but that isn’t what determines who gets them. Access to public education also isn’t priced. Taxpayers support schools precisely so that every child can attend for free. Many people would

find it repugnant to allow money to decide who gets a kidney or a seat in a sought-after public kindergarten. When there aren't enough kidneys to go around (and there aren't) or seats in the best public schools (there never are), scarce resources must be allocated by some kind of matching process.

Market Design

Sometimes a matching process, whether formal or ad hoc, evolves over time. But sometimes, especially recently, it is designed. The new economics of *market design* brings science to matchmaking, and to markets generally. That's what this book is about. Along with a handful of colleagues around the world, I've helped create the new discipline of market design. Market design helps solve problems that existing marketplaces haven't been able to solve naturally. Our work gives us new insights into what really makes "free markets" free to work properly.

Most markets and marketplaces operate in the substantial space between Adam Smith's invisible hand and Chairman Mao's five-year plans. Markets differ from central planning because no one but the participants themselves determines who gets what. And marketplaces differ from anything-goes laissez-faire because participants enter the marketplace knowing that it has rules.

Boxing was transformed from brawl to sport when John Douglas, the ninth Marquess of Queensberry, endorsed the rules that bear his name. The rules make the sport safe enough to attract competitors but don't dictate the outcome. In just this way, marketplaces, from big ones like the New York Stock Exchange to little ones like a neighborhood farmers' market, operate according to rules. And those rules, which are tweaked from time to time to make the market work better, are the market's design. *Design* is a noun as well as a verb; even markets whose rules have evolved slowly have a design, although no one may have consciously designed them.

Internet marketplaces have very precise rules, because when a market is on the Web, its rules have to be formalized in software. And now that we can access the Internet from mobile devices, we're never far from a market.

Markets are connected: Internet markets depend on the markets for radio spectrum that have allowed smartphones and other mobile access to flourish where only television and radio used to be.

I've helped design some of the markets and matching processes that I'll introduce in this book. Almost all American doctors, for example, get their first jobs through a clearinghouse called the National Resident Matching Program. In the mid-1990s, I directed the redesign of the NRMP matchmaking algorithm, which today matches more than 20,000 young doctors with about 4,000 residency programs every year. My colleagues and I helped design matchmaking procedures for doctors later in their careers as well. We also helped design the current system for matching students to high schools in New York City (well after Jerry Green navigated that system) and for schools in Boston and other big cities. The exchanges that Jerry and Pam's flights helped accomplish were arranged by the New England Program for Kidney Exchange (NEPKE), which sprang in part from a design I proposed with two economist colleagues, Utku Ünver and Tayfun Sönmez. In 2004, we helped a group of surgeons and other transplant experts found NEPKE, which used the algorithms we wrote to match donors and recipients, and since then we've helped our surgical colleagues make kidney exchange a standard part of transplantation.

Marketplaces

The first task of a successful marketplace is bringing together many participants who want to transact so they can seek out the best transactions. Having a lot of participants makes a market *thick*. Making a market thick takes different forms in different markets. To build clearinghouses for kidney exchange, for example, we first had to make the market thick by building databases of patients and donors.

Efforts to keep markets thick often concern the timing of transactions. When should offers be made? How long should they be left open? You can see that even in marketplaces for commodities, from a local farmers' market to a stock exchange. The farmers' market near my old home opens at a fixed time, and if you happen to come a bit early, vendors hesitate to sell you so much as a raspberry beforehand. If they did, they would incur the wrath of their fellow merchants, who worry that if some vendors started to sell before the market officially opened, some customers would come earlier, and an afternoon market could unravel to become an all-day market, requiring the vendors to spend more time selling in a "thinner" market. That's more or less the same reason — to keep the market thick — that the New York Stock Exchange opens for business at the same time each day and closes just as punctually.

Congestion is a problem that marketplaces can face once they've achieved thickness. It's the economic equivalent of a traffic jam, a curse of success. The range of options in a thick market can be overwhelming, and it may take time to evaluate a potential deal, or to consummate it. Marketplaces can help organize potential transactions so that they can be evaluated fast enough that if particular deals fall through, other opportunities will still be available. In commodity markets, price does the job well, since a single offer can be made to the entire market ("Anyone can buy a pint of my raspberries for \$5.50"), but in matching markets, each transaction may have to be considered separately, as in job markets, in which each candidate has to be evaluated individually.

Although it's great to have a marketplace that gives you an abundance of opportunities, these may be illusory if you can't evaluate them, and they can cause the market to lose much of its usefulness. Think of an Internet dating site on which women with appealing photos receive far more messages than they can answer and men find that very few of their messages draw responses. This causes men to send more, and hence more superficial, messages and women to respond to fewer and fewer of them. Just as women can have more messages than they can answer, employers can have more applications than they can interview. In both cases, congestion has set in, and that can make it impossible for participants to identify the most promising alternatives the market has to offer.

While buyers like to see many sellers, and sellers like to see multitudes of buyers, sellers aren't so wild about competing with all those other sellers, nor are buyers necessarily glad to have such a crush of competition. So sometimes someone will try hard to transact before the marketplace opens, and in some of the labor markets we'll see in this book, this has led to increasingly early offers or increased insistence that the offers be answered immediately, before other offers can be entertained. It can be hard to determine when early "exploding" offers are meant to gain an advantage over potential competitors and when they are just attempts to deal with congestion (i.e., if there isn't enough time to make enough offers, start early and move fast). In either case, early exploding offers dilute the thickness of the market and sometimes lead to big reorganizations, such as the development of the labor market clearinghouses for doctors.

One thing that all markets challenge participants to do is to decide what they like. Students have to consider which colleges will suit them, and colleges have to sort through thousands of applications. What often makes matching markets especially challenging is that everyone has to puzzle through not only their own desires but also those of everyone else and how all those other market participants might act to achieve their preferences. College admissions officers aren't simply trying to pick the

best students. They're trying to pick the best students who will choose to attend if admitted (and this involves considering where else those students have applied and whom those competing colleges are likely to admit). And so students have to try to signal to colleges not only how *good* they are but also how *interested* they are. Should they apply, via binding early admission, to one school? If so, should they pick the school that they like best but that might be a long shot, or should they apply to a school that's more likely to value their expression of commitment and admit them? In short, both students and colleges have to make decisions that depend a lot on those made by many other students and colleges. (As they say about football, everything is complicated by the presence of the other team!)

Decisions that depend on what others are doing are called *strategic decisions* and are the concern of the branch of economics called *game theory*. Strategic decision making plays a big role in determining who does well or badly in many selection processes. Often when we game theorists study a matching process, we learn how participants "game the system." Well-designed matching processes try to take into account the fact that participants are making strategic decisions. Sometimes the goal of the market designer is to reduce the need to game the system, allowing choosers to concentrate on identifying their true needs and desires. Other times the goal is to ensure that even if some gaming is inevitable, the market can still work freely. A good marketplace makes participation *safe* and *simple*.

When a market doesn't deal effectively with congestion and participants may not be able to find the transactions they want, it might not be safe for them to wait for the marketplace to open if some opportunities are available earlier. Even when going early isn't an option, the marketplace might force participants to engage in risky gambles.

This was the issue that led Boston Public Schools to invite my colleagues and me to help redesign the system for matching children to schools. Under Boston's old system, parents had to strategize about which school they named as their first choice, since the assignment rules made it difficult to get their child assigned to a good school if they didn't list that school first. That wasn't simple. The new system, in contrast, makes it safe for parents to list their true preferences and frees them to think about which schools they actually like best, without having to decide which one school they're prepared to gamble on.

Every market has a story to tell. Stories about market design often begin with failure — failure to provide thickness, to ease congestion, or to make participation safe and simple. In many of the stories in this book, market designers are like firefighters who come to the rescue when a market has failed and try to redesign a marketplace, or design a new one, that will restore order.

But markets can succeed on their own practical terms and still fail in the eyes of those who don't want to participate in them. Some markets are regarded as repugnant; these run the gamut from slave markets to illegal drugs to prostitution. Kidney exchange arose in the shadow of laws around the world that criminalize buying and selling human organs for transplantation (despite which laws, black markets exist, some of which work very badly indeed).

Repugnant transactions — transactions that some people don't want others to engage in — don't have to involve money. Witness the debates on the status of same-sex marriage. But often the addition of money makes an otherwise acceptable transaction seem repugnant, which is why there are laws against selling kidneys but not against kidney exchange, and why consensual sex is generally acceptable but prostitution is generally not. Note, however, that in some places consensual sex (say, between unmarried partners) is considered repugnant. And in some places, prostitution is legal. Repugnance shows with particular clarity what all markets reveal: people's values, desires, and beliefs.

For me, economics has always had the fascination of gossip: it exposes intimate details of other people's lives and choices. It tells us what kinds of choices we must be prepared to make in our own lives and also which ones we would have faced if we'd chosen a different path.

I hope this book offers insights into matches that you face. Are you trying to get your child into good kindergarten? Or help her navigate college admissions? Are you applying for a new job? I aim to get you thinking in new ways about navigating those matching processes.

I also hope this book will help you better understand how some forms of organization work well and some badly.

I want to shed light on the frequently simplistic assertions we hear from politicians about free markets. Just what is it that allows a market to function freely? When we speak about a free market, we shouldn't be thinking of a free-for-all, but rather a market with well-designed rules that make things work well. A market that can operate freely is like a wheel that can turn freely: it needs an axle and well-oiled bearings. How to provide that axle and keep those bearings well oiled is what market design is about.

Finally, this book — and here is my fondest hope — aims to unveil the economic world in the way that hikes with my friend the Israeli botanist Avi Shmida open my eyes to plants and animals. Once, in the southern Jordanian desert, Avi pointed out a single succulent green plant where the only other growth was dry, dusty scrub. "What do you know when you see a green plant in the desert?" he asked. I shook my head, and he exclaimed: "It's poison! Otherwise something would have eaten it by now."

Another time, Avi commanded me to stick my finger deep into the flower of a sage plant. When I withdrew my finger, it had a line of pollen on the back. Avi then explained how this flower has evolved so that bees have to reach deep inside to get nectar, and thus only big bees with long tongues can get it. The pollen sticks to their backs, where it will be safely transmitted to the next flower they visit. The flower of this plant and bees have coevolved to take advantage of what each offers the other. The flower offers an especially rich source of nectar that can be harvested only by big bees. Big bees, therefore, have a reason to specialize in this kind of flower, which means that the pollen has a good chance of being delivered to another flower of the same species (which is the point of the flower, from the plant's point of view). In this case, evolution has been the matchmaker.

The economic world is just as full of surprising detail as the natural world, and markets also often arise by a kind of evolution, by trial and error, without any intelligent design. But markets can also be designed, sometimes from scratch but often after trial and error leads to a market failure. Much of what we've learned about market design — and from market design about markets more generally — has come from observing market failures and figuring out how to fix them. Not all markets grow like weeds; some, like hothouse orchids, need to be nurtured. And some carefully nurtured marketplaces on the Internet are now among the world's biggest and fastest-growing businesses.

Like flowers of different species, marketplaces for different kinds of goods and services are often quite different from one another. But, also like different species of flowers, even very different marketplaces have some things in common, since they arose from a need to solve similar problems.

When I look into markets that are suffering from some sort of failure, not only do I get to see how other people's lives unfold at some of their most important junctures, but I also get to meet an exciting cast of characters whom I'd like to introduce you to. Because economics touches on just about everything, economists have an opportunity to learn something from just about everyone, and I've met and worked with some remarkable people in each of the markets I've helped design.

Market design is giving new scope to the ancient profession of matchmaking. Consider this book a tour of the matching and market making happening around us. I hope it will give you a new way to see the world and to understand [who gets what — and why](#).

Markets for Breakfast and Through the Day

MARKET DESIGN IS SO pervasive that it touches almost every facet of our lives, from the moment we wake up. The blanket you chose to sleep under, the commercial playing on your clock radio — even the radio itself — embody the hidden workings of various markets. Even if you eat only a light breakfast, you likely benefit from the global reach of multiple markets. And while most of those markets are easy to participate in, even that apparent simplicity may disguise a sophisticated market design.

For example, you probably don't know where your bread was baked — but even if you do, your baker doesn't have to know who grew the wheat that went into the flour used to make the bread. That's because wheat is traded as a *commodity* — that is, it is bought and sold in batches that can all basically be considered the same. That simplifies things, although even commodities need to be designed, so that the market for wheat doesn't have to be a matching market, as it was as recently as the 1800s.

Every field of wheat can be a little different. For that reason, wheat used to be [sold “by sample”](#) — that is, buyers would take a sample of the wheat and evaluate it before making an offer to buy. It was a cumbersome process, and it often involved buyers and sellers who had successfully transacted in the past maintaining a relationship with one another. Price alone didn't clear the market, and participants cared whom they were dealing with; it was at least in part a matching market.

Enter the Chicago Board of Trade, founded in 1848 and sitting at the terminus of all those boxcars full of grain arriving in Chicago from the farms of the Great Plains.

The Chicago Board of Trade made wheat into a commodity by classifying it on the basis of its quality (number 1 being the best) and type (winter or spring, hard or soft, red or white). This meant that the railroads could mix wheat of the same grade and type instead of keeping each farmer's crop segregated during shipping. It also meant that over time, buyers would learn to rely on the grading system and buy their wheat without having to inspect it first and to know whom they were buying from.

So where once there was a matching market in which each buyer had to know the farmer and sample his crop, today there are commodity markets in wheat, corn, soybeans, pork bellies, and numerous other food items that are as anonymous — and efficient — as financial markets. Just as investors don't worry about which particular shares of AT&T stock they buy, buyers don't care which particular 5,000 bushels of number 2 hard red winter wheat they have shipped to them. Thanks to the rating system, they can buy wheat without seeing it. Commodifying wheat via a reliable grading system helped make the market safe.

Wheat can even be sold *before* it's harvested, as *wheat futures* — a promise of wheat to come. This allows big millers and bakers to make their purchases and lock in their costs in advance. They can do so without fear, because the standardized description of what is being purchased means they don't

have to worry about what will be delivered. The purchase of wheat futures is a purely financial transaction, with no wheat even present in the marketplace.

As for the transaction itself, brokers inspecting and buying lot by lot have been replaced by commodity traders on the floor of the Chicago Board of Trade signaling and calling out their bids and offers in the trading pits of the open outcry markets that came to dominate this kind of transaction. Nowadays traders also buy and sell enormous volumes of grain while sitting at computer screens.

Turning a market into a commodity market helps make it really thick, because any buyer can buy from any seller, and any seller can sell to any buyer. At the same time, it also helps the market deal with one of the main sources of congestion in matching markets, since in a commodity market each offer to sell can be made to all buyers, and each offer to buy can be made to all sellers. So unlike the market for jobs, or for houses, no one has to wait for an offer to be made to him personally; anyone who sees (or hears) a price he likes can take it. We'll see in more detail how such markets can work when we look into financial markets in chapter 5, and we'll see just how fast commodity markets can sometimes operate.

Coffee and More

Turning a product into a commodity can affect not just how it's bought and sold but even what is produced. Still keeping our sleepy eyes squarely on the breakfast table, let's shift our attention to coffee and its own remarkable market tale.

Coffee beans have been grown in Ethiopia for centuries, but until the twenty-first century they were traded a lot like nineteenth-century American wheat. If you wanted to buy Ethiopian coffee in bulk from the source, you had to have an agent there who could extract a sample from deep inside each sack to taste and evaluate it.

That changed in 2008 with the creation of the Ethiopia Commodity Exchange. At its heart is a system of anonymous coffee grading, in which professional tasters sample and grade each lot put up for sale. (By the way, there was also some thoughtful market design that went into the rules — that is, the market design — involved in organizing quality grading. For example, tasting must be “blind”; the tasters can't know whose beans they're tasting. Otherwise they could be bribed by the seller to inflate the grades.)

The standardization of coffee can actually improve the quality of the coffee harvest. Coffee beans grow inside a “cherry,” and the best coffee is harvested when the cherry is ripe and red. But the beans are sold after being removed from the cherry and dried. So when buyers simply see coffee beans, they can't tell whether they were harvested from ripe red cherries or from unripe green ones. Before coffee was graded, coffee farmers sometimes were tempted to harvest a whole hillside at once, red and green beans, ripe and unripe. But now that tasters can tell the difference, it makes sense to have coffee pickers pluck only the red cherries and to come back later to harvest the rest of them when they are ripe. Since the graders can tell the difference, the market reliably rewards such care with a higher grade and a higher price. The ultimate result is that foreign buyers can now buy Ethiopian coffee beans in bulk from a distance, without having to taste them on the spot, and from multiple sellers without worrying about the sellers' reputation or pedigree.

So as you sip your morning coffee, you are benefiting from some fairly recent design in the marketplace for an ancient agricultural commodity, which wasn't always as standardized — or as good — as it is today.

That said, your coffee doesn't necessarily come to you anonymously, even if you don't know who grew the beans. You may run out to pick up your coffee already brewed from Starbucks or a more local coffee shop, but in either case you know quite a bit about the seller. You may have chosen your coffee joint for its convenience, for the pastries it sells with the coffee, or even for the designs the barista swirls into the foam on your latte. And if you're a regular, that seller may also know a lot about you — for instance, getting your “usual” ready when she sees you walking in.

Coffeehouses try hard to differentiate their products so that customers will want to return and buy regularly from them. Of course, if you're in a strange city, you may find yourself seeking a big chain such as Starbucks precisely because of the standardization of the drinks it sells, since you haven't had a chance to locate a more idiosyncratic coffee shop that might suit you better.

Notice the tension between commoditization and product differentiation — that is, between wanting to sell in a thick market to buyers even if they don't care who you are, and trying to make your product special enough that many buyers will care enough about you to seek you out. Sellers enjoy selling in a thick market of buyers, but they don't enjoy being interchangeable with other sellers. Giant brand leaders such as Apple and Microsoft sell products that are enough like commodities that you don't care which particular iPhone or copy of Microsoft Office you have, but they are differentiated enough that you can't buy the same phones and software from anyone else. Part of Apple's success is that it sells a unique brand of laptop computers, while the PCs pioneered by IBM became a commodity that could be sold by other companies as well. This opened the door to Microsoft's near-monopoly on the operating system that runs all PCs, since their spread created a big, thick market for software on the PC platform.

In much the same way, there's a tension between commodity markets and matching markets. You care who brews your coffee, but your coffee shop sells to all comers. That is, in the market for a cup of coffee, your coffee shop has to be chosen, but you get to choose — and you care whom you choose. So the distinction between perfectly anonymous commodity markets and relationship-specific matching markets isn't a thin bright line. Rather, there are markets at different points along a spectrum from pure commodity to pure matching. When I buy bread in the supermarket, I don't really know the baker, but I can recognize that it's the usual bakery, since the baguettes I get come with the bakery's name printed on the bag, along with the information that it has been cheerfully baking bread since 1984.

Buyers have some of the same ambivalence as sellers: while we like the fact that some goods are commodities that we can buy without inspecting, we also enjoy variety and seek out unusually high and hard-to-standardize quality. Sometimes on Sunday mornings, my wife and I buy our breakfast at a local farmers' market — an ancient format that still attracts busy city dwellers. It's an attractive place to shop, not least because of the perceived freshness available in a marketplace that is open only one day a week. You know for sure that the goods came to the market that day and didn't languish in a supermarket's storage room before being put on the shelf.

Moreover, the farmers showing their wares are typically local. And because the farmers themselves (or their families) are usually manning the stand, you can easily find out something about them. The result is more of a matching market than when you stock up in your local grocery store, although the store is open every day, which makes it more convenient.

The grocery store may be open every day, but it's not open all the time, because it's costly to keep a store open when there are only a few potential shoppers. But whether you shop at the farmers' market or the local supermarket, you still have to go there to make your purchases. The Internet is changing all that and making markets more ubiquitous.

These days, with your smartphone and your credit card, you can buy a plane ticket, make a hotel reservation, order a meal to be delivered, or purchase a pair of shoes. On the Web, you can buy from millions of different sellers — and if you point the browser on your phone or your computer at a big Internet marketplace such as Amazon, you can fill your virtual shopping cart with items from multiple sellers and buy them in a single transaction. That's part of what makes Internet markets so easy to use and so successful. When my watch breaks, I might go to Amazon to buy a new one. But I might also buy a mirror for my bike helmet and a book I've been planning to read, then pay for them all with my credit card and have them shipped to my home. It looks to me like a single transaction, even though I may have bought each item from a different seller that subscribes to Amazon's marketplace services.

In attracting so many shoppers and so many merchants, Amazon has created a thick marketplace, one in which there are many participants ready to make many different kinds of transactions. The thickness of the Amazon marketplace — the ready availability of so many buyers and sellers — is self-reinforcing. More sellers will be attracted by all those potential buyers, and more buyers will come to this marketplace because of the ever-expanding variety of sellers. So Amazon lets me shop easily for many different things in the same place, and my phone lets that place be wherever I am.

Your smartphone is a marketplace not only for goodies from Amazon but also for software applications, or apps, that expand what your phone can do. That's why your phone almost certainly runs on one of the two most popular smartphone operating systems, Apple's iPhone or Google's Android. People want phones with a long list of apps to choose from, and they know that they'll want some apps later that haven't even been invented yet. At the same time, a software developer writing an app wants to sell it in a marketplace with lots of potential buyers so the app will have a chance to become a big hit.

Phone buyers and app developers are looking to meet in a thick marketplace — one with many possibilities on the *other* side of the market. That's why independent developers first write apps for phones with many users, and phone buyers look for phones with an abundance of apps. Your phone's operating system is the key to the marketplace, since each app has to be written to be compatible with a particular operating system.

Apple and Google both launched their proprietary operating systems with a multitude of apps already available so that customers would be attracted immediately by their thickness. But Apple and Google made other, notably different choices when designing their markets. Apple chose a "closed" operating system that allowed it to control which apps could be sold to iPhone users. Google, which came later to the game, opted for an "open" system, publishing the code so that any developer could build for it. These choices echoed similarly opposing strategic decisions made by Apple and Microsoft at the dawn of the personal computer age. Anybody could make software for the PC platform, but only Apple (or those developers it allowed to do so) could make software for its personal computer, the Mac. These choices allowed the market for PC software to grow thick much more quickly than the market for Mac software. But Apple's decision to keep both its hardware and software on a proprietary standard eventually allowed it to reap huge profits.

As with other kinds of markets, popular operating systems quickly get more and more popular, and they attract both new buyers and new sellers. In time, they become *de facto industry standards* — meaning they essentially establish a marketplace in which products (new applications) can be sold. Once this happens, they can, at least for a time, so completely dominate their markets that competing operating systems can't attract enough users and developers to be anything but niche offerings.

That's exactly what happened in the smartphone market. The two most popular operating systems, iPhone and Android, have captured so much of the market that they've become almost self-perpetuating. In the process, they have displaced earlier popular Internet phone operating systems, notably the BlackBerry, which in turn had replaced non-Internet phones and non-phone digital assistants such as the PalmPilot.

Notice how markets interact with one another. Amazon couldn't have become the marketplace it is without the Internet, which couldn't have become a marketplace without first computers and then smartphones. And smartphones couldn't have become marketplaces without a way to pay for purchases over the phone. At the farmers' market and the supermarket, anyone can pay in cash if they want to. On the Internet, it's convenient to pay with a credit card. And a credit card is also a marketplace, which is why there's a good chance you have one of the big ones: Visa, MasterCard, or American Express. Consumers who use credit cards and merchants that accept them are all looking for a thick market, with lots of participants on the other side.

I'm old enough to remember when people paid for most things by cash or check. It was hard to pay by check if you were away from home, since merchants didn't like to take the risk that your check would bounce and they wouldn't get paid. But if you were a regular at a local restaurant, the owner was usually glad to take your check — although even then you'd sometimes see a sign over the cash register that read IN GOD WE TRUST; ALL OTHERS PAY CASH.

[Credit cards offered merchants](#) safety, but that safety came at the cost of transaction fees. Most merchants were willing to pay those fees because accepting credit cards brought in customers they might otherwise have missed, and also because credit cards made it safe for them to take non-cash payment from customers they didn't know well, since the bank guaranteed payment as a form of insurance.

It took a while for the markets facilitated by credit cards to become thick by settling on just a few major cards, but it is hardly surprising that this happened. Imagine how much less useful credit cards would be if the markets had moved in the other direction and every store used a different one. In the early days, some people carried several credit or charge cards, and various businesses accepted only certain ones. This sometimes led to embarrassing moments when the check was delivered at a restaurant. So the cards that were most popular became the most useful ones to carry and to accept, since they gave access to the thickest markets — that is, to the most restaurants and shops on one side and the most diners and buyers of other goods and services on the other. By the late 1960s, an industry shakeout had already begun. A number of famous cards — most notably Diners Club, which was the first credit card in widespread use — faded into the background.

Part of what makes credit cards work is that they simplify transactions for both buyers and sellers. Concentrating on just a few cards further simplifies matters on both sides of the market. Thus even since the big shakeout, no new credit cards have joined the ranks of the majors; the barrier to market entry has proved to be too great. That said, in recent years the Internet revolution has opened the door to competition from wholly new directions — including new kinds of payment services, such as PayPal; an international network of automatic teller machines to challenge old standbys such as traveler's checks; and maybe even new types of “virtual money” such as Bitcoin. As I write this in 2014, Apple has announced a new payment system on the latest iPhones, and we can reasonably expect that it and/or other new payment systems that make use of mobile devices will become commonplace.

The bank that handles Amazon's transactions, or the one that manages the account of your favorite restaurant, is typically different from the bank that issued your credit card and takes your payment. So behind the scenes, there is an interbank market, too, through which payments flow. This hidden

market eases the congestion that could otherwise result from settling very large numbers of relative small transactions, in the same way that Amazon itself eases the congestion of making several little purchases from different sellers. This interbank market lets each merchant deal with just one bank, just as your monthly credit card statement enables you to make a single payment that settles your account with many merchants.

Your credit card also acts as a lender. (That's what distinguishes credit cards from charge cards, which offer only the ease of a cashless transaction.) It offers you access to the market for credit, so any time you want to buy something, you can borrow money, though typically at an exorbitantly high interest rate, simply by not paying the full amount you owe when your bill arrives. The bank that issued your credit card can get away with such high rates because once you've made your purchases, the bank isn't facing a lot of competition in offering you easy credit. In fact, you might have chosen this card because it provided cash back on some purchases. It turns out that lots of people who do this never pay much attention to the interest rate, because they're planning to pay their bills in full. But then [they seldom switch cards](#). So there isn't much pressure on banks to lower their rates. I hope you don't borrow on your credit card very often: it's a bad deal — the kind of deal you're likely to be offered when the other side of the market isn't thick.

In thicker markets, where customers have ready alternatives, it's harder for a seller to get away with such bad deals. At one time, merchants tried to pass on the cost of credit card purchases to consumers by charging a premium for using the card instead of cash. This didn't catch on, in part because credit card purchasers disliked it so much and could take their business elsewhere. Instances in which consumers recoil from offers that strike them as unfair are more common than you might think. Even marketing giants are sometimes surprised by what they *can't* get away with. In 1999, for example, Coca-Cola tested vending machines that could automatically raise prices in hot weather. The backlash was quick — and the company abandoned the idea just as quickly. So regular folks who find certain transactions particularly distasteful do have some recourse when they can take their business elsewhere or simply withhold it — and this, too, plays a role in shaping markets.

Incidentally, the fact that most purchases cost the same whether they are paid for by credit card or by cash opens the door to an attractive-looking kind of competition among credit cards that may not be as attractive as it seems. Many credit cards now compete on how much “cash back” they offer to consumers. Those refunds come out of the fees that credit card companies charge to merchants and are reflected in the prices that merchants charge their customers. So when two customers stand in line at the cash register with identical purchases, and one pays with a credit card and one pays cash, the one who is paying cash is paying for the discount that the credit card customer is receiving. That is, more consumers are attracted to higher cash-back deals, and as credit cards successfully compete for customers by raising these kickbacks, merchants pay larger credit card fees and raise prices in response. And a discount from a higher price isn't such a good discount, especially for those who are paying cash. To put it another way, we pay a cost for the convenience of using a middleman, and this is partly because the [middlemen](#) — in this case, the credit card companies — compete for our business in a way that mutes the price competition among merchants that might otherwise bring prices down. It's something to remember: competition can take many forms, and it isn't always easy to see who gains and who loses.

Each of these ubiquitous marketplaces has found a way to succeed not only in making markets thick and uncongested, and safe, but also in making them *simple to use*. Making a market simple to use, however, may not be *simple*. Behind Amazon's one-stop shopping, for example, are storage and

shipping, fast Web servers, and secure ways of paying, with encrypted credit card numbers on file so that regular customers don't have to be troubled each time they make a purchase.

Simplicity is a competitive tool that sometimes allows new market platforms to displace old ones. Credit cards replaced paper checks, and it remains to be seen whether mobile payment systems will replace credit cards. If they do, it will be because it's simpler to swipe your phone than your credit card, more secure, or simpler for the merchant to accept payment that way. Notice that when competition among marketplaces causes previously successful markets to fail, it is often the result of undermining the previous success in establishing a thick market. If, for example, mobile payments turn out to be more attractive to merchants than credit cards, then as the mobile payment market becomes thick, some merchants might stop accepting credit cards that charge them a high fee. That would in turn make those credit cards less attractive to consumers, which would make them unattractive to even more merchants, and a previously thick market would start to become thin.

In the chapters to come, you will begin to see markets in sharper focus, with more attention to the details of how they work, the "rules of the game."

A few of the marketplaces I'll tell you about are ones that I've helped design or that I've studied carefully. Others are just markets that I participate in, as you do — such as the market for phone credit cards, or that morning cup of coffee.

When we think of markets, most of us typically imagine the stock exchange, or a retail store offering products to customers, or the surging demand for new smartphones, or maybe just a traditional farmers' market. But as we've already seen, we encounter many other markets every day, and our world would be utterly different (and a lot less pleasant) without them. These markets include not only our experiences at the supermarket or phone store but also those in getting into college, finding a job, eating breakfast — even getting a kidney transplant.

One thing we'll see is that the "magic" of the market doesn't happen by magic: many marketplaces fail to work well because of poor design. They may fail to make the market thick or safe, or to deal with congestion, and so there's an opportunity to help them work better. And sometimes there's an opportunity to build a marketplace from scratch, to serve an entirely new market, to facilitate a new kind of exchange. We'll see that in the next chapter, where I tell you about kidney exchange.

Lifesaving Exchanges

DR. MICHAEL REES was tired of watching his patients suffer and die.

Too often, that's what happened when he told someone with kidney failure that he would have to wait until a cadaver kidney became available. What made that conversation even harder was that so many patients had come to him filled with hope. They'd already found someone — a family member, a close friend, sometimes just an acquaintance — who was willing to donate a kidney to them (a donor, like any healthy person, needs only one of the two kidneys she was born with). A timely donation can not only save people with kidney disease from the long wait for a deceased-donor organ, but also spare them the grueling downward spiral of dialysis.

But a willing donor isn't enough. Blood types have to be compatible, and a patient's immune system must not immediately reject the new kidney. Time after time, Mike did those tests at the University of Toledo Medical Center, only to give his patients the bad news that none of the prospective donors was compatible. He hated that conversation. He'd become a doctor to cure people, not to make them stand in line at death's door, waiting for some other unfortunate person, with sour kidneys, to die.

Then, in early 2000, Mike heard that a kidney "exchange" had been conducted at Rhode Island Hospital. The transplant team, led by Anthony Monaco and Paul Morrissey, had found itself with two incompatible patient-donor pairs and noticed that each donor's kidney would work for the other patient. With the patients' and donors' permission, they did the swap.

Wondering if he might help his patients with similar exchanges, Mike carried home two boxes of patient and donor charts. After putting his kids to bed, he sat at his kitchen table and spent the next four hours poring over them, noting each patient's blood and tissue incompatibilities. Soon charts covered the table. One by one, he compared each patient chart with all of the donor charts. "I didn't really have a strategy," he recalls. "I stayed up that night until I figured out two pairs that might match."

Because of advances in immunosuppression drugs, which reduce the chance that a person will reject a donated organ, a person can receive a kidney from someone who isn't an identical twin or even a blood relative. But finding a match is harder than just getting the right blood type. The fact that my wife and I are parents, for example, reduces the likelihood that she could accept one of my kidneys. During childbirth, she might have been exposed to some of my proteins that our children inherit, and her immune system might have developed antibodies against them.

That was what happened with one of Mike's potential exchanges. Although the exchange looked like it would work because the blood types of the patients and donors were compatible, one of the patients had antibodies against some of the proteins in the proposed donor's kidney. That transplant wouldn't work, and hence that exchange couldn't be done.

Mike's first attempt had failed, but he realized that a kidney exchange could work. What he needed was a big enough database of patient-donor pairs to improve the odds, as well as software that could evaluate the potential combinations. With both of those factors in place, Mike was certain he'd find matches.

Kidneys and cadavers may seem out of place in a discussion about markets. But the story of the creation of kidney exchanges — in which I played a major role — touches on almost every subject I will discuss in the chapters to come, about how market design has to solve problems related to incentives, thickness, congestion, and timing, and how some kinds of transactions can be widely seen as repugnant. In describing how the marketplace for kidney exchange was created, I will be introducing the major themes of this book.

Just as important, the very fact that something as intimate, personal, and, frankly, disturbing as the exchange of human kidneys can not only be organized as a marketplace but can be made better, fairer, and more efficient in the process underscores the first thing I hope you'll start to notice all around you. It is that *markets and marketplaces come in many forms, some of which don't conform to conventional notions of markets, and some in which money may play little or no role.*

So let's return to our story of Dr. Michael Rees's hopes for kidney exchange and use it as an introduction to the design of markets and marketplaces.

When we see a long line of people waiting to buy some scarce good, we suspect that demand exceeds supply. If we know a little bit about economics, we also may conclude that this imbalance is occurring because the price is too low to generate more supply.

As I write this, more than 100,000 people are waiting for a kidney transplant in the United States. Meanwhile, the price of kidneys is zero, since it's illegal here and in most of the rest of the world to buy or sell kidneys for transplant. Sure, lots of money must be spent for hospitals, doctors, and drugs before a transplant can happen. But by law, the kidney itself must be a gift.

So kidneys must be exchanged without money changing hands, in a kind of barter transaction.

In the late 1800s, the economist William Stanley Jevons pointed out that the invention of money was a market design solution that overcame a major problem that severely limited barter, namely the need to find someone who both has what you want and wants what you have. Money eases the need to find this “double coincidence”: with money in the market, it's enough to find someone who has what you want. You can buy what you want from that person without having to find someone with whom you can trade goods.

The difficulty that Mike Rees found when he tried to arrange his first exchange was precisely the one Jevons pointed to: no exchange could happen without a double coincidence. The question then became, how do you design a clearinghouse for kidney exchange that can function as an efficient marketplace, but without using money?

Trading Cycles

I was a newly minted game theorist when I arrived at the University of Illinois in 1974. I had just graduated from a Ph.D. program in operations research at Stanford University. Early in my studies, I learned that most of the mathematical tools available for organizing operations focused on things, not people. The kinds of mathematical optimization developed for organizing factories and warehouses

and for scheduling freight trains and passenger planes didn't address the fact that different people may have different goals that might have to be accommodated. The exception was the just-emerging field of game theory — the study of strategic interactions. I gravitated toward game theory because I cared about how people made choices and organized themselves. Game theorists try to put themselves in the shoes of market participants to understand how they might use the strategies that are available to them.

That same year, two veteran game theorists, [Lloyd Shapley and Herb Scarf](#), published an article in the very first issue of the *Journal of Mathematical Economics* in which they posed a thought experiment: *How can people trade indivisible goods if everyone needs just one, has one to trade, and can't use money?* Though Shapley and Scarf didn't have any particular market in mind, they called the goods "houses." As will become clear to you — as it eventually became clear to me — the people in their thought experiment could be incompatible patient-donor pairs, with each pair needing a kidney and having a kidney to trade.

But I was far from thinking about kidney exchange in 1974. Although thought experiments like this one can in time turn into practical tools, they start life as toys. Just as children prepare to be grown-ups by playing, an abstract mathematical model allows economists to play with possibilities in a simplified, uncomplicated way. So Shapley and Scarf had proposed a new toy that could be used to explore how exchange might work in a hard case where you couldn't use money and trade had to be one for one, because everyone had one indivisible item to trade — that is, you couldn't trade something for just a part of something else.

Such trades can take place in *cycles*. The simplest kind of trade would be a two-way cycle, between two patient-donor pairs in which each donor was compatible with the patient in the other pair. A bigger cycle, among three pairs, would accomplish an additional transplant, with the donor from the first pair giving a kidney to the patient in the second pair, the donor in the second pair giving a kidney to the third pair, and the donor in the third pair giving a kidney to the first pair, thus closing the cycle.

Shapley and Scarf showed that for any preferences that patients and their surgeons might have regarding which kidneys they would like, there was always a way to find a set of cyclical trades they called "top trading cycles," with the property that no group of patients and donors could go off on their own and find a cycle of trades that they liked better. Organizing trades this way would help make it safe for surgeons to enroll their patients in such a market, since the patients couldn't do better by trading differently among themselves.

As I began to play with this model, I started to think of it as the potential architecture for a centralized clearinghouse that could help traders overcome the obstacles to barter. But for such a clearinghouse to find the most desirable set of trades, it would need to have access to patients' needs and preferences, and so participation would have to be safe in another way, too.

Since preferences are by and large private information, for a clearinghouse to work people would have to reveal this information. But patients and their doctors might worry that if they told the clearinghouse too much, the clearinghouse might use that added information to give them a less desirable kidney because they were willing to accept it, even when one they preferred was also available. Or they might worry that by trying and failing to get their most preferred outcome, they would lose their chance to get a kidney that was almost as good, because it wasn't their first choice. In 1982, however, I was able to show that top trading cycles made it possible to organize a clearinghouse in such a way as to guarantee to patients and their surgeons that it was [safe for them](#) to be completely candid in revealing this kind of information.

Also in 1982, I moved to the University of Pittsburgh, which had the most active organ transplant

center in the country. Its director, Thomas Starzl, who'd performed the first successful live transplant, was a local hero. I used to see him, surrounded by younger surgeons, at the coffee shop near campus. That put organ transplants at the front of my mind. When I taught about trade in indivisible goods without money, I started using kidneys as an example of what was being exchanged instead of Shapley and Scarf's "houses."

Kidneys were a better example than houses because, in the real world, houses are actually traded for money, but it's against the law to use money to trade kidneys. While students are prepared to tolerate being taught about "toy" models, they're happier when they can see that these simple models might have a practical application. And although I am a great believer in the value of abstract models, I'm also happier when I can see where my work might possibly be heading.

In 1998, I moved to Harvard. Shortly after that, in 2000, the first kidney exchange in the United States took place. In the meantime, progress on another problem had laid the groundwork for more further thinking about kidney exchange. Two Turkish economists, Atila Abdulkadiro ğlu and Tayfun Sönmez, had been looking at the problem of dormitory room allocation — yet another problem where money doesn't play a central role.

Allocating college dorm rooms has more in common with organ exchange than you might think. Some students — freshmen — don't have a room and need one. On the other side, there are rooms that have been vacated by graduating seniors that don't have an occupant. There are also rooms that have an occupant who is interested in trading up for another room he prefers. Now apply this to kidney exchange. Patients with incompatible donors are like occupants who'd like to trade. Patients without a living donor are like roomless freshmen. And deceased-donor kidneys are like the rooms vacated by seniors.

In 2002, a former Ph.D. student of mine from Pitt, Utku Ünver, came to Harvard from Koç University in Istanbul as a research fellow. I suggested we give a lecture on kidney exchange for my market design course. We posted our notes on the Web, and Tayfun, Utku's colleague at Koç, read them and suggested that he join us to collaborate on designing practical kidney exchange.

Our collaboration was intense and tiring, but also exhilarating. The seven-hour time difference between Istanbul and Boston made it seem as if we were working around the clock. When we finished, we had designed an algorithm both for kidney exchange among patient-donor pairs and for integrating these exchanges with "nondirected donors," such as deceased donors (and a growing number of living donors) who'd volunteered to give a kidney to someone in need but who weren't paired with a particular intended recipient.

An exchange that begins with a non-directed donor is a *chain* rather than a cycle, since it doesn't have to return to its beginning: the non-directed donor is an altruistic person who arrives without a patient and is prepared to give a kidney without receiving one in return. In the past, deceased and other non-directed donations had always been directed to someone at the top of the waiting list for deceased-donor kidneys. But kidney exchange now made it possible for a non-directed donation to spark more transplants, since a chain could start with the non-directed donor, include some patient-donor pairs, and end with a donation to someone on the waiting list.

Our algorithm found both top trading cycles among patient-donor pairs and chains that began with non-directed donors, in a way that made it safe for patients and their surgeons to participate. Now all we had to do was turn theory into practice and convince surgeons that we could help them. That wasn't so easy. Doctors don't automatically think of economists as fellow members of the helping professions.

[We posted our paper](#) on the Web and sent copies to kidney surgeons across the country. At first only one doctor, Frank Delmonico, a Harvard surgeon and the medical director of the New England Organ

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