

nosa deploys a metallophore of unknown molecular identity in airway mucus secretions to colonize the lungs of cystic fibrosis patients (9). Ghssein *et al.*'s findings suggest that this metallophore is staphylopine.

Staphylopine is likely to play a central role in the competition between host and microbe for nutrient metals. Future chemical and biological investigations should aim to decipher the interactions between CntA and metal-bound staphylopine. The interplay between staphylopine and host factors that contribute to the metal-withholding response also warrants exploration. Given that *S. aureus* contributes to polymicrobial infections, it will also be important to determine whether staphylopine affects microbe-microbe interactions and the compositions of polymicrobial communities. ■



A strategy for growth. *Staphylococcus aureus* is commonly found in the nose, in the respiratory tract, and on the skin; this false-color SEM image shows the bacteria (0.5 to 1.0 μm in diameter) on finger ridges. Ghssein *et al.* show that the bacteria use staphylopine to capture metals from their environment and support their growth.

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ECONOMICS

Matching markets in the digital age

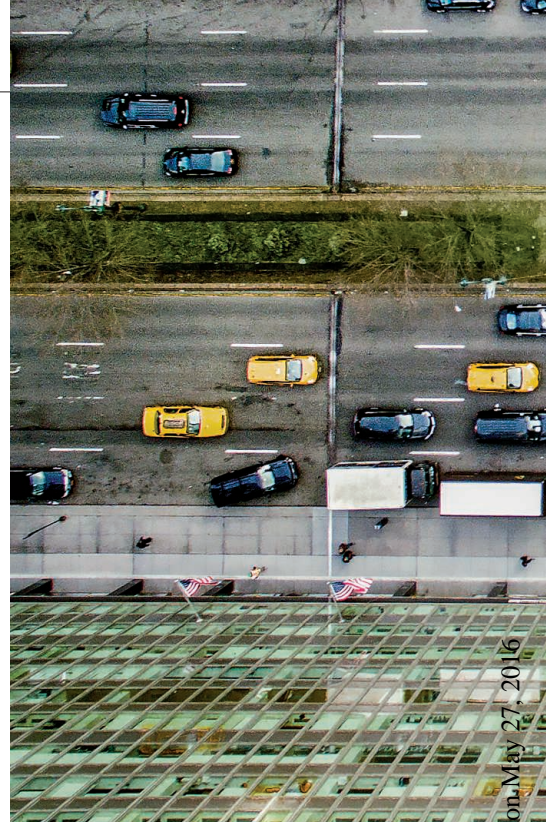
Digital markets make it easier to match companies and customers

By Eduardo M. Azevedo¹ and E. Glen Weyl^{2,3}

Recent advances in information technology are enabling new markets and revolutionizing many existing markets. For example, taxicabs used to find passengers through chance drive-bys or slow central dispatching (see the photo). Location tracking, computer navigation, and dynamic pricing now enable ride-sharing services such as Uber to offer low and consistent delay times of only a few minutes. In a recent study, Cramer and Krueger (1) show that ride-sharing has dramatically increased the usage of drivers and their cars, cutting costs for riders. The results highlight the opportunities provided by digital markets. Further efficiency gains may come from academia-industry collaborations, which could also help to ensure that the markets develop in ways that further the public interest.

Taxi services are an example of what economists call “matching markets.” In such markets, participants care about who they transact with, rather than just about whether a transaction takes place. In the case of taxis, getting a ride from a driver who is miles away is much less convenient for both rider and driver than being matched with a nearby taxi. Similarly, a consumer looking for a new car may find advertising on this topic useful, whereas an automobile manufacturer will find it valuable to reach just these consumers. Other consumers will find such an advertisement to be an annoying distraction. Other examples include dating, travel lodging, personal entertainment, and payments.

Traditionally, these markets have been decentralized and used little technology. Finding a good match has been difficult and



time-consuming. Information technology has improved matching efficiency by dramatically increasing the ability to process the data relevant to making a good match. Cramer and Krueger provide clear empirical evidence of this effect. UberX drivers, who use their own vehicles to drive Uber customers, spend roughly 40% more time and miles with a passenger in their cars than do standard cabs. Other studies have shown that standard cabs are clustered in the wrong parts of cities and that dynamic pricing, which charges higher prices when demand peaks, helps to ensure the consistent availability of cars (2–5). Thus, ride-sharing provides transportation services at a much lower cost than standard cabs by using fewer drivers and cars. It also ensures that consumers who value rides the most get them, even in times of peak demand.

Today's ride-sharing technology has made personal transport more efficient, in the same way that the industrial revolution's power loom made the textile industry more efficient. Many other services have seen remarkable improvements. Advertisements used to be broadcast uniformly across a whole population, many of whom found them useless or worse. On the Internet, tracking technology has made advertisements more relevant to consumers and more useful to firms (6). Elsewhere, people learn in real time about potential romantic matches in their physical vicinity. Listeners discover music through personalized recommendations. In recent years, economists have researched the functioning and design aspects of these markets (7).

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However, advances in enabling these digital marketplaces have emerged mostly from the private sector. Academic involvement has been limited, possibly because these advances require the integration of a range of skills. Cramer and Krueger highlight many factors critical to the value that UberX creates: Computerized optimization of routing allows multiple riders on different routes to share a car through the UberPool system; a simple user interface supplies necessary information; and tight targeting of prices across time and space responds to supply and demand conditions. Given the highly specialized nature of most academic institutions—how often do professors in design schools collaborate with economists?—it is not surprising that such collaboration failed to emerge in academia.

Nevertheless, academic research can augment the performance of these markets for three reasons. First, start-up companies implemented many features while growing rapidly, and the resulting systems are therefore not always optimal. Research can help to fine-tune these features. For example, Chen *et al.* (8) argue that Uber's pricing algorithm, by reacting to instantaneous supply and demand, causes short-lived price spikes. Drivers moving across the city to respond to these spikes often find that prices have fallen by the time they arrive. Hall *et al.* (3) suggest that this may lead to persistent fluctuations in prices following an initial shock. Economists have been familiar with these phenomena since 19th-century agricultural markets (9, 10). It took the introduction of commodities futures to

stabilize markets by allowing consumers and producers to anticipate future prices. Economists who have studied these markets for years may develop more stable algorithms for clearing markets dynamically. More generally, market design researchers may engineer rules to make markets work more efficiently (11).

Second, academic research is important because it produces innovations that are freely available through publications, whereas innovations developed in industry may take years to spread. An example of this spread occurred in the 1990s, when the U.S. government started auctioning radio spectrum rights. It used an auction format developed by academic game theorists in which different goods being sold are bid up in parallel to one another. Many other countries have since adopted this format.

Finally, because matching markets exhibit economies of scale, they tend to be dominated by a few powerful platforms. These platforms may enhance efficiency, but their primary interest is in profit. It is not in the industry's interests to highlight the inconvenient failures of these two standards to align. By contrast, academic research often focuses on how matching platforms should be regulated to ensure that they use their market power in the public interest (12).

For example, Nobel Laureate Jean Tirole has analyzed when credit card companies' practice of requiring merchants to accept both debit and credit cards if they accept one may align or conflict with social welfare (13). In particular, Rochet and Tirole

Picking up business. Traditional taxis—such as those on Park Avenue, New York, shown here—tend to find customers through chance drive-bys. By using location tracking, dynamic pricing, and ride-sharing, companies such as Uber achieve much higher usage of drivers and their cars (1).

have shown that this “honor all cards” rule is often useful to help establish the right balance of payments between credit and debit cards, when only credit cards are subject to competition given that debit cards are tied to a bank account; however, this rule may also in some cases limit the ability of merchants to steer consumers toward the most cost-effective payment method, reducing the efficiency of transactions (14). Similar controversies have arisen regarding the pricing and labor practices of Uber, which have been the subject of legal battles around the world over the past year.

Digital markets offer an exciting chance to make the economy work better. If economists wish to contribute to these gains, they will have to engage in new and challenging collaborations. The increasing presence of economists in the technology industry (one of us works at and the other is visiting a corporate research lab designed precisely to facilitate this sort of collaboration) is a natural locus for this interaction. However, academic institutions should also actively foster this collaboration to harness opportunities for research on unique data and employment of their graduates. ■

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