

## Parag Pathak: Winner of the 2018 Clark Medal

Ariel Pakes and Joel Sobel

**P**arag Pathak was born in the Finger Lakes region of New York State to parents who had immigrated from Kathmandu, Nepal. Parag's father obtained a medical degree in Nepal, did an ear-nose-and-throat residency at Georgetown University, and practiced in New York. Parag's mother went to university in India. She was born into a famous family of priests that dates back to the early nineteenth century. Her grandfather was a noted Sanskrit scholar with the title "Nayaab Bada Guruju," which translates as "Great Teacher" or "Royal Preceptor." Parag has two sisters. Rachana is an assistant attorney general in New York. While Parag was still at home, she taught at Elmira College and Parag was often a sounding board for her lectures. Parag credits her with developing his early interest in social science. Sapana is an emergency room physician in Charlotte, North Carolina. Parag's youth was spent in a scholarly family environment.

Parag received his AB summa cum laude in Applied Mathematics from Harvard in 2002, and a SM in Applied Math the same year. He received his doctorate in economics from Harvard in 2007. Since then, Parag has been employed at MIT where he is presently the Jane Berkowitz Carlton and Dennis William Carlton Professor of Microeconomics. Parag is married to Dr. Rhuma Rjbhandati, and they have two children. The American Economic Association awarded the 2018 John Bates Clark Medal to Parag Pathak for his research on the impacts of educational policies. We will survey some highlights from this work, as listed in Table 1.

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**Parag Pathak**

## An Overview of the Economic Researcher

Parag is part theorist, part empiricist, and fully problem-motivated. His major work is grounded in the institutional details of the educational system. The theory identifies ways to improve that system, while the empirical work determines what aspects of the theory were most important to implement and evaluates the consequences of policy changes. In addition, Parag actively communicates his and his coauthors' findings to the policy community. As a result, those findings have had a major impact on school reforms in many cities both within the United States and abroad. This is a rare combination of qualities for any economist, but especially rare for an economist under the age of 40.

Parag's most influential contributions are about market design and its application to the problem of the allocation of students to schools. That literature dates to a paper by Abdulkadiroğlu and Sönmez (2003) in the *American Economic Review* that motivated the head of the Boston Public School system to contact a group working on mechanism design. New York City, which was using an allocation system that was not functioning well, made a similar request.

Parag and collaborators analyzed the performance of the systems used in Boston and New York and proposed alternatives that were ultimately implemented. Parag's subsequent research on school allocation used theory to deepen our understanding of the implications of both the mechanisms that had not yet been reformed and of the institutional constraints that had been incorporated into some of the reformed allocation mechanisms. These implications were communicated to administrators,

Table 1

## Selected Papers by Parag Pathak

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1. "The New York City High School Match" (with Atila Abdulkadiroğlu and Alvin Roth). 2005. *American Economic Review* 95(2): 364–367.
2. "The Boston Public Schools Match" (with Atila Abdulkadiroğlu, Alvin Roth, and Tayfun Sönmez). 2005. *American Economic Review* 95(2): 368–371.
3. "Leveling the Playing Field: Sincere and Sophisticated Players in the Boston Mechanism" (with Tayfun Sönmez). 2008. *American Economic Review* 98(4): 1636–52.
4. "Strategy-Proofness versus Efficiency in Matching with Indifferences: Redesigning the NYC High School Match" (with Atila Abdulkadiroğlu and Alvin E. Roth). 2009. *American Economic Review* 99(5): 1954–78.
5. "Incentives and Stability in Large Two-Sided Matching Markets" (with Fuhito Kojima). 2009. *American Economic Review* 99(3): 608–627.
6. "Inputs and Impacts in Charter Schools: KIPP Lynn" (with Joshua D. Angrist, Susan M. Dynarski, Thomas J. Kane, and Christopher R. Walters). 2010. *American Economic Review* 100(2): 239–43.
7. "Accountability and Flexibility in Public Schools: Evidence from Boston's Charters and Pilots" (with Atila Abdulkadiroğlu, Joshua D. Angrist, Susan M. Dynarski, and Thomas J. Kane). 2011. *Quarterly Journal of Economics* 126(2): 699–748.
8. "Who Benefits from KIPP?" (with Joshua D. Angrist, Susan M. Dynarski, Thomas J. Kane, and Christopher R. Walters). 2012. *Journal of Policy Analysis and Management* 31(4): 837–60.
9. "Explaining Charter School Effectiveness" (with Joshua D. Angrist and Christopher R. Walters). 2013. *American Economic Journal: Applied Economics* 5(4): 1–27.
10. "School Admissions Reform in Chicago and England: Comparing Mechanisms by Their Vulnerability to Manipulation" (with Tayfun Sönmez). 2013. *American Economic Review* 103(1): 80–106.
11. "The Elite Illusion: Achievement Effects at Boston and New York Exam Schools" (with Atila Abdulkadiroğlu and Joshua Angrist). 2014. *Econometrica* 82(1): 137–96.
12. "The Distributional Consequences of Public School Choice" (with Christopher Avery). 2015. NBER Working Paper 21525.
13. "The Efficiency of Race-Neutral Alternatives to Race-Based Affirmative Action: Evidence from Chicago's Exam Schools" (with Glenn Ellison). 2016. NBER Working Paper 22589.
14. "Charters Without Lotteries: Testing Takeovers in New Orleans and Boston" (with Atila Abdulkadiroğlu, Joshua D. Angrist, and Peter D. Hull). 2016. *American Economic Review* 106(7): 1878–1920.
15. "The Welfare Effects of Coordinated Assignment: Evidence from the New York City High School Match" (with Atila Abdulkadiroğlu and Nikhil Agarwal). 2017. *American Economic Review* 107(12): 3635–89.
16. "Minimizing Justified Envy in School Choice: The Design of New Orleans' OneApp" (with Atila Abdulkadiroğlu, Yeon-Koo Che, Alvin E. Roth, and Olivier Tercieux). 2017. NBER Working Paper 23265.
17. "Demand Analysis Using Strategic Reports: An Application to a School Choice Mechanism" (with Nikhil Agarwal and Paulo Somaini). 2018. *Econometrica* 86(2): 391–444.
18. "Reserve Design: Unintended Consequences and the Demise of Boston's Walk Zones" (with Umut M. Dur, Scott Duke Kominers, and Tayfun Sönmez). 2018. *Journal of Political Economy* 126(6): 2457–79.

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generating both additional impetus for reforms in the older allocation mechanisms and further refinements in those mechanisms proposed by Pathak and his collaborators. The depth of Parag's knowledge of the institutions in Boston and his ability to communicate ways to improve the assignment mechanism to administrators led the late Mayor Thomas Menino to appoint Pathak as chief technical advisor for Boston's student assignment plan in 2013.

While focusing on school assignment, the knowledge of the institutional structures in the educational system that Parag developed led him and his coauthors to innovative empirical work on the impacts of different types of schools in different neighborhoods. This included empirical results on the impact of charters, pilots, and exam schools.

The data generated by the new allocation mechanisms has enabled Parag and a somewhat different set of coauthors (though not totally different; Parag has collaborated extensively with Atila Abdulkadiroğlu on both theoretical and empirical work) to estimate detailed models of school choice that are capable of empirically analyzing a wide assortment of questions. The choice models, in conjunction with different assignment rules, allow for counterfactual analysis that enables a quantitative comparison of different allocation systems. They can also be used to analyze the effect of the assignment mechanisms on students with different characteristics. These papers have proved particularly valuable to administrators, as they clarify just what aspects of the reforms are central to the gains that come from different assignment rules.

### **The Underlying Issue: Allocation Mechanisms That Do Not Involve Price**

Design of a school allocation system is part of a class of problems that arise when objects have to be allocated without the use of prices. In markets where prices are used, allocations are determined by a combination of factors: tastes, the prices of the goods marketed, and endowments. However, there are many circumstances in which society (or a relevant subset like a sports league) does not want to allow endowments to overly impact allocations (the National Basketball Association conducts a draft rather than letting wage offers clear the market for the entering cohort of players). One example is our society's notion that students should have equal opportunity to their preferred schools (at least for the schools in the public school system).

Of course, there is a question of defining what equal opportunity means in this context, but conditional on our definition, we would like to allocate positions in schools in as efficient a way as possible. Families have heterogenous tastes; they differ in their preferences for school characteristics (importantly in the location of the school, but also in the importance of different educational resources). An allocation mechanism with desirable properties requires a procedure for eliciting those preferences. This is done through the requirement that families submit a preference list for the schools in the system. Consequently it would be useful if the allocation mechanism be "strategy proof"; that is, it should be in the interest of families to report their preferences honestly.

What other properties would we like? The most obvious other desirable property is Pareto efficiency; we should not be able to reallocate and improve one person's welfare without reducing somebody else's welfare. For school choice problems a stability property called "no justifiable envy" is also important. Assume that schools assign a priority to each student. An allocation has justifiable envy if a student would prefer another school to his assignment and a student of lower priority has a place at the preferred school.

## The School Matching Problem: Some Background

The goal of the school choice problem is to assign each student to exactly one school. Students submit a ranking of schools to the school administration. Schools have capacities that limit the number of students that they can accept. They also have priorities, which are rankings over students. The priorities reflect institutional restrictions—for example, obligations to serve students who live nearby the school before admitting students who live further away, or to serve students who already have an older sibling in the school. A matching is an assignment of schools to students such that each student is assigned to one school and, for each school, the number of students assigned to the school does not exceed its capacity.

When Pathak began working on this problem, the theoretical literature on matching mostly studied variations on the college assignment problem introduced by Gale and Shapley in a celebrated 1962 paper. Roth and Sotomayor had published a monograph surveying matching theory in 1990. The theory already had significant impact on the design of markets, most prominently in the use of a matching algorithm to assign graduates of medical school to residency programs (Roth and Peranson 1999). The college assignment problem of Gale and Shapley is quite similar to the school choice problem. Students have rankings over colleges, and colleges have rankings over students. Colleges also have capacities that limit the number of students that they can accept. A matching is an assignment of schools to students such that each student is assigned to one college and, for each college, the number of students assigned to the college does not exceed its capacity. Gale and Shapley formulate the problem and then present the "deferred acceptance" algorithm, which is a procedure that generates a matching that has desirable properties. We describe the deferred acceptance algorithm in more detail later.

Abdulkadiroğlu and Sönmez's (2003) paper was the immediate precursor for Pathak's work. Abdulkadiroğlu and Sönmez formulated the school choice problem and compared it to the college assignment problem. They identified the most important formal difference between the problems. In the college assignment problem, each side of the market has preferences defined over the other side (and staying unmatched). Efficient matches have the property that there is no other match that makes all agents and all colleges better off. In school matching, it makes sense to consider the welfare of students, but it is less meaningful to talk about the preferences of schools. A match in the school choice problem is efficient if it is not possible to find another match that makes all students better off.

The literature notes that schools may face constraints about the kind of students they would like. To take account of this, the school matching literature considers allocation mechanisms that are consistent with “priorities”—in particular, the “no justifiable envy” property is conditional on the priorities assigned to students. Priorities may be the same for all schools. For example, if there are district-wide tests, schools may assign higher priority to students with higher test scores. Priorities may be specific to each school. For example, schools may assign higher priority to students who live closer to the school or have an older sibling who attends the school. Priorities may be set by the central administration (as in New York’s system prior to reforms) or by individual schools (as in Boston’s system prior to reforms). Some aspects of priorities may be captured by student preferences, but others will not be. For example, if Student 1 lives close to School 1 and Student 2 lives close to School 2, but Student 1 prefers School 2 to School 1 and Student 2 prefers School 1 to School 2, then the students would be happy with an assignment that places Student 1 in School 2 and Student 2 in School 1. The district, however, might not like the transportation costs associated with this assignment. When students near to the school have higher priority, then the assignment of Student 1 to School 1 and Student 2 to School 2 will not have justifiable envy.

Abdulkadiroğlu and Sönmez (2003) point out that satisfying all three of the desirable properties introduced above—1) strategy-proofness, 2) efficiency, and 3) no justifiable envy—is generally not possible. (This observation is a consequence of a result of Balinski and Sönmez 1999.) Abdulkadiroğlu and Sönmez discuss how the Gale–Shapley deferred acceptance algorithm applies to the school choice problem. The field of market design was emerging from infancy and headed for practical applications.

Parag’s first two papers [1 and 2, as listed in Table 1], published while still a graduate student, appeared in the *Paper and Proceedings* issue of the *AER* in 2005. “The Boston Public School Match” (with Abdulkadiroğlu, Roth, and Sönmez) details the old allocation mechanism in Boston, explains the impact of the absence of incentives for students to report their preferences truthfully in that system, and outlines the way an incentive-compatible system would work in the schooling context. “The New York City High School Match” (with Abdulkadiroğlu and Roth) describes the old New York City high school system and the problems that it created. These articles identified ways in which the existing systems failed to satisfy desirable properties. The authors point to evidence that parents and students were confused about how the mechanisms operated, essentially showing that the mechanism was not strategy-proof and that outcomes were inefficient, leaving students with poorer matches than was possible. These observations explain why New York chose the student-proposing deferred acceptance allocation mechanism that we will describe below.

Subsequently, Parag’s research on school allocation focused on using theory to deepen our understanding of the consequences of different allocation mechanisms given the institutional constraints the schools systems faced. To discuss Parag’s contributions in these matters in more detail, it is useful to describe four mechanisms: serial dictatorship, first preferences first, the student-optimal deferred acceptance mechanism, and the top-trading-cycle mechanism.

In a “serial dictatorship” mechanism, students make choices in sequence. It requires a method, typically based on test scores, which orders students. The first student then picks a favorite school. Subsequent students pick their favorite school subject to availability of seats. Serial Dictatorships are efficient and strategy-proof, but they are guaranteed to lead to stable outcomes only when the priorities assigned to students by every school is equal to the ordering of students. This situation arises in the college matching mechanisms in some countries where students are ordered by outcomes on national entrance exams. Serial dictatorship is inherently unfair because the students who choose early in the sequence have more choices than those who move later. This procedural unfairness influences the final match unless the order students make choices is equal to a common priority of the students.

Prior to Parag’s research, several locations assigned students to schools using some form of a “first preferences first” or the old Boston mechanism. In these mechanisms, students rank schools. Assignments begin by looking at first choices. At each school, students who ranked a particular school first are assigned one-by-one to that school according to the priority assigned by the school until either all the seats at the school are filled or all students who ranked the school first are assigned to the school. If unassigned students remain, the mechanism moves to the next step. The next step looks at the second choice of the students yet to be assigned and assigns these students one-by-one according to priority assigned by the school until no seats remain or all unassigned students who ranked the school are assigned. The  $k$ th step of the algorithm looks at the  $k$ th choice of all students yet to be assigned and proceeds in an analogous manner. This mechanism is not strategy proof. Students should not rank their first choice first if they perceive that there will not be sufficient capacity for them at that school. The two papers published in the 2005 *AER Papers and Proceedings* discuss this weakness of the first-preference-first assignments and explore some of its ramifications.

In the student-optimal deferred acceptance mechanism, students first apply to their first-choice school. Each school rejects the lowest-ranking students in excess of its capacity, keeping the rest of students, but only temporarily. Students not rejected at this step may be rejected later. In the second round, students rejected in the first round apply to the school next in their ranking. Each school considers these students and students who are temporarily held from the previous step together, and rejects the lowest-ranking students in excess of its capacity, keeping the rest of students temporarily. The  $k$ th step of the algorithm looks at the students not yet placed, and proceeds analogously. The deferred acceptance mechanism is strategy proof, and guarantees stability (that is, no justified envy), but not efficiency.

The top-trading-cycle mechanism is a modification of Gale’s top-trading-cycle mechanism introduced in a 1974 paper by Shapley and Scarf. The top-trading-cycle algorithm asks each student to designate their favorite school and each school to designate its highest priority student. Starting with any student, these designations create a chain. The odd elements of the chain are students. The even elements are schools. Following any student is the student’s favorite school; following any school is the school’s highest priority student. Because there are a finite number of students,

any such chain must contain a cycle: a series of designations that begins and ends with the same student. The algorithm assigns students in a cycle to the schools that they prefer most. In the next step of the algorithm, students with assignments are removed; the capacities of schools that received a student are reduced; and once again a cycle is found. This process repeats with the remaining students indicating their favorite school (among those with unused capacity) and schools now pointing to the highest priority unassigned student. The top-trading-cycle mechanism is strategy proof and guarantees efficiency but does not rule out justified envy.

## Parag and School Assignment

As noted, prior to Pathak's work, Boston and many other cities used first-preference-first procedures. The fact that these mechanisms were not strategy proof was a primary reason for the reforms. There are a number of arguments that lead to prioritizing strategy-proofness. Students could "game" the Boston mechanism, and, as a result, students who had more information could do better than others; a fact that Parag explores in joint work with Sönmez [3], work we discuss in more detail later. The strategy-proof mechanism eliminates the incentive to game and with it the potential for confusion when submitting preferences. For the same reason, it enables school districts to advise students sincerely that it is in their interest to report preferences honestly.

Also, it is much easier to estimate the distribution of utility functions from submitted preferences that are truthful than from those that are not. It is the distribution of utilities that is required for the analysis of the welfare implications of different assignment mechanisms (or, for that matter, any other rule change). As is illustrated in Parag's empirical work with Abdulkadiroğlu and Agarwal [15], in order to predict the outcome of the Boston mechanism, one needs a model for how students form their rank-order list when preference orderings can be strategic, and that model should take into account the student's perceptions of what other students are likely to do.

However, the argument that the deferred acceptance algorithm is strategy proof depends on the assumption that students can submit preferences of arbitrary length. For practical reasons, school districts impose limits on the number of schools that students may rank (and students may not take the trouble to submit a complete ranking). If students can rank only a small number of schools, even the deferred acceptance algorithm is not strategy proof. Students may wish to exaggerate their preference for a school, fearing that they will not have a high enough priority to be assigned to one of their top choices. It was already known that it is impossible to find a mechanism that is strategy proof, stable, and efficient, but even strategy-proofness alone may also be hard to guarantee in practice. Motivated by these constraints and a need to advise administrators, Parag has shown that deferred acceptance is still less subject to manipulation than other mechanisms.

“School Admissions Reform in Chicago and England: Comparing Mechanisms by their Vulnerability to Manipulation” (with Sönmez) [10], proposes a way to rank mechanisms that are not strategy proof. This article connects the theoretical results to events related to school choice mechanisms that occurred in Chicago and England around the time they were writing the paper. The Chicago school district changed their assignment system in 2009, asking 14,000 participants to submit preferences under two different mechanisms. The rationale for the change was a concern that the matches were sensitive to unimportant details (“high-scoring kids were being rejected simply because of the order in which they listed their college prep preferences”). However, the change involved moving from a first-preferences-first mechanism that was vulnerable to manipulation to a deferred acceptance mechanism with finite lists that was also vulnerable to manipulation. Pathak and Sönmez [10] provide a framework that can compare two manipulable mechanisms to identify if one is less manipulable than the other. They show that the old Boston mechanism was the most manipulable mechanism, providing an argument in favor of the change. In England, by a 2007 Act of Parliament, the “first-preferences-first” mechanisms were ruled illegal. Just as in Chicago, new manipulable mechanisms were adopted, but Pathak and Sönmez [10] show again that these mechanisms were less manipulable than their predecessor.

One way to see why the deferred acceptance algorithm is harder to manipulate than other procedures is to note that the others are particularly easy to manipulate. Take the Chicago first-preferences-first mechanism in which students submit lists of finite length greater than one. Assume that there are more students than openings at schools so that at least one student is unassigned. Consider a preference profile in which no student can manipulate the Chicago mechanism. It must be the case that students are assigned to their first choice. To see this, note that otherwise one student must be assigned to a school that is not her first choice. But then some school does not fill all of its openings in the first round of the algorithm. An unassigned student could receive a place at that school by ranking it first. This argument suggests that the only preference profiles that are not subject to manipulation in the Chicago mechanism are quite special. The deferred acceptance algorithm will work well with these profiles too.

The deferred acceptance algorithm with finite lists may not be strategy proof, but it is less subject to manipulation than alternatives. There is another reason why the possibility of manipulation may be limited. Pathak (with Kojima) has written about the performance of matching markets with a large number of participants in the paper “Incentives and Stability in Large Two-Sided Matching Markets” [5]. Real school choice problems have a lot of participants, and there is a general intuition that incentives to manipulate may decrease in large markets. These results are relevant for the school choice literature reviewed above, but are more broadly significant for applications of market design to other situations. Kojima and Pathak’s paper [5] also studies what happens when mechanisms permit schools and students to submit truncated lists of preferences. The paper shows that the fraction of participants with incentives to misrepresent their preferences when others are truthful approaches

zero as the market becomes large. Hence, it provides another reason to be reassured that deferred acceptance works well, even when students submit truncated preference lists. The observation that the Chicago mechanism is subject to manipulation unless all students assigned to schools are assigned to their first choice suggests that large numbers alone will not make other mechanisms less subject to manipulation.

The complexity of certain school choice mechanisms leads to distributional concerns that Parag captures in another paper with Sönmez: “Leveling the Playing Field: Sincere and Sophisticated Players in the Boston Mechanism” [3]. The deferred acceptance algorithm identifies a matching that Pareto dominates any equilibrium outcome of the Boston mechanism provided everyone is submitting their true preference ordering. The puzzle is that some parent groups resisted the change from the Boston mechanism to the deferred acceptance mechanism. The paper provides a compelling solution to the puzzle. Pathak and Sönmez look at outcomes of the Boston mechanism when a subset of the population is naïve (and reports preferences honestly) while the rest of the population is strategic. The equilibrium with mixed levels of sophistication may have justifiable envy and, importantly, may lead to an assignment in which the sophisticated agents are better off than they are from the deferred acceptance match. The analysis provides a fairness justification for the deferred acceptance mechanism and explains why changes to school assignment mechanisms—even ones that provide Pareto improvements when all players are sophisticated—need not receive unanimous approval. Hence, the deferred acceptance algorithm “levels the playing field” by eliminating an advantage for strategic sophistication built into the Boston mechanism. As noted above, this was one of the goals of the assignment reforms.

Deferred acceptance algorithms are the most common allocation system recommended by market designers. These mechanisms are attractive because they generate stable outcomes (eliminating justified envy) while maintaining incentives for truthful revelation. They have the theoretical weakness in that they do not provide Pareto-efficient matches. No incentive-compatible mechanism can both eliminate justified envy and guarantee efficiency, but the deferred acceptance mechanism comes close in the sense that it weakly dominates all other incentive-compatible mechanisms that eliminate justified envy. “Minimizing Justified Envy in School Choice: The Design of New Orleans’ OneApp” (with Abdulkadiroğlu, Che, Roth, and Tercieux) [16], establishes a dual result for the top-trading-cycle mechanism. It shows that no incentive-compatible Pareto-efficient mechanism has less justified envy (fewer blocking pairs) than the top-trading-cycle mechanism. Using data from New Orleans (which at the time used a top-trading-cycle mechanism), the paper demonstrates (in a setting not covered by the paper’s theorem) the ability of top-trading-cycle mechanisms to perform better than other procedures that are Pareto-efficient and incentive compatible. The practical message of the paper is a new argument for using top-trading-cycle mechanisms when efficiency is the primary goal.

Pathak has moved from making persuasive arguments that led to changes in allocation systems, to studying details of actual markets to better align theory to practice, to conducting detailed analysis of the performance of school allocation methods.

After schools gained experience with new allocation procedures, there were opportunities to evaluate how the reforms were working. The research brought some new conceptual challenges. Theoretical studies of the college assignment problem recognized that important results required the assumption of strict preferences. For the most part, the literature ignored the problem of a possible tie in the ranking of different preferences. It viewed such ties as unlikely to arise in practice. However, ties are a practical concern in the school assignment problem. For the schools, priorities play the role of preferences. Priorities frequently do not distinguish between pairs of students (two students who both live outside of the school district and have no siblings in the school may have the same priority). One can implement the algorithm by breaking these ties arbitrarily, but tiebreaking rules have consequences. The deferred acceptance algorithm still generates stable and strategy-proof outcomes, but some stability constraints are artificial consequences of tiebreaking rules and may have negative impact on efficiency.

“Strategy-Proofness versus Efficiency in Matching with Indifferences: Redesigning the NYC High School Match” (with Abdulkadiroğlu and Roth) [4] is an example of a study that assesses the consequences of reforms in the matching procedures. Because tiebreaking rules have consequences, it is important to study the implication of different kinds of rules. It is useful to distinguish single-tiebreaking (assigning an order to students that breaks ties the same way for all schools) and multiple-tiebreaking (using different tiebreaking rules at different schools). Motivated by simulation results that showed advantages of single tiebreaking rules, the paper demonstrates that although there are outcomes that can be produced using the deferred acceptance algorithm with multiple tiebreaking that cannot be produced using single tiebreaking, these outcomes will not be student-optimal stable matchings. They also show that there is no tiebreaking rule that is strategy proof and dominates deferred acceptance with single tiebreaking. These results acknowledge that ties may cause problems (single tiebreaking is not guaranteed to lead to a student-optimal stable match), but describe a sense in which single tiebreaking provides as good an allocation as alternatives.

Another way in which the practical implementation of matches differs from the theory is the possibility that priorities differ for different subsets of the schools’ seats. In “Reserve Design: Unintended Consequences and the Demise of Boston’s Walk Zones,” Pathak and coauthors Dur, Kominers, and Sönmez [18] identify unusual properties of matching mechanisms when priorities for school seats have a slot-specific nature. For example, in Boston, initially walk-zone priority applied at half of a school’s seats, while it did not at the other half. Students were allowed to apply to both halves, but the order of their application in both had an important effect on the overall assignment. Surprisingly, the fact that the slots were processed sequentially resulted in an assignment nearly identical to that without any walk-zone priority, despite the perception that walk-zone applicants gain an edge. The paper establishes formal results on priorities and precedence, and describes how transparency on these results contributed to the end of Boston’s walk-zone priority.

## Parag and Educational Policy

As Parag got to know the administrative structure of different school systems, he became aware of opportunities to use that structure to unravel policy-relevant facts on the impacts of other aspects of educational policy. We focus on his contributions to the understanding of the impacts of charter schools and then note how Parag and his coauthors' research have interfaced with broader aspects of educational policy.

In "Accountability and Flexibility in Public Schools: Evidence from Boston's Charters and Pilots," Parag and coauthors (Abdulkadiroğlu, Angrist, Dynarski, and Kane) [7] examine the impact of two competing models of school autonomy in Boston on student achievement. Charter schools are treated as their own independent school districts and are not subject to the teachers' union contract. Pilot schools have most of the flexibility of charter schools but continue to be covered by the union contract provisions for the teachers. The authors use the random assignment nature of lotteries for entry into oversubscribed charter and pilot schools in Boston as a plausible identification strategy. They compare test scores of students with similar backgrounds who applied and were not accepted to an oversubscribed school to an accepted student, three years after the lottery decision was made. The results are striking. On one hand, among the students who subscribe to an oversubscribed charter school, winning the lottery is consistently associated with large increases in test scores. On the other hand, among students who subscribe to an oversubscribed pilot school that use lotteries to determine acceptance, winning the lottery is not associated with increased performance.

These results left open two questions. First, what were the characteristics of the oversubscribed charters that led to their effectiveness in serving the population that applied to them? Second, what were the characteristics of the students who applied and benefitted from them? A series of papers pursued these issues. In joint research with Angrist, Dynarski, Kane, and Walters [8], Pathak conducted the first evaluation of a Knowledge is Power Program (KIPP) charter school using assignment lotteries. The KIPP schools are the so-called "No Excuses" schools and feature a long school day and year, selective teacher hiring, strict behavior norms, and encourage a strong student work ethic. They are the largest charter school system in the United States.

The KIPP schools in Lynn, Massachusetts, were initially undersubscribed and then oversubscribed. Using the lottery system in the oversubscribed years to construct a quasi-experimental evaluation, "Who Benefits from KIPP?" [8] and "Inputs and Impacts of Charter Schools: KIPP Lynn" [6] (both with coauthors Angrist, Dynarski, Kane, and Walters) provide evidence that KIPP Lynn generated substantial score gains for lottery winners, with the estimates being remarkably similar to those reported for Boston charters. The gains seemed a bit larger for those who entered with lower achievement levels.

These results added to a growing body of evidence suggesting that urban charter schools have the potential to generate impressive achievement gains, especially for minority students living in high-poverty areas. A puzzling fact is that there

is little evidence of achievement gains at charter schools outside of high-poverty urban areas. In “Explaining Charter School Effectiveness” [9], Pathak and coauthors Angrist and Walters examine a large sample of charter schools throughout Massachusetts using the lottery research design. The paper indicates that the relatively higher effectiveness of urban charter schools might be explained by adherence to the “No Excuses” approach to urban education discussed above.

One problematic feature of the lottery studies is that they rely on select samples of students: specifically, those who apply to a subset of schools and were lottery assigned. Were a more inclusive segment of the population to attend charters, the average effect of charters might be different. In the paper “Charters Without Lotteries: Testing Takeovers in New Orleans and Boston,” Parag and his coauthors Abdulkadiroğlu, Angrist, and Hull [14] look at schools that were taken over by charters, focusing on students who were grandfathered into the charter system. Following Hurricane Katrina, state legislation allowed the Louisiana Department of Education to take control of and delegate the operation of low-performing schools to outside operators. By 2015, the Recovery School District became the first all-charter school district in the United States. Takeovers of underperforming schools have also occurred in Boston and are increasingly being used in other states and countries. Though there is still some selection involved in the takeover experiments (some students may switch out of the district to which the school is assigned) the selection problem in takeover studies is likely to be much less serious than in situations where student apply to charters. Their results from the takeover studies in low-performing urban environments suggest that charters boost achievement by as much or more than the gains estimated from lottery studies in low-performing urban environments.

There are a number of other educational policy areas where Parag and his coauthors have been influential contributors. In “The Elite Illusion: Achievement Effects at Boston and New York Exam Schools” [11], Parag together with Abdulkadiroğlu and Angrist use a regression discontinuity design to examine whether students who scored close to the acceptance line and were accepted to an exam school in New York and Boston did better than those who were close to the acceptance line but rejected. Marginally accepted students show only scattered gains from attending the exam school. This result depends on the characteristics of the marginally accepted applicants, but it does raise two questions. First, do exam schools help, and if so, whom do they help? Second, overall performance at exam schools is much higher than at alternative schools, so the paper also raises questions on the validity of prior findings of peer effects on school achievement. Prior findings were mixed, leaving the possibility that peer effects matter while Parag’s results suggest instead that students perform better because they are more qualified, since the impact of school assignment (and hence of peer achievement) has a small impact on the marginally accepted students.

Parag’s recent work, as yet unpublished, follows up on themes that were related though not central to his prior work but very much in the public policy debate. “The Efficiency of Race-Neutral Alternatives for Race-Based Affirmative Action: Evidence from Chicago’s Exam Schools” (NBER Working Paper 22589) [13] with Glenn Ellison measures the welfare costs of affirmative-action programs. School districts

wish to balance diversity goals with matching high-quality students to high-quality schools. Ellison and Pathak examine admission procedures at elite public schools in Chicago. These schools have shifted from a system that used explicit race-based quotas to one in which schools admit a fraction of their classes on the basis of performance measures only, while allocating the remaining fraction to districts using (not directly race-based) proxies of neighborhood socioeconomic status. The paper makes the straightforward theoretical observation that when racial diversity is valuable, limiting attention to race-neutral schemes is inefficient. It elaborates upon this observation with an analysis of data from the Chicago school district that provides a quantitative measure of the efficiency costs. Diversity goals lead to a reduction in test scores of elite schools, but in the two schools that are the focus of this study, a race-based system would eliminate more than three-quarters of the reduction that seem to be caused by the school district's race-neutral procedure. The paper points out that Chicago's current system also fails to achieve the socioeconomic diversity achieved by a system that takes race into account. Loosely, the efficiency losses arise because a race-neutral system may give priority to low scorers in one district over higher scorers from demographically similar districts.

Chris Avery and Parag present a model in "The Distributional Consequences of Public School Choice" (NBER Working Paper, 21525) [12] to compare school choice to residential-based assignment when housing markets are modeled explicitly. These papers make it clear that Parag has a lot left to contribute to our understanding of the impacts of different education policies, a fact that is likely to maintain interest in Parag's work for some time to come.

## **Evaluating School Assignment Mechanisms**

With more than ten years of experience, it is now possible to evaluate the impact of reforms to school choice mechanisms. In "The Welfare Effects of Coordinated Assignment: Evidence from the New York City High School Match" [15], Parag and coauthors Abdulkadiroğlu and Agarwal return to the original problem of examining school assignment mechanisms, but now with the data and econometric tools that enable them to assess the impact of the reforms. The empirical assessment allows for the impacts of both administrative constraints and possible behavioral differences from what is assumed in the theoretical results. This is a powerful way to assess the impact of the reforms.

This paper and a related paper with Agarwal and Somaini [17] also break new ground methodologically. To evaluate welfare, one must employ a utility function. The fact that applicants provide an ordered ranking of multiple schools enables the authors to use methodology that allows them to estimate an extremely rich set of utility functions quite precisely. Crucial here is the fact that the submitted ranking order across multiple schools generates an ability to let important characteristics, like school and home location, have coefficients that differ across applicants due to unmeasured factors (for example, a parent whose working day is longer than the

school day may submit a ranking with preferred schools all near a relative's home). The second methodologically innovative aspect of these papers is the development of a framework that can evaluate allocations when the submitted preference lists can be strategic—that is, when truth-telling is not a dominant strategy (as in the Boston mechanism). They also show that under certain cognitive assumptions, there is a sense that truth-telling, on the one hand, and the assumption that each agent best responds to the actual distributions of others' play, on the other, bound the results from different allocation mechanisms.

Prior to the reform, New York high school students applied to 5 out of 600 school programs; they could receive multiple offers and be placed on a wait list. The students were allowed to accept only one offer and one wait list, and the process went on for two more rounds. This is labeled the uncoordinated system. After the reform, all schools were integrated into one match, students could rank up to 12 programs, and the student-proposing deferred acceptance algorithm determined the allocation. In both cases, unmatched students were administratively assigned.

The empirical results show a marked improvement in the distribution of welfare as a result of the reform. There were welfare gains for all groups, but they were largest for the disadvantaged. This was mostly because in the new allocation mechanism, fewer students got none of their listed choices. (These students were allocated in the administrative placement round, leading to assignments less desirable than any of the listed choices.) So the main qualitative finding is that the new system matches more than 80 percent of the students in the main round of the algorithm, while prior to reforms this figure was about 50 percent. The students who are assigned administratively do not have a say in their school assignment.

Parag's paper with Abdulkadiroğlu and Agarwal [15] provides comparative results on the following mechanisms: neighborhood assignment, the uncoordinated system, the reformed system, a student-optimal stable match, Pareto-efficient matching, and a utilitarian optimal matching with equal weight to all individuals (this last requires knowledge of the distribution of utility functions, and hence was not administratively feasible). Big increases in welfare were found when going from the neighborhood assignment to the uncoordinated system, and then again from the uncoordinated system to the reformed system that used a deferred acceptance system with an incomplete ranking of schools. However, further increases in going to Pareto efficiency or to a full deferred acceptance algorithm were very small.

These results are extremely useful to administrators as they provide guidance on where to assign priorities when institutional and perhaps cognitive constraints limit their ability to fully implement one of the theoretically preferred mechanisms.

## Summary

Parag's work has both improved our understanding of important aspects of the education system and improved the system itself. He combines knowledge of how institutions work with a theorist's ability to formulate models, an applied

economist's ability to develop and use tools for program analysis, and a policy adviser's ability to communicate findings and recommend changes to decisionmakers. He formed working relationships with a wide range of colleagues, each of whom could help him unravel different aspects of the problems that he faced. He created relationships with and acquired detailed knowledge of the workings of many school districts, and the problems they face. This allowed him to do innovative empirical work. From the very start of his career, he has been able to use what he learned on the school districts' problems to motivate new conceptual developments and then to use the theory to solve the motivating problem.

He and his coauthors' work on school admission mechanisms, much of it on the impact of different allocation rules, led to improvements being made to those mechanisms over the last decade and a half. When data became available to empirically analyze the impact of the changes, he developed and applied techniques needed to quantify the impacts. This led to further improvements of the institutions. During the interim, he used the institutional knowledge he had gained from studying admission rules to do innovative studies of other central features of education policy, most notably the impact of charters and other semi-autonomous school systems.

Through all of this Parag has paid great attention to detail, both in the institutions being analyzed and in the analysis per se. This is a major reason that his work has been so influential and is a lesson to economists everywhere. The economics profession has a lot of tools. Parag has mastered many and used them—always with utmost care and precision—to bring fresh insight into the analysis of education policy and ultimately to improve the outcomes of our education system.

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