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Identifying the Harm of Manipulable School-Choice Mechanisms†

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An important but under-explored issue in student assignment procedures is heterogeneity in the level of strategic sophistication among students. Our work provides the first direct measure of which students rank schools following their true preference order (sincere students) and which rank schools by manipulating their true preferences (sophisticated students). We present evidence that our proxy for sophistication captures systematic differences among students. Our results demonstrate that sophisticated students are 9.6 percentage points more likely to be assigned to one of their preferred schools. Further, we show that this large difference in assignment probability occurs because sophisticated students systematically avoid over-demanded schools. (*JEL* D82, H75, I21, I28)

The market design literature has reshaped our understanding of school choice in public school systems in the past 15 years. Academically, the seminal work by Abdulkadiroğlu and Sönmez (2003) and other papers demonstrated how to approach this critical public policy issue as a market design problem. Practically, a number of school districts (most notably the Boston School District) followed the recommendations of these researchers to replace their existing school-choice mechanism (hereafter, the Boston Mechanism) with the celebrated Deferred Acceptance algorithm of Gale and Shapley (1962). However, in practice, the Boston Mechanism continues to be the most widely used school-choice mechanism.

The main objection to the Boston Mechanism is that some students can benefit from strategically misreporting their preferences. To see how this incentive arises, consider the order of matching in the Boston mechanism. First, the algorithm assigns as many students as possible to their first-choice school. Second, it then assigns as many of the students as possible who remain unmatched to their second choice,

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and so on. Consider then the strategic situation faced by a student whose first two schools (A and B, respectively) are in high demand, but who has "priority" to attend only the school B. If she truthfully reports school A as her first-choice school, but then does not get a spot, she may not get a spot at school B either, since it could be already filled by students who ranked school B first. She could avoid this risk by instead ranking school B first, where she would be guaranteed a spot by her priority, but then she loses out if there is in fact space at school A. In contrast, truthful reporting of preferences is always a (weakly) dominant strategy in algorithms that economists recommend to replace the Boston Mechanism.

The manipulability of the Boston Mechanism raises a number of key policy concerns. First, this mechanism lowers the overall match quality of school assignments, in the sense that two students might ex post each prefer the others' school spot (yet such trades will not occur). Second, the Boston Mechanism may implicitly discriminate against some students who do not respond appropriately to the complex incentives to misreport their school preferences. This potential becomes even more troubling if the students who lose out in this way already come disproportionately from disadvantaged backgrounds. It was precisely this concern that Boston Public Schools' Superintendent Thomas Payzant cited when he advocated a switch to a deferred acceptance algorithm:

> *A strategy-proof algorithm "levels the playing field" by diminishing the harm done to students who do not strategize or do not strategize well . . . The need to strategize provides an advantage to families who have the time, resources, and knowledge to conduct the necessary research*
> (Payzant 2005).[1]

We provide the first direct evidence of the gains for sophisticated students at the expense of sincere students in the Boston Mechanism. Following the terminology in Pathak and Sönmez (2008), we refer to students who rank schools following their true preference order as "sincere" students. In contrast, students who rank schools by manipulating their true preferences in response to their probability of admission to each school are "sophisticated" students.[2] While there has been much interest in this question both theoretically and empirically, all empirical papers have faced the same identification problem: the researcher cannot know which students are sincere and which students are sophisticated.

We exploit the details of the assignment procedure used by the Wake County Public School System in North Carolina to identify "sophisticated" and "sincere" students.[3] In their application procedure, students have a two-week window during which they must log into a website and submit their preferences. A student is free to change her ranking as many times as she wishes. Moreover, upon each visit, a student learns how many students have ranked each school first. Therefore, a sophisticated

[1] See the literature on student assignment policies in Boston (Abdulkadiroğlu et al. 2005) and New York City (Abdulkadiroğlu, Pathak, and Roth 2005, 2009).

[2] These terms *do not* imply that sincere students are unsophisticated or sophisticated students are insincere. Instead, they are simply shorthand for whether true preferences are submitted. Velez (2015) also uses this terminology.

[3] The Wake County Public School System is the 15th largest school system in the United States (WCPSS 2015).

student benefits from logging into the website multiple times or logging in closer to the deadline. On the other hand, a student submitting her true preferences needs only to log into the website once.

Following this logic, our classification of sincere and sophisticated students is drawn from the number of logins to the application website. Specifically, we classify students who log in once as sincere and those who log in more than once as sophisticated. We then show a series of results to demonstrate that our login proxy for sophistication is capturing important, systematic differences across students. For instance, some students who visit the application website multiple times change their rankings near the end of the selection period by removing popular (i.e., over-demanded) schools from the top of their rankings. More generally, we demonstrate that sophisticated students avoid over-demanded schools by not ranking them as their first choice. As a result, sophisticated students are more likely to receive an assignment but, conditional on receiving an assignment, are less likely to be assigned to a highly over-demanded school.

We then assess Superintendent Payzant's key concern and study the demographics of sophisticated students. We find that the likelihood of being a sophisticated student varies as a function of demographic characteristics. For instance, we find that Asian students are significantly more likely to be sophisticated, while Black students are significantly more likely to be sincere. However, demographic characteristics explain only a small fraction of the variation in the incidence of sophistication, which highlights the importance of our approach for classifying students as sincere or sophisticated.

In general, the welfare impact of sophisticated students on sincere students is ambiguous. On the one hand, a sincere student is harmed by applying to a school to which she has no chance of being assigned. Therefore, when schools have strict priorities, we expect sincere students to be harmed by sophisticated students (see Pathak and Sönmez 2008). On the other hand, in practice, schools do not have strict priorities, and as a result, a student faces a lottery over possible outcomes. This raises the possibility that the Boston Mechanism may in fact favor sincere students.[4] Intuitively, we expect sophisticated students to not apply to the most over-demanded school but instead to a school that is almost as good but at which she stands a greater chance of being assigned. A sincere student is more likely to get into the most over-demanded schools, since the sophisticated students avoid them; however, she is less likely to get into the "next best" schools. Therefore, we expect a sincere student to have more extreme outcomes (including a greater chance of being unassigned).

Our empirical analysis finds evidence that is consistent with these predictions. Sophisticated students (based on our proxy) are 9.6 percentage points more likely to be assigned to a magnet school than are sincere students. This represents a 15.1 percent increase in the likelihood of receiving an assignment. Further, sophisticated

[4] Under a strategy-proof mechanism, a student is not able to express the intensity of her preferences. Under the Boston Mechanism, a student does not rank her favorite school if an alternative gives her a higher expected utility. This induces an efficient sorting of students to schools as the students who are nearly indifferent get lower ranked schools with higher probability, and the students with intense preferences receive their favorite school with a higher probability. See Abdulkadiroğlu, Che, and Yasuda (2011); Miralles (2008); Troyan (2012); Akyol (2013); and Featherstone and Niederle (2014) for formal discussions.

students systematically avoid over-demanded schools. Together, these results suggest that sophisticated students gain an advantage at the expense of sincere students in the Boston Mechanism, supporting a move to a strategy-proof mechanism. Indeed, after consultation with the authors, the Wake County Public School System moved from the mechanism studied here to a strategy-proof mechanism.

These results provide new insights into the complex role of strategic behavior in school choice when the assignment mechanism is manipulable. Earlier work on school-choice assignment has provided evidence of the effects of assignment on long-term, important economic outcomes. For example, Deming et al. (2014) studies college enrollment and degree completion, building on a large literature on the determinants and effects of school quality (e.g., Hanushek 1986; Card and Krueger 1992; and Rivkin, Hanushek, and Kain 2005). Our work complements this literature by analyzing how heterogeneity in strategic sophistication allows some students to improve their assignment outcomes.

Related Literature.—The importance of carefully designing matching mechanisms for school assignment is well-known (Pathak 2011, Abdulkadiroğlu and Sönmez 2013). Further, the Boston Mechanism is known to be manipulatable (Abdulkadiroğlu and Sönmez 2013) and is not Pareto efficient when true preferences are not reported (Ergin and Sönmez 2006). Despite this, the Boston Mechanism continues to be widely used in practice (for example, it is used in Cambridge, Massachusetts; Charlotte-Mecklenburg, North Carolina; Miami-Dade, Florida; Minneapolis, Minnesota; and Tampa-St. Petersburg, Florida, among other places). Strikingly, the Seattle school district replaced the Boston Mechanism with a strategy-proof mechanism only to switch back in 2011 (Kojima and Ünver 2014). Drawing on the matching literature, our goal is to identify the harm of using a manipulatable mechanism to assign students to schools.

Related to our work, several papers have used school-choice data to analyze preference manipulations. Agarwal and Somaini (2014) find evidence of significant gaming of the Boston Mechanism in Cambridge, Massachusetts. The authors use structural estimation to recover cardinal utilities from preference reports and find evidence of strategic manipulations.[5] Using data from Beijing, China, He (2012) estimates a structural model that explicitly accounts for heterogeneous levels of sophistication. He measures strategic behavior with survey responses that parents provided concerning their expected probability of admission into a given school, where strategic behavior implies that one's subjective beliefs equal the empirical distribution from submitted lists.

Finally, Hastings, Kane, and Staiger (2009) (using data from Charlotte-Mecklenburg, North Carolina) and Burgess et al. (2015) (using data from England) have similar sets of findings. Both papers find that students prefer a school with good academic performance and this preference is stronger for higher socioeconomic-status students. Hastings, Kane, and Staiger (2009) take reported preferences as

[5] Interestingly, the authors' estimates suggest that the welfare of the average student would be lower under the Deferred Acceptance algorithm. One explanation comes from Abdulkadiroğlu, Che, and Yasuda (2011), who show that Deferred Acceptance may be ex ante Pareto dominated by the Boston Mechanism.

truthful because they argue that the procedure was poorly understood and students were advised to report truthfully. Burgess et al. (2015) are less concerned with strategic manipulations because some of their data come from districts that use a mechanism that is strategy-proof.

I. Student Assignment in Wake County, North Carolina

We use data from the Wake County Public School System (WCPSS), which is the 15th largest school system in the United States by enrollment, with 153,300 students enrolled during the 2013–2014 school year (WCPSS 2015). Student enrollment is growing at a rate of 2.6 percent per year between the 2006–2007 and 2013–2014 school years. Further, the state of North Carolina is forecasted to be one of the fastest growing states in terms of primary and secondary school enrollment growth over the next decade.[6] There are 170 schools in the system, including 38 magnet schools, which are partially choice-based assignment schools aimed at "reduc[ing] high concentrations of poverty and support[ing] diverse populations."[7]

The school system was formed in 1976 with the voluntary merger of the urban Raleigh City school district with the suburban Wake County school district (Flinspach and Banks 2005). The school system is diverse in terms of race and ethnicity with the following racial composition of enrolled students: 6.8 percent Asian, 24.4 percent black, 15.7 percent Hispanic or Latino, 48.6 percent white (not Hispanic), and 4.5 percent other/multiple races (WCPSS 2015). In 2011, 38.6 percent of students in WCPSS were eligible to receive subsidized meals as part of the Free and Reduced-Price Lunch program, while 50.3 percent of students across North Carolina and 48.1 percent of students across the United States were similarly eligible.[8] Diverse geographical areas are encompassed within the school system including the city of Raleigh, North Carolina (population of 431,746), the town of Cary, North Carolina (population of 151,088), and the surrounding suburban and rural areas.[9]

A. *The Assignment Algorithm in Wake County*

Students in WCPSS are assigned to a base school and can apply for reassignment through the magnet-school application process.[10] Assignment of a student's base school is determined by an optimization algorithm, which (according to WCPSS) "balances proximity to school, building utilization, anticipated growth, and impact of future base attendance areas."[11] The base-school algorithm relies on insights

[6] See http://nces.ed.gov/programs/digest/d13/tables/dt13 203.20.asp.
[7] See http://www.wcpss.net/magnet.
[8] See http://www.ncpublicschools.org/fbs/resources/data.
[9] See http://quickfacts.census.gov/qfd/states/37/3755000.html.
[10] We focus on magnet applications, but there are other ways that students can apply to change their assignment. Students can apply to an application school (test-score dependent schools that are known as exam schools in other districts) or can request a transfer to a school other than their base through the calendar transfer application (requesting reassignment to a year-round school from a traditional-calendar school or vice versa) or non-calendar transfer application (requesting reassignment to any other school in the district on the same calendar as their base school). Magnet applications provide the most interesting variation in terms of heterogeneity in sophistication but our future work will study the other application processes as well.
[11] See http://www.wcpss.net/enrollment-proposal/about-the-plan.html.

from the operations research literature (Taylor, Vasu, and Causby 1999). An important part of the assignment process in WCPSS is that students "lose" their assignment to the base school if they are assigned to a magnet school. As a result, the magnet-application process emphasizes that students should not list a school on their application unless they prefer it to their base school.

Magnet seats are assigned using students' submitted lists of preferences over schools and students' priority points. The construction of priority points in WCPSS is based on the district's *Four Pillars*: student achievement, stability ("stay where you start"), proximity, and operational efficiency. Ties among students with the same number of priority points are broken randomly using a lottery number that is not shown to students. For elementary schools, priority points at school s depend on whether the student's sibling will attend school s next year (highest priority), whether the student lives in a high-performing node based on historical test-score data (second highest), and whether the student's base school is overcrowded (third highest).[12] For middle and high schools, priority points depend on siblings (highest priority), magnet pathway (second highest), magnet non-pathway (third highest), high-performing node (fourth highest), and overcrowded base (fifth highest). The second and third highest priority levels for secondary schools are reserved for students who currently hold magnet seats and are applying to the magnet middle or high school that follows their magnet program's pathway/feeder schools (second highest) or are applying to a magnet school that is not on their pathway (third highest).

Given this priority construction, 90 percent of magnet seats are assigned via the Boston Mechanism (Abdulkadiroğlu and Sönmez 2003). WCPSS used the Boston Mechanism for the reason that Boston and many other districts used it: it is intuitive, easy to explain, and maximizes the number of students assigned to their reported first choice. The Boston Mechanism considers all students who ranked a school first and assigns the highest-priority students up to its capacity, only considering students who ranked it second if seats remain.[13] As explained in the introduction, the main problem with the Boston Mechanism is that students can receive a more-preferred assignment by manipulating their true ranking of schools. This paper focuses on these manipulations and heterogeneity in understanding how to game the algorithm.

Finally, 10 percent of magnet seats are assigned through a pure lottery; specifically, a lottery that is independent of a student's priority points. The district introduced the 10 percent lottery to encourage more students to participate in the magnet application process. WCPSS policy dictates that non-priority students will not be assigned to a magnet seat (non-priority students are those who do not receive points from any of the enumerated priority levels). As a result, many neighborhoods (i.e., those in a non-high-performing node and whose base is not crowded) were excluded from the magnet process before the introduction of the 10 percent lottery.

[12] A node is WCPSS's terminology for a geographic area that is comparable to a large neighborhood.

[13] In partnership with the authors, starting with assignment for the 2015–2016 school year, WCPSS replaced the Boston Mechanism with the Deferred Acceptance algorithm of Gale and Shapley (1962). The present paper considers data prior to the switch and future work will examine how well students appear to understand the fact that the Deferred Acceptance algorithm is not manipulable.

⇩ **School Options Information** (click on school name for more information)

MAGNET SCHOOLS	Program Description	Calendar	Sibling Priority	Transportation	Current 1st Choice Applicants
A. B. Combs Magnet Elementary (XC)	Combs Leadership	Traditional		Parent	13
Brentwood Magnet Elementary (EN)	Engineering Magnet	Traditional		Express	4
Brooks Museums Magnet Elementary (MU)	Museums Magnet	Traditional		Parent	12
Bugg Magnet Elementary (CA)	Creative Arts and Science Program	Traditional		Express	13
Conn Magnet Elementary (GC)	Active Learning and Technology	Traditional		Express	3
Fuller Magnet Elementary (GT/AG)	Gifted and Talented/AG Basics Program	Traditional		Neighborhood	14
Green Elementary (LW)	Leadership and World Languages	Traditional		Parent	3
Hodge Road Elementary (DS)	Spanish Dual Language Immersion	Year Round		Parent	1
J. Y. Joyner Magnet Elementary (LA)	Center for Spanish Language/International Baccalaureate Primary Years Programme	Traditional		Parent	4
Jeffreys Grove Elementary (SI)	Spanish Immersion	Traditional		Parent	1
Kingswood Elementary (MT)	Montessori Program grades PK–03; STEM grades 04–05	Traditional		Parent	3
Partnership Elementary (PE)	School of Choice	Modified		Express	1
Stough Elementary (CI)	Chinese Immersion	Traditional		Parent	3
Washington Magnet Elementary (GT)	Gifted and Talented Program	Traditional		Neighborhood	16
Wiley Magnet Elementary (IN)	International Studies	Traditional		Parent	5

Figure 1. Screenshot of the Application Website

Notes: The figure shows a screenshot of the list of schools available to a given student. Each school name contains a link to their website. The screenshot shows the magnet program(s) available at the school, whether the school operates on a traditional calendar or a year-round calendar, whether the applicant has sibling priority at the school, whether they would be provided bus transportation if assigned to the school, and the number of current first-choice applicants to the school among all applicants who have previously logged in and submitted preferences.

B. *Students' Level of Information*

We now describe the application website where students submit their ranking of schools. Our focus is on how informed students are during the application process. Rankings are not considered submitted until the selection window closes (i.e., students can change their ranking at any point during the two-week period). Further, the website allows students to rank up to 3 schools, out of 23 elementary, 11 middle, and 4 high schools. The ability to rank only three schools is another feature that introduces strategic opportunities. The data contain a record of each time a student's account was used to visit the website, irrespective of whether the student ranked or changed their ranking of schools during the visit.

Figure 1 shows a screenshot of the list of schools available to a given student. Each school name contains a link to their website. Further, the application website shows the magnet program(s) available at the school, including programs such as Gifted and Talented, International Baccalaureate, Language Immersion, etc. It is these specialized programs that are the "magnet" that attracts students to apply to magnet schools. Students are also shown whether the school operates on a traditional calendar or a year-round calendar and whether they would be provided bus transportation if assigned to the school.

It is important to consider what students know about their priority points specifically and probabilities of admission to each school broadly. An important component of the application website is that students are prominently shown the number of "Current 1st Choice Applicants" (as shown in Figure 1). The number of current first-choice applicants updates upon logging into the application website. As a result, a student can log into the application website multiple times to observe the change in relative demand for each school. In fact, we will argue in the next section that the number of times that a student logs in reflects their level of strategic sophistication. We show that some students remove from the top of their list those schools with the highest number of current first-choice applicants (i.e., over-demanded schools). As a result, we argue that some students are logging into the website multiple times in order to manipulate their rankings.

Further, in the process of forming their preferences over schools, students and/or parents visit several schools during the two months leading up to the application selection window. These tours provide information intended to assess the fit of a student to the school and also provide information about the number of available seats the school has at a given grade and the number of applicants to the school last year. Given the information provided on the application website concerning current first-choice applicants and information from the school about capacity and historical demand, students have a good sense of the popularity of each school.

Finally, the application website shows at which school a student has sibling priority, which implies that students know whether they are in the top priority level. Students also know which schools follow their pathway in the transition from elementary to middle to high schools. However, beyond sibling and pathway priorities, priority points for a high-performing node and overcrowded base are not readily obvious. A student may have a sense of the level of crowding of their base, but this information is likely to be imperfect. Further, the historical performance level of a student's node is neither readily obvious nor readily available to students. Our conversations with WCPSS staff indicate that a student can call the district office and ask which priority points they receive, but we have no data on how common this is. Finally, a student's lottery number is never made available to her.

In total, the above discussion suggests that students have a very good sense of which schools are over-demanded and a loose sense of where they fall in the priority order.[14] Taken together, these details have important implications for the exercise of identifying sincere and sophisticated students. A student who knows how over-demanded a school is but not her exact number of priority points faces a difficult strategic decision.

II. Identifying Sincere and Sophisticated Students

We seek to identify which students are sincere and which are sophisticated by using auxiliary data from the application process. In contrast, the related literature uses structural inference of submitted preferences lists but does not identify student-level markers of strategic behavior. Specifically, Agarwal and Somaini (2014) and He (2012) do not classify individual students as sincere or sophisticated in their analysis and instead estimate structural models that allow for strategic behavior. These alternative approaches can be used to identify which students find truth-telling

[14] The school system does not offer general advice to students on the assignment mechanism. Our conversations with WCPSS staff indicate that, when a student asks for details on the specifics of the assignment process, staff will recommend that she consider her probability of admission in her ranking. However, we have no information on how common it is for a student to inquire along these lines.

to be a best response but do not identify which students are sincere and which are sophisticated, which is our goal.[15]

Our application data come from the website where students log in to submit their preference list. We will present evidence that a student's login behavior reveals her type—sincere or sophisticated. As a result, our classification of sincere and sophisticated students is drawn from the number of logins to the application website. While the results that follow are robust to a number of alternative specifications of the login variable, we identify students who log in once as sincere and those who log in more than once as sophisticated. A student can engage in strategic behavior but log in only once to submit their list and a student can log in multiple times but still submit their true list. However, several pieces of anecdotal evidence, along with empirical results that we will present, convince us that our login proxy for sophistication is capturing important, systematic differences among students.

Before classifying students as sincere or sophisticated, we clean the login data to capture *unique* visits to the application website. Specifically, we construct a 30 minute rolling window around each visit and count all visits within the half-hour as a single, unique visit.[16] Based on the number of unique visits, students visit the application website an average of 5.70 times (standard deviation = 12.92) during the selection period of two weeks (January 28 through February 11, 2014). The distribution of visits ranges from 1 to 104 visits, with 1, 2, and 4 visits as the twenty-fifth, fiftieth, and seventy-fifth percentiles, respectively. Using our designation, 63.4 percent of the applicants are classified as sophisticated. See Figure 2 for the distribution of unique visits, separately for students who were assigned or not assigned to a magnet school.

Next, we compare single-visit students (sincere) and multiple-visit students (sophisticated). First, the demographic characteristics we consider are the student's gender, race, and ethnicity. The data contain self-identified designations for race and ethnicity separately. We interact race with ethnicity to create variables that identify non-Hispanic Asian students, non-Hispanic black students, non-Hispanic students of other/multiple races, and Hispanic students. The omitted group throughout our analysis contains non-Hispanic white students. For brevity, we refer to non-Hispanic Asian students as Asian students (likewise for other races). Two other

[15] Different approaches have been taken in the existing literature to measure manipulations in school assignment. First, Agarwal and Somaini (2014) use a regression-discontinuity approach to compare students on either side of the radius around a school, where students within the area around a school have priority at that school, while students outside do not. The authors find discontinuities in the probability of ranking a school first at the proximity-priority boundary. However, if preferences are affected by the information that students are given on their proximity-priority schools (i.e., these schools become focal), then discontinuities do not imply manipulations. Second, Calsamiglia and Güell (2014) use an unexpected change in the determination of neighborhood schools in Barcelona, Spain. The authors find that the number of students ranking the new neighborhood school first increased from 9 percent to 17 percent. Again though, because students are told which school is their neighborhood school, one must assume that this information does not affect preferences. Third, He (2012) presents evidence that students are strategizing using data from a survey that asks which school is "the best." He demonstrates that students often report a best school that is different from the school they ranked first.

[16] A rolling window implies that three visits on a given day at 9:00 PM, 9:29 PM, and 9:58 PM all count as one unique visit, while two visits at 9:00 PM and 9:58 PM each count as a separate visit. We initially used a 1-hour window but found that results using a 1-hour window were less precisely estimated, for a subset of the results that follow, relative to a 30-minute window or a longer window. As a result, we include results that are broadly representative of the effect sizes but more precisely estimated for some of our results. The online Appendix shows the robustness of the results to alternative windows, specifically 1- and 6-hour windows.

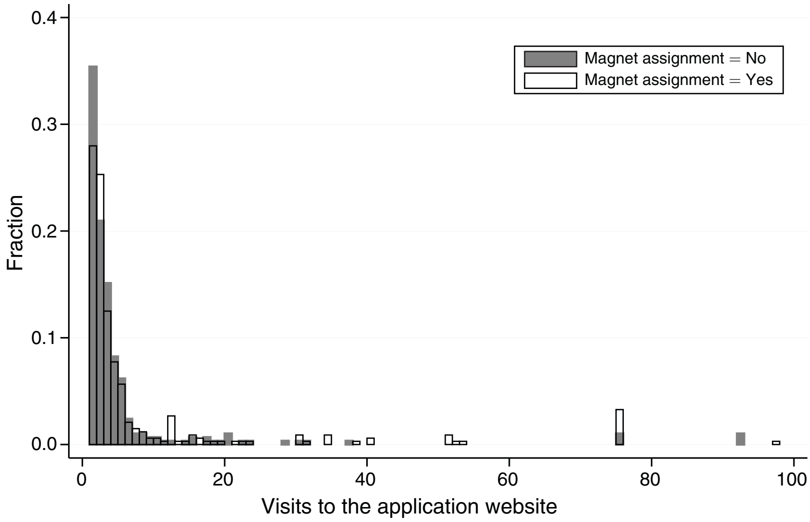

Figure 2. Website Visits by Magnet Assignment

Notes: The figure shows the distribution of unique visits to the application website during the selection period of two weeks (January 28 through February 11, 2014), separately for students who were assigned or not assigned to a magnet school. Unique visits are determined using a 30-minute rolling window around each visit and counting all visits within the half hour as a single, unique visit.

characteristics of interest are whether the student is classified as having limited English proficiency (LEP) or as academically gifted. LEP students are identified as speaking a language other than English at home (self-identified) and in need of additional support (self-identified and staff-identified). Finally, academically gifted students are identified via Cognitive Abilities Test scores that exceed 85 percent; other factors, including classroom performance/growth, can be part of the academically gifted identification process.

Before presenting summary statistics by sophistication, Table 1 summarizes these student characteristics. Column 1 presents the data for all grade-entry students in WCPSS. All of our analysis will focus on grade-entry students because magnet application process outcomes are quite different for non-grade-entry students (i.e., students rising into a grade other than kindergarten, sixth grade, or ninth grade).[17] Next, column 2 includes only magnet applicants, while column 3 includes only successful magnet applicants (i.e., students who were assigned to one of their ranked schools). Finally, columns 4 and 5 are subsets of columns 2 and 3, respectively, where column 4 includes only applicants who have priority points in an intermediate range, which we refer to as non-guaranteed, priority students (NG Priority).

The NG Priority restriction excludes: students with no priority points because WCPSS does not assign students without priority points to magnet seats (except through the 10 percent lottery), and students whose priority points are high enough

[17] For example, non-grade-entry students do not get sibling priority. Further, non-grade-entry students make up a small portion of the applicant pool and are dramatically less likely to receive a magnet assignment.

Table 1—Summary Statistics of Student Characteristics

	All (1)	Applicants (2)	Successful (3)	NG Priority applicants (4)	NG Priority successful (5)
Female	0.485	0.504	0.490	0.494	0.494
Asian	0.078	0.165	0.192	0.114	0.106
Black	0.221	0.240	0.235	0.336	0.412
Other race	0.041	0.050	0.049	0.055	0.059
White	0.505	0.476	0.463	0.382	0.294
Hispanic	0.155	0.070	0.062	0.113	0.128
LEP	0.120	0.067	0.067	0.062	0.079
Gifted	0.190	0.321	0.413	0.093	0.128
Observations	32,953	3,790	2,416	627	328

Notes: The table presents means for several student characteristics using data from applications for seats for the 2014–2015 school year in the Wake County Public School System (WCPSS) in North Carolina. We include all grade-entry students in WCPSS in column 1. Columns 2 through 5 include only applicants to the magnet assignment process; this sample excludes students whose assignment was the result of the 10 percent assignment lottery (233 students) or was the result of an administrative assignment (176 students for reasons including special educational needs, etc.). Column 2 includes students who submitted a magnet application. Column 3 includes all who submitted a magnet application and received assignment at one of their ranked schools. Column 4 includes all non-guaranteed, priority (NG Priority) magnet applicants. Column 5 includes NG Priority magnet applicants who received assignment. NG Priority students excludes guaranteed students (with a very high number of priority points) and non-priority students (with no priority points). The student characteristics are as follows: female students, non-Hispanic Asian students, non-Hispanic black students, non-Hispanic students of other or multiple races (which includes American Indians, Alaskan Natives, multiracial students, Native Hawaiians, and other Pacific Islanders), non-Hispanic white students, Hispanic students, limited English proficiency (LEP) students (identified by WCPSS based on factors such as home language), and academically gifted students (identified by WCPSS based on factors such as test scores).

that they are guaranteed a seat at the magnet school they ranked first. For example, WCPSS policy guarantees seats to students with sibling priority and, for secondary schools, students who apply to their pathway/feeder school. Our analysis focused on students who have nonzero priority points, but who are not guaranteed a seat, because these are the students for whom our analysis is most tightly linked to the matching theory literature.[18] It is important to note that NG Priority applicants are only 17 percent of total applications.

Comparing columns 1 and 2 of Table 1 reveals several differences between the applicant pool and the non-applicant pool. Specifically, magnet applicants, relative to non-applicants, are significantly more likely to be Asian and academically gifted but much less likely to be Hispanic and LEP. Smaller differences exist for other characteristics: applicants are also more likely to be female, black, and other/multiple races but are less likely to be white. Comparing columns 2 and 3 indicates that students whose magnet applications are successful are different from unsuccessful applicants. Specifically, successful magnet applicants, relative to unsuccessful applicants, are more likely to be Asian and academically gifted, but other differences are

[18] Our analysis de-emphasizes guaranteed students (with a very high number of priority points) or non-priority students (with no priority points). Guaranteed students have a less interesting strategic decision because they have enough priority points to obtain their desired school, irrespective of the degree to which they strategize. Non-priority students have a less interesting strategic decision because they will not be assigned to any school except through the 10 percent lottery; the 10 percent lottery seats are awarded based on a student's first choice, implying that a non-priority student should always truthfully list her first choice, removing her strategic incentive.

smaller or nonexistent. The implications of columns 1, 2, and 3 of Table 1 are that the magnet application process is being used, and being successfully used, differentially by different types of students.

To understand whether this fact ought to be of concern to policymakers, we analyze heterogeneity in strategic sophistication among these students. Before doing so, columns 4 and 5 of Table 1 show the main students of interest for our analysis (non-guaranteed, priority students), with applicants in column 4 and successful applicants in column 5. The key item of note from comparing column 2 to column 4 is that non-guaranteed, priority applicants are different than all applicants in terms of race/ethnicity but also strongly in terms of academically gifted status. Since academically gifted students receive high priority status, it *necessarily* holds that a substantially smaller share of non-guaranteed priority applicants are academically gifted. Finally, several interesting findings emerge from comparing column 3 to column 5, but these findings are more cleanly evident in our formal analysis of magnet assignment probability; we defer this discussion until Section IVA.

After classifying students as sincere or sophisticated, we find in Table 2 that Asian students are significantly more likely to be classified as sophisticated, while black students are significantly more likely to be classified as sincere. Further, academically gifted students are also more likely to be classified as sincere. However, as just emphasized, academically gifted students also have more priority points than non-academically gifted students, on average. Students with more priority points have a lower incentive to be sophisticated because often they are guaranteed assignment at their first choice; this is an important motivation for our focus on non-guaranteed, priority students in order to highlight strategic ranking behavior as a driving factor in assignment outcomes.[19] All of these differences are simply unconditional raw probabilities and should not be taken as causal. But Table 2 does suggest that sincere and sophisticated students differ along some observed dimensions (e.g., race) but not others (e.g., gender).

III. Evidence of Strategic Behavior

To provide evidence in favor of our classification of students as sincere or sophisticated, we test several hypotheses.

HYPOTHESIS 1: *Sophisticated students will receive a magnet assignment with a higher probability*, *relative to sincere students.*

Sophisticated students are more likely to receive a magnet assignment, unless preferences of sincere and sophisticated students are drawn from systematically different distributions. This is the case because sophisticated students are responding to their probability of admission to schools, while sincere students are submitting their

[19] Because academically gifted status raises a student's priority, academically gifted students appear in our sophisticated sample less often because of their high number of priority points. As emphasized in the text, the analysis that follows controls for priority points and other factors when looking at the differences between sincere and sophisticated students.

Table 2—Fraction of Sophisticated Students by Student Characteristics

	Mean (1)	Difference (2)
Male	0.631	
Female	0.637	0.006
		(0.016)
Non-Asian	0.618	
Asian	0.697	0.079
		(0.020)
Non-black	0.644	
Black	0.592	−0.051
		(0.019)
Non-other race	0.634	
Other	0.584	−0.050
		(0.037)
Non-white	0.634	
White	0.629	−0.005
		(0.016)
Non-Hispanic	0.629	
Hispanic	0.660	0.031
		(0.030)
Non-LEP	0.634	
LEP	0.630	−0.004
		(0.031)
Non-gifted	0.656	
Gifted	0.587	−0.069
		(0.017)

Notes: The table includes all magnet applicants. We classify students who log in to the WCPSS application website once as sincere and those who log in more than once as sophisticated. Column 1 indicates the fraction of students of a given characteristic who are classified as sophisticated. Column 2 indicates the difference between the fraction sophisticated across the two levels of the characteristic. Standard errors are in parentheses.

true preferences regardless of admission probabilities. As a result, sophisticated students will be more likely to receive admission.

HYPOTHESIS 2: *Sophisticated students will be assigned to a less over-demanded school*, *relative to sincere students*, *conditional on receiving a magnet assignment.*

If a sincere student receives a magnet assignment, then she is more likely to be assigned to a highly over-demanded school. Hypothesis 2 is a direct implication of Hypothesis 1. If sincere students are applying to and sophisticated students are avoiding the most over-demanded schools, then sophisticated students will be assigned to less over-demanded schools.

HYPOTHESIS 3: *Students who have a younger sibling are more likely to be sophisticated than sincere.*

Students who have a younger sibling can affect the assignment of their younger sibling because of sibling priority. Specifically, the younger sibling is guaranteed admission to the school if the older sibling is assigned to it. Because of the greater payoff from being sophisticated, we predict that older siblings are more likely to be sophisticated.

To test these hypotheses, we use data from applications for seats for the 2014–2015 school year. The analysis excludes students whose assignment was the result of the 10 percent lottery (233 students) or was the result of an administrative assignment (176 students for reasons including special educational needs, etc.). After these exclusions, our main dataset consists of 3,790 students who submitted a magnet application, 63.8 percent of whom received a magnet assignment. Further, when comparing students' assignment outcomes (Hypotheses 1 and 2), we restrict attention to non-guaranteed, priority (NG Priority) students; as previously discussed, this excludes guaranteed students (with a very high number of priority points) and non-priority students (with no priority points). NG Priority applicants are only 17 percent of total applications. Finally, recall that we focus on entry-grade students, that is, students whose next grade is kindergarten, sixth grade, or ninth grade.

Before presenting evidence testing these hypotheses, we emphasize that our empirical setting is especially appropriate for understanding the effects of strategic behavior on assignment outcomes in school choice. Recall that the students whose outcomes we study have an existing assigned school (i.e., their base school) and are applying to change their assignment to a preferred magnet school. Further, only 63.8 percent of these students received a magnet assignment, implying a nontrivial chance of being unassigned (i.e., a student remains assigned to her base school). Finally, recall that students can only list three schools in their magnet application, which is highly truncated relative to the choice set. This implies an even greater role for strategic behavior relative to a setting using a manipulable mechanism but a less highly truncated list. These factors provide a large scope for a sophisticated student to gain an advantage in assignment outcomes, if our hypotheses hold.

A. *Probability of Magnet Assignment*

Table 3 presents the results of a Probit regression where the dependent variable is equal to 1 if the student received a magnet assignment, focusing on non-guaranteed, priority students. Priority points and controls for grade level are added in column 2. Further, other student characteristics are added in column 3, specifically the student's gender, race/ethnicity, status as having limited English proficiency (LEP), and status as academically gifted. Finally, column 4 adds fixed effects for the zip code of the student's home address. These zip code fixed effects control for unobserved characteristics of the student's neighborhood, which are important because of residential segregation along characteristics such as income.

In support of Hypothesis 1, column 1 shows that sophisticated students are 8.6 percentage points more likely to receive a magnet assignment. When adding controls, the probability-of-assignment advantage for sophisticated students is 10.0, 9.7, and 9.6 percentage points in columns 2 through 4, respectively. The effect size represents a quantitatively large and statistically significant effect of sophistication

Table 3—Determinants of Receiving a Magnet Assignment

	(1)	(2)	(3)	(4)
Sophisticated	0.086	0.100	0.097	0.096
	(0.043)	(0.043)	(0.040)	(0.039)
Priority points		3.324	2.978	3.036
		(0.830)	(0.807)	(0.881)
Middle school		0.047	−0.170	−0.288
		(0.052)	(0.054)	(0.048)
High school		0.110	−0.067	−0.072
		(0.048)	(0.049)	(0.046)
Female			0.006	−0.008
			(0.038)	(0.036)
Asian			0.067	0.157
			(0.061)	(0.062)
Black			0.325	0.257
			(0.041)	(0.047)
Other race			0.173	0.126
			(0.080)	(0.073)
Hispanic			0.155	0.096
			(0.063)	(0.062)
LEP			0.211	0.174
			(0.078)	(0.081)
Gifted			0.347	0.327
			(0.054)	(0.054)
Zip code fixed effects	No	No	No	Yes
Observations	627	627	604	598
log likelihood	−430.998	−419.564	−370.272	−324.669

Notes: The table includes non-guaranteed, priority magnet applicants (i.e., students who have nonzero priority points but who are not guaranteed a seat). The dependent variable in this Probit regression is equal to one if the student received a magnet assignment. The "Priority points" variable is the student's number of priority points received in the magnet assignment process. During the year under study, WCPSS used a single variable for priority points that was calculated after students' lists were submitted. "Middle school" and "High school" are dummy variables that equal one if the student is rising into sixth grade or ninth grade, respectively. Zip code fixed effects are included in the final column using the student's home address in the WCPSS data. Marginal effects are shown, defined as the effect of a one unit change in each independent variable on the predicted probability that the dependent variable equals one, evaluated at the mean of each independent variable. Robust standard errors are in parentheses.

on magnet assignment. Recalling that 63.8 percent of students received a magnet assignment, our results imply that sophistication is associated with a 15.1 percent increase in the likelihood of assignment. This large effect provides strong evidence that our proxy for sophistication is picking up important features of how students behave with respect to the assignment process. Further, note that students with a higher priority are assigned more often, which is a useful sanity check.

The other results of note in Table 3 concern demographic and other student characteristics that affect magnet assignment. We find a quantitatively small effect of gender but quantitatively large effects of race/ethnicity.[20] Next, students with

[20]The results for race/ethnicity on magnet assignment suggests that black students have a higher probability of assignment than white students (the omitted group). This is an interesting pattern because magnet schools are

limited English proficiency are 17.4 percentage points more likely to receive a magnet assignment. We do not have an explanation for this result, but we note that there are a small number of LEP-identified students included in this regression and thus we avoid saying too much about a very small, specialized group. Finally, students designated as academically gifted are 32.7 percentage points more likely to receive a magnet assignment, which is intuitive because some magnet seats are reserved for academically gifted students.

B. *Demand of the Assigned School*

Hypothesis 2 says that sophisticated students will be assigned to a less over-demanded school, relative to sincere students, conditional on receiving a magnet assignment. Conditioning on magnet assignment allows us to separately isolate the two effects of sophistication: probability of assignment versus demand of the assigned school when assigned. Given that we have shown that sophisticated students receive an assignment more often, we now study the school to which they are assigned. The outcome of interest is the assigned school's demand among magnet applicants, which is measured by its over-demanded ratio. This ratio equals the number of first-choice magnet applications received by the school divided by its capacity (e.g., equals two when there are two first-choice applicants for each seat). As in the previous section, only non-guaranteed, priority students are considered.

Table 4 reports the results of an OLS regression of the over-demanded ratio of the student's assigned school, conditional on the student receiving a magnet assignment. With the full set of controls, we find that sophisticated students are assigned to less over-demanded schools, conditional on receiving a magnet assignment, in keeping with Hypothesis 2. The magnitude of the effect suggests that sophistication is associated with 0.09 fewer first-choice applicants per seat, on average. The mean of the over-demanded ratio in this regression sample is 1.33 first-choice applicants per seat, implying that sophisticated students are assigned to schools that have 6.4 percent less demand. The other results in Table 4 are as follows: higher priority is associated with more over-demanded schools, which is intuitive; assigned elementary schools have higher over-demanded ratios relative to middle and high schools; there are moderate effects of gender and race/ethnicity on demand of the assigned school, but the effects are noisily estimated; unlike with assignment probability, there are no differences in outcomes for LEP students in terms of demand; and finally, academically gifted students are assigned to more over-demanded schools.

Our conclusion is that the evidence supports Hypothesis 2, suggesting that sophisticated students are avoiding over-demanded schools and receiving seats at less over-demanded magnet schools. This analysis looks only at the characteristics of the schools to which sincere and sophisticated students are assigned. We demonstrate that the outcomes of sophisticated students are consistent with our hypothesis that

intended to attract high socioeconomic groups to schools located in low socioeconomic neighborhoods. The likely explanation is that black students apply to magnet schools that are less over-demanded than those of white students, which is consistent with the next section's results on demand by race/ethnicity. One possible reason for this difference could be preferences concerning the racial makeup of schools, where black students may prefer schools with higher percentages of minority students and such schools may be less over-demanded overall.

Table 4—Determinants of Demand of a Student's Assigned School

	(1)	(2)	(3)	(4)
Sophisticated	0.029	−0.019	−0.035	−0.086
	(0.057)	(0.047)	(0.044)	(0.044)
Priority points		4.778	4.399	3.915
		(1.123)	(1.117)	(1.144)
Middle school		−0.338	−0.431	−0.321
		(0.063)	(0.069)	(0.087)
High school		−0.473	−0.496	−0.484
		(0.039)	(0.042)	(0.054)
Female			0.050	0.047
			(0.045)	(0.047)
Asian			0.197	0.039
			(0.090)	(0.105)
Black			−0.072	−0.062
			(0.056)	(0.059)
Other race			−0.144	−0.072
			(0.079)	(0.072)
Hispanic			−0.005	−0.033
			(0.134)	(0.118)
LEP			−0.030	0.005
			(0.088)	(0.074)
Gifted			0.218	0.261
			(0.083)	(0.081)
Zip code fixed effects	No	No	No	Yes
Observations	328	328	320	320
Adjusted R^2	−0.002	0.270	0.315	0.420

Notes: The table includes non-guaranteed, priority magnet applicants who received a magnet assignment. This table replicates the specifications in Table 3, except replacing the dependent variable with the over-demanded ratio of the student's assigned school, conditional on the student receiving a magnet assignment. A school's over-demanded ratio equals its number of first-choice magnet applications divided by capacity (e.g., equals two when there are two first-choice applicants for each seat). The econometric specificaiton is an OLS regression. Robust standard errors are in parentheses.

these students avoid over-demanded schools in order to receive assignment more often. To complete the story, we also need to consider the schools ranked by sincere and sophisticated students, in addition to their assigned schools. Section IV presents this analysis and provides further support for our argument that sophisticated students are systematically avoiding over-demanded schools. Before doing so, we present additional evidence in favor of our novel classification methodology for identifying sincere and sophisticated students in school-choice matching mechanisms.

C. *Birth Order and Sophistication*

According to Hypothesis 3, students who have a younger sibling have a larger incentive to be sophisticated because their assignment confers higher priority to their younger sibling.[21] An ideal test would identify all children in the county, but

[21] We identify siblings as students who live at the same physical address, including apartment number if present. This approach falsely identifies a very small number of non-sibling students who share an address, possibly because

Table 5—Fraction of Sophisticated Students by Birth Order

	All levels (1)	Elementary (2)	Middle (3)	High (4)
Not oldest	0.600	0.681	0.605	0.470
	(0.017)	(0.024)	(0.032)	(0.032)
Other	0.648	0.734	0.648	0.574
	(0.009)	(0.017)	(0.013)	(0.017)
Difference	−0.048	−0.053	−0.043	−0.104
	(0.019)	(0.029)	(0.035)	(0.036)
Observations	3,626	1,087	1,481	1,058

Notes: The table includes all magnet applicants, excluding twins and triplets. We show the mean fraction of students who are classified as sophisticated, depending on the student's siblings who are observed in the data. We identify siblings as students who live at the same physical address, which is how WCPSS identifies siblings. A student who is identified as having an older sibling is in the "Not Oldest" category. All other students are in the "Other" category, which includes students who are identified as having a younger sibling and students who are identified as not having any sibling. Specifically, the "Other" category includes students that we identify as having a younger sibling in a WCPSS school, students who are the oldest child but whose younger siblings have yet to enter WCPSS, students who are the youngest child but whose older siblings have already graduated, and students who do not have any siblings. Robust standard errors are in parentheses.

our data are limited to students currently attending a WCPSS school. As such, we put students into two groups: the first group contains students that we identify as having an older sibling, while the second group contains all other students. This second group contains four types of students: (1) students that we identify as having a younger sibling in a WCPSS school, (2) students who are the oldest child but whose younger siblings have yet to enter WCPSS, (3) students who are the youngest child but whose older siblings have already graduated, and (4) students who do not have any siblings. Types (1) and (2) of those in the other students category are the students that we would like to have as the comparison group in our test, but Types (2), (3), and (4) of those in the other students category cannot be distinguished from one another. As a result, we simply ask whether students who we know are not the oldest behave in a way that is consistent with differential behavior of oldest and not-oldest children.[22]

Consistent with Hypothesis 3, Table 5 shows that students who we know to be a younger sibling are less likely to be sophisticated than other students. Looking at all students, not-oldest siblings are 4.8 percentage points less likely to be sophisticated.

they cohabitate but are unrelated or are related but not siblings. Further, students may live at the same physical address but different specific residences, such as multifamily dwellings that do not report separate unit numbers (e.g., a long-term hotel or homeless shelter). However, we identify siblings following WCPSS's approach when assigning sibling priority and the relevant question in our sibling analysis is whether a student will have sibling priority.

[22] We exclude twins and triplets from Table 5 because these sets of students are co-applying for the same grade in their applications.

The predicted relative levels of sophistication hold in all three grade levels and the difference increases in grade level. In particular, not-oldest high school students are 10.4 percentage points less likely to be sophisticated than other high school students. The fact that this difference is largest for high school students cuts against an alternative interpretation of these results, specifically that not-oldest students are more familiar with the application website because their older sibling previously used the website. Given that our proxy for sophistication is drawn from students' login intensity, students may be logging in multiple times because they are unfamiliar with the website. However, high school students are likely to have previous experience with the WCPSS application process, which implies that the large difference in sophistication for high school students runs counter to this familiarity hypothesis. As a result, we interpret Table 5 as supportive of the hypothesis that oldest children are more likely to be sophisticated because of the incentive imbedded in the sibling priority.

D. *Robustness Checks and Additional Evidence*

The online Appendix includes further evidence. We present several robustness checks to demonstrate the choice of specification does not alter our conclusions. We also present additional hypotheses in favor of our classification of students as sincere or sophisticated. This section provides an overview of the evidence in the online Appendix.

The robustness checks in the online Appendix show that the definitions and specifications used in our main results are remarkably robust to several alternatives. First, we count each student's number of visits to the application website using different methodologies. Second, we proxy for sophistication with more nuanced measures of website visits rather than a discrete measure. Third, we redefine our discrete measure of sophistication to incorporate login timing into the classification of a student as sincere or sophisticated. Finally, we estimate the determinants of assignment outcomes separately by grade level. The quantitative magnitudes of the results in terms of assignment probability and demand are very stable across this battery of checks. The statistical precision of the results is highly consistent for assignment probability and somewhat consistent for demand. There are specifications in the online Appendix in which the effect of sophistication on demand is statistically insignificant but, in these specifications, the effect size is similar to the included results. We conclude that our main results hold up to a large number of robustness checks.

To provide more detail, the online Appendix includes the following specifications: different rolling windows (specifically, one and six hours) in which we count visits to the application website as overlapping; a continuous measure of sophistication where we use a log transformation of the student's number of unique visits to the application website; a categorical measure of sophistication where we use four categories of visits (two, three, four, and more than four visits) relative to students who visited only once; a discrete measure of sophistication that excludes students who logged in only once but whose single login was during the last two days of the application period; and separate estimation by grade level: elementary, middle, and high school.

These checks are primarily intended to demonstrate robustness but two of the results are of independent interest. First, the results we observe in terms of assignment probabilities and demand are driven by the most-frequent website visitors, specifically students who visited the website more than four times (20.8 percent of students). This is consistent with our argument that sophisticated students are repeatedly visiting the application website to observe the growth in demand of schools by observing changes in the number of current first-choice applicants as shown on the website. Second, there is some evidence of heterogeneous effects by grade level such that the effect of sophistication on assignment is largest for middle and high schools, while the demand results suggest that the effect is largest for high school. However, we are limited in how far we can take any interpretations of these differences because of concerns over a multiple hypothesis testing problem (see, e.g., List, Shaikh, and Xu 2016).

The summary of the additional evidence in the online Appendix is that additional hypotheses can be tested to support our classification of students as sincere or sophisticated; the evidence provides further support for our approach. First, we show that sophisticated students rank more choices than sincere students. Sophisticated students are 4.1 percentage points less likely to list only one school and 3.0 percentage points more likely to submit a list that uses all three slots. Second, we find that sophisticated students whose magnet applications were unsuccessful are more likely to exit the school system than unsuccessful sincere students.[23] Further, we do not observe a difference in exit probability for sophisticated students whose applications were successful (i.e., sophisticated students who were assigned) relative to successful sincere students. Our hypothesis is that sophisticated students have a better understanding of the assignment process and thus may also have a better understanding of their outside options (i.e., the schools available to them if they are not assigned to their preferred magnet school(s)). Our results support this conjecture. More importantly for our purposes, these two additional hypotheses allow us to provide further support for our approach for classifying students as sincere or sophisticated.

IV. Sophistication and Ranking Behavior

To fully understand how aggregate assignment outcomes are achieved, we use data from students' rankings during the two-week application period. Recall that, in our empirical setting, students can change their rankings at any point during the two weeks and upon each visit are shown the number of current first-choice applicants of all applicants who have already logged in. This section uses data on each student's rank-ordered list of schools that she entered upon first visiting the application website as well as any changes made upon additional visits (switches). The evidence presented thus far strongly supports our hypotheses that sophisticated students receive an assignment more often and, when assigned, are assigned to less

[23] To make these comparisons, we merge our applicant data with the following school year's data on whether a student holds a seat at any school in the system (their base school, a magnet school, or any other WCPSS school). Otherwise, a student is said to have exited.

over-demanded schools. What remains for us to show is that sophisticated students are systematically avoiding over-demanded schools.

These results are of primary importance to understanding strategic behavior in school-choice settings; however, we present these results after the results on aggregate outcomes because the data on switches are necessarily incomplete. This analysis is incomplete because we only observe students who switched, not students who considered switching. Our delineation of students as sincere and sophisticated conjectures that sophisticated students consider their admission probabilities in their ranking behavior. Observing that a sophisticated student does not switch could suggest that this student never considered her admission probabilities or the number of current first-choice applicants (which suggests that we incorrectly classified her as sophisticated). Alternatively, observing that a sophisticated student does not switch could suggest that her current ranking remains optimal (either because it does not lead her to meaningfully change her beliefs about her admission probabilities or because the current ranking is optimal under both sets of beliefs).

In these data, 130 students switch their rankings during the application period. This rate of switching represents 5.4 percent of sophisticated students. By definition, 0 percent of sincere students switched because these students logged in only once. Our hypothesis is that many more of the sophisticated students considered switching but did not find it optimal to do so. Because this counterfactual cannot be tested in the data, the analysis provided here looks at the ranking behavior of the switchers relative to the non-switchers. For switchers, we will separately consider these students' initial rankings and their final rankings; the initial rankings are those entered upon the student's first visit to the application website, while only the final rankings affected their assignment.

The results are shown separately for elementary, middle, and high schools in Figures 3, 4, and 5, respectively. Schools are plotted in bins along the x-axis according to the degree to which they are over-demanded. The over-demanded ratio reflects the number of applicants who ranked the school as their first choice on their final rankings divided by its capacity (e.g., equals two when there are two first-choice applicants for each seat). Panel A in each figure shows the demand of non-switchers.[24] The bottom two panels consider students who switched from their initial ranking (panel B) to their final ranking (panel C). The y-axis shows the fraction of those students demanding the schools in each bin. To illustrate, consider non-switching elementary school students in Figure 3. In panel A, the most over-demanded set of schools is the right-most bin: approximately 11 percent of non-switchers ranked the most over-demanded schools first. The most under-demanded set is the left-most bin: approximately 6 percent of non-switchers ranked the most under-demanded schools first.

The final submitted rankings of the switchers are more compressed than the rankings of the non-switchers. In other words, switchers move away from the most

[24] The online Appendix shows the demand of sincere students, who did not switch by definition, relative to non-switching sophisticated students. The results show that, while these two groups have somewhat different demands, those differences are quite small relative to the shifts in demand of the switchers from their initial to their final rankings.

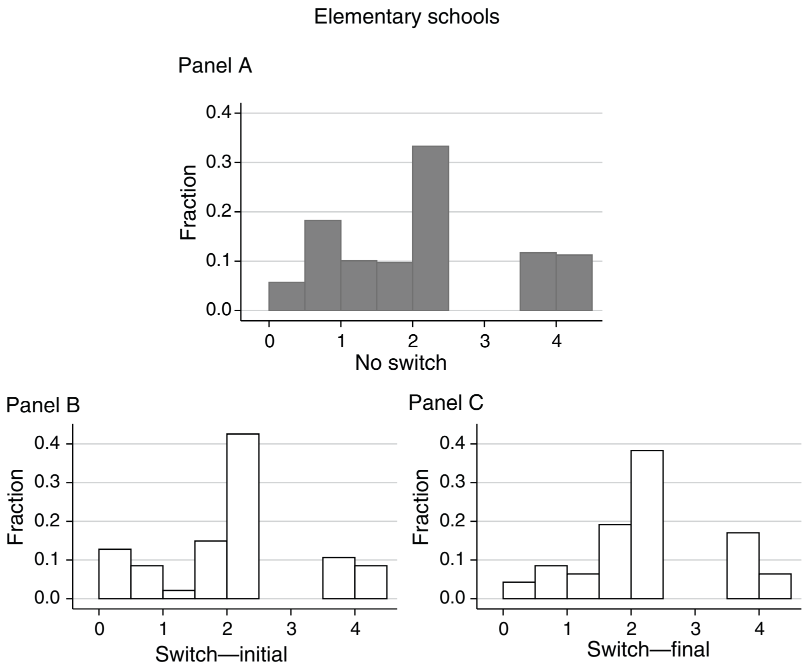

Figure 3. Demand of First-Choice Elementary Schools and Ranking Changes

Notes: The figure shows the demand of first-choice schools for elementary schools, separately for students who changed their rankings upon additional visits (switchers) relative to non-switchers. Schools are plotted in bins along the *x*-axis according to the degree to which they are over-demanded. The over-demanded ratio reflects the number of applicants who ranked the school as their first choice on their final rankings divided by its capacity (e.g., equals two when there are two first-choice applicants for each seat). Panel A shows the demand of non-switchers. The bottom two panels consider students who switched from their initial ranking (panel B) to their final ranking (panel C); the initial rankings are those entered upon the student's first visit to the application website, while only the final rankings affected their assignment. The *y*-axis shows the fraction of those students demanding the schools in each bin.

over-demanded and most under-demanded schools toward schools with intermediate levels of demand. To see this, compare panel C of each figure to panel A. There is in general a smaller fraction listing the most over-demanded and most under-demanded schools for the final rankings of the switchers relative to the non-switchers. Next, compare panel B to panel C to understand how switchers change their rankings. Switchers tend to move away from the most over-demanded and most under-demanded schools as they change their rankings.

Consider high schools in Figure 5, where each bin contains exactly one school. The figure shows that demand from switchers falls for every high school as switchers change their rankings, except the second-most over-demanded school. Strikingly, in their final rankings, the demand from switchers for the second-most over-demanded high school (57.9 percent) is very similar to the demand from non-switchers (58.4 percent). The demand was substantially lower upon switchers' initial rankings (15.8 percent). In Figures 3 and 4, each bin represents a set of schools but the same general pattern holds. For all grade levels, switchers move away from the most over-demanded set of schools (i.e., the height of the right-most

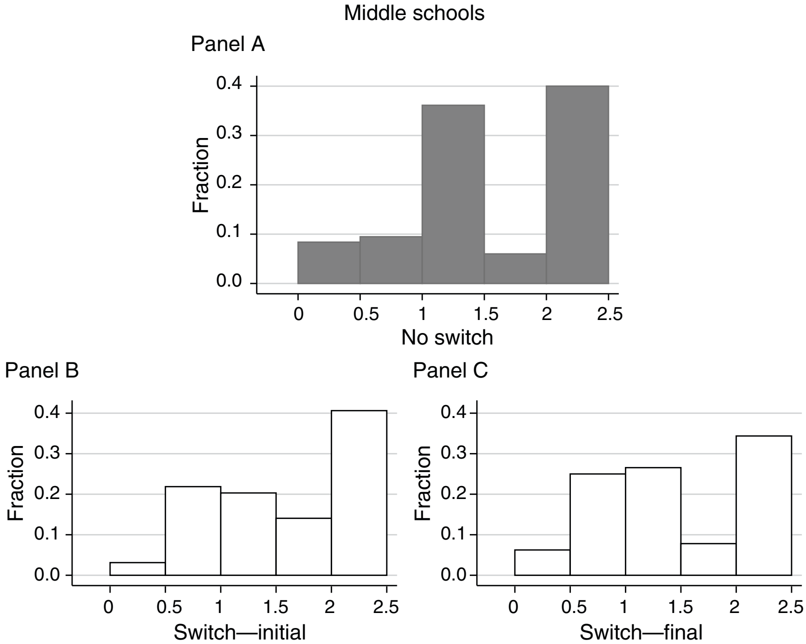

Figure 4. Demand of First-Choice Middle Schools and Ranking Changes

Notes: The figure shows the demand of first-choice schools for middle schools. Schools are plotted in bins along the *x*-axis according to the degree to which they are over-demanded. Panel A shows the demand of non-switchers. The bottom two panels consider students who switched from their initial ranking (panel B) to their final ranking (panel C). The *y*-axis shows the fraction of those students demanding the schools in each bin. The notes to Figure 3 provide more detail.

bin falls). For elementary and high schools, switchers also move away from the most under-demanded set of schools; for middle schools, switchers move away from the most and the second-most over-demanded set of schools, but have a slight movement toward the most under-demanded set.

In total, we interpret these results as strong evidence that a subset of sophisticated students (switchers) change their rankings to avoid the most over-demanded and most under-demanded schools. Both parts of these results are consistent with strategic behavior and support our classification of students as sincere or sophisticated. First, switchers avoid the most over-demanded schools because they believe their admission probability is low. Second, switchers avoid the most under-demanded schools because they update their beliefs regarding their ability to gain admission to a "better" (higher demand) school.

To test this formally, we categorize switchers based on the degree to which their initial first-choice school is over-demanded (i.e., the number of applicants per seat at the school they initially rank first).[25] For switchers whose initial first-choice school was among the most over-demanded, these students switched from schools with an

[25] The analysis categorizes schools into groups and refers to the most over-demanded initial first-choice schools and the most under-demanded initial first-choice schools. Both of these groups were chosen to be equal sized and

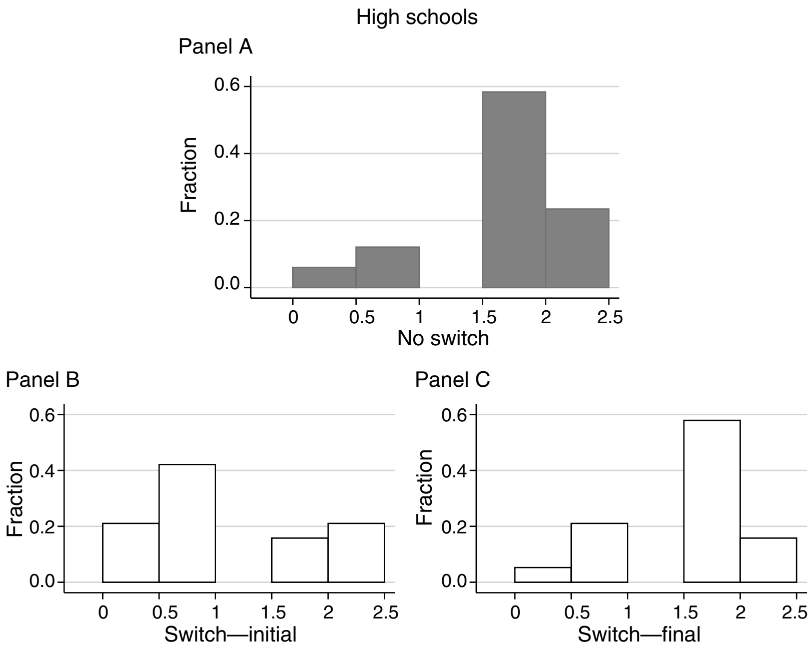

Figure 5. Demand of First-Choice High Schools and Ranking Changes

Notes: The figure shows the demand of first-choice schools for high schools. Schools are plotted in bins along the x-axis according to the degree to which they are over-demanded. Panel A shows the demand of non-switchers. The bottom two panels consider students who switched from their initial ranking (panel B) to their final ranking (panel C). The y-axis shows the fraction of those students demanding the schools in each bin. The notes to Figure 3 provide more detail.

over-demanded ratio of 2.49 to schools with an over-demanded ratio of 2.03; this difference is 0.46 (standard error = 0.10), which is statistically significant (t-statistic = 4.61, p-value = 0.00). Switchers whose initial first-choice school was among the most under-demanded switched from schools with an over-demanded ratio of 0.41 to schools with an over-demanded ratio of 1.43 (difference = −1.02, standard error = 0.26, t-statistic = 3.93, p-value = 0.02).

These results support what was evident in Figures 3, 4, and 5: when sophisticated students change their rankings, they move away from the most over-demanded and most under-demanded schools. This supports the evidence in Section III on assignment outcomes of sincere and sophisticated students. While the switching analysis is necessarily limited to only those sophisticated students who changed their rankings during the application period, the observed ranking changes give insight into the mechanism that generates the outcome differences we have documented. Specifically, sophisticated students systemically avoid the most over-demanded schools in their ranking behavior. This drives the 9.6 percentage point increase in assignment probability for sophisticated students relative to sincere students.

include the top one-fourth and bottom one-fourth of schools in terms of the over-demanded ratio, which includes 5 (out of 23) elementary schools, 2 (out of 9) middle schools, and 1 (out of 4) high school.

Further, sophisticated students also avoid the most under-demanded schools as their first choice, suggesting that one aspect of sophistication is understanding that these schools are obtainable even if the student ranks it lower on her list. While we did not hypothesize this a priori, the fact that sophisticated students also avoid the most under-demanded schools is an additional aspect of the outcome differences we hypothesized and found. As discussed in the introduction, the welfare consequences of heterogeneity in strategic sophistication are ambiguous. Consistent with this, we are not able to objectively sign the welfare effect in our data. However, our interpretation of the evidence is that sophistication is conferring an advantage to students who respond to their admission probabilities because sophistication is associated with a strong increase in assignment probability and also with avoiding the most under-demanded schools.

V. Conclusions

The majority of choice-based assignment procedures are manipulable, in the sense that a student can obtain a more-preferred assignment by reporting preferences over schools that differ from her true preferences. We provide evidence on which students are in fact responding to the manipulability of assignment mechanisms. Our analysis uses a novel set of auxiliary data from the application website where students in the Wake County Public School System submit their rankings of schools. We find meaningfully important differences between students who repeatedly log into the application website, relative to students who log in only once. These data therefore allow us to segment students according to whether they submit their true preferences (sincere students) or whether they rank schools in response to their probability of admission (sophisticated students). We find strong evidence supporting our approach for classifying students as sincere or sophisticated.

When changing from the manipulable mechanism that was used by Boston Public Schools, the discussions focused on "leveling the playing field" for all students (Payzant 2005). Our results suggest that sophisticated students gain at the expense of sincere students because sophistication is associated with a 15.1 percent increase in the probability of being assigned to a magnet school. From a policy standpoint, we interpret these results as evidence that sophistication confers an advantage that undermines the objectives of the school system. Consistent with this claim, in partnership with the authors, the Wake County Public School System moved from the mechanism studied here to a strategy-proof mechanism for assignment in the 2015–2016 school year. However, the majority of school districts continue to use manipulable mechanisms. We recommend that policymakers consider the distributional consequences that are implied by our results when making student assignment decisions.

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