Stand and Deliver:
Post-Secondary Outcomes at Boston's Charter High Schools

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April 2013

Abstract

We use admissions lotteries to estimate the effect of charter school attendance on college preparation, attendance and choice. Boston's charter high schools increase the likelihood of taking an Advanced Placement (AP) exam, the number of AP exams taken, and scores on AP Calculus. Charter attendance has little effect on the likelihood of taking the SAT, but shifts the distribution of scores rightward, moving students into higher quartiles of the state SAT score distribution. Charter school attendance also increases pass rates on the high-stakes exam required for high school graduation in Massachusetts, with especially large effects on the likelihood of qualifying for a state-sponsored college scholarship. Charter attendance induces a large shift from two- to four-year institutions, though the effect on overall college enrollment is modest. The increase in four-year enrollment is concentrated among four-year public institutions in Massachusetts.

*This research was funded by the US Department of Education by the Institute for Education Sciences under grant number 08120031. The authors are grateful to Boston's charter schools and to Carrie Conaway and the staff of the Massachusetts Department of Elementary and Secondary Education for data and assistance. Annice Correia provided excellent research and administrative support. Daisy Sun and Peter Hull provided expert research assistance. The views expressed here are those of the authors alone, and do not necessarily reflect positions of the Boston Foundation or any government agency or funder.

1 Introduction

One of the most important questions in education research is whether the gains from interventions for which we see short-term success can be sustained. For example, test score gains generated by pre-school interventions, highly effective teachers, and elementary-school class size reductions often appear to fade as students progress through school, though some of these gains may re-emerge later in non-cognitive outcomes.[1] The possibility of short-lived impacts is especially relevant in research on charter schools, where charter operators who face high-stakes assessments have a strong incentive to "teach to the test." The fact that charter schools are subject to intense scrutiny and evaluation may create incentives for teacher cheating (Jacob and Levitt, 2003), highly-strategic instruction (Jacob, 2007), and an instructional focus on small groups of students that are pivotal for official accountability measures (Neal and Schanzenbach, 2010).

The purpose of this paper is to assess the effect of attendance at Boston's charter high schools on outcomes or which the link with human capital and future earnings seems likely to be sustained and strong. Specifically, we focus on outcomes that are either essential for or facilitate post-secondary schooling: high school graduation, the attainment of state competency thresholds, scholarship qualification, Advanced Placement (AP) and SAT scores, college enrollment, and college persistence. Importantly, most of these outcomes are less subject to strategic manipulation than the state's test-based assessments. As in our earlier work, the research design implemented here exploits randomized enrollment lotteries at over-subscribed charter schools.

[1]See, for example, studies of the effect of Head Start by Currie and Thomas (2000), Garces et al. (2002), and Deming (2009) and investigations of class size effects by Dynarski et al. (2011) and Chetty et al., (2011). Three randomized, preschool interventions enerate fading effects on cognitive test scores but may affect labor force attachment and crime (Anderson, 2008). Teacher assignment and international educational interventions also appear to generate impacts that fade (see Kane and Staiger, 2008; Jacob et al., 2010; Andrabi et al.,2011; and Banerjee et al. (2007).

These estimates are likely to provide reliable measures of average causal effects for charter applicants.

The analysis here focuses on Boston's charter high schools. For our purposes, an analysis of high schools is both a necessity and a virtue. It's necessary to study high schools because most students applying to charters in earlier grades are not yet old enough to generate data on post-secondary outcomes. Charter high schools are also of substantial policy interest: a growing literature suggests that high school may be too late for cost-effective human capital interventions (see, for example, Cunha et al., 2010). Indeed, impact analyses of interventions for urban youth have mostly generated disappointing results.[2] We're interested in ascertaining whether charter schools, which are largely budget-neutral, can have a substantial impact on the life course of affected students. The set of schools studied here comes from an earlier investigation of the effects of charter attendance in Boston on test scores (Abdulkadiroğlu et al., 2011). The high schools in our earlier study, which enroll the bulk of charter high school students in Boston, generate statistically and socially significant gains on state assessments in 10th grade. We turn here to the question of whether these gains are sustained.

Our findings suggest that the gains from Boston's high-performing charter high schools are remarkably persistent. While the students who were randomly offered a seat at these high schools graduate at about the same rate as those not offered, lottery estimates show gains on Advanced Placement (AP) tests and the SAT. Charter attendance doubles the likelihood that a student sits for an AP exam and increases the share of students who pass AP Calculus. Charter attendance does not increase the likelihood of taking the SAT, but charters boost scores,

[2]For example, Dynarski et al. (1998) and Dynarski and Gleason (2002) document an array of discouraging findings for interventions meant to reduce dropout rates. Dynarski and Wood (1997) and Kemple and Snipes (2000) look at alternative schools and career academies, with findings that are mixed at best.

especially in math. Charter school attendance also increases the pass rate on the exam required for high school graduation in Massachusetts, with especially large effects on the likelihood of qualifying for a state-sponsored college scholarship. Other estimates suggests that charter attendance may increase college enrollment, but the number of charter applicants old enough to be in college is still too small for this result to be conclusive. By contrast, our results show that charter attendance induces a clear shift from two-year to four-year colleges, with gains most pronounced at four-year public institutions in Massachusetts.

2 Background

Boston's over-subscribed charter schools generate impressive gains on tests taken through the Massachusetts Comprehensive Assessment System (MCAS). Lottery estimates show that each year spent at a charter middle school boosts MCAS scores by about a fifth of a standard deviation in English Language Arts (ELA) and over a third of a standard deviation in math. High school gains are just large (Abdulkadiroğlu et al., 2011). These results are in line with those generated by urban charters elsewhere in Massachusetts, as we've shown in studies of a Knowledge is Power Program (KIPP) school in Lynn, Massachusetts (Angrist et al., 2010, 2012), and in an analysis of charter lottery results from around the state (Angrist et al., 2011a,b).

The defining feature of Massachusetts' successful urban charter schools appears to be adherence to *No Excuses* pedagogy, an approach to urban education described in a book of the same name (Thernstrom and Thernstrom, 2003). *No Excuses* schools emphasize discipline and comportment, traditional reading and math skills, extended instruction time, and selective teacher hiring. Massachusetts' *No Excuses* charters also make heavy use of Teach for America (TFA) participants and alumni and provide extensive and ongoing feedback to teachers. Like most

Boston charter schools, the high schools studied here largely identify with the *No Excuses* approach, a fact documented in an appendix table describing school characteristics.[3]

Charter schools are a recent innovation; Massachusetts' first charter schools opened in 1995. Not surprisingly, therefore, most evidence on charter effectiveness to date comes from outcomes measured while children are still enrolled in elementary and secondary school. An exception is Dobbie and Fryer (2012)'s recent lottery-based study, which follows applicants to a single charter middle school in the Harlem Children's Zone, estimating effects on college enrollment while also looking at non-educational outcomes related to crime and teen pregnancy. Dobbie and Fryer (2012) find that Promise Academy students are more likely to go to college, while girls are less likely to get pregnant and boys are less likely to be incarcerated. Earlier work by Booker et al. (2008) uses statistical controls and distance instruments to identify the effect of charter school attendance on high school graduation and college enrollment. Both of these empirical strategies suggest gains for charter students. We complement this earlier work with new results on post-secondary preparation and enrollment for a large cohort of charter high school students in an urban setting of considerable policy interest.

3 Data and Sample

School Selection

We set out to study the effect of attendance at six charter high schools in Boston. Applicants to these schools comprise the sample used to construct the lottery-based estimates of charter high school achievement effects reported in our earlier study (Abdulkadiroğlu et al., 2011), and they

[3]Other lottery-based evidence for *No Excuses* effectiveness includes the Dobbie and Fryer (2011a) study of a charter school in the Harlem Children's Zone, the Dobbie and Fryer (2011b) study of a larger sample of New York charters, and results for a sample of KIPP schools from around the country (Tuttle et al., 2013).

account for the bulk of charter high school enrollment in Boston today.[4] Two other charter high schools serving Boston students in the same period are now closed; one school has poor records and appears unsuitable for a lottery-based analysis.

Appendix Table A1 describes features of the charter schools included in this study, as well as those of the full set of charter high schools in Boston and Boston's traditional public schools (including exam schools). Charters are classified according to whether they cover grades 9-12 or are limited to grades 9-12. The three groups of charter schools described in Table A1 are similar: Boston's charters run a longer school year and day than traditional public schools. They also make frequent use of Saturday school. Most adhere to the *No Excuses* instructional approach. Panel B of Table A1 compares teacher characteristics, per-pupil expenditure, and Title I eligibility. Charter teachers are younger than their traditional public school counterparts: 76 percent of teachers in our analysis sample are 32 or younger, compared to 23 percent of public school teachers. Similarly, only 5 percent of (study sample) charter teachers are 49 or older, while 38 percent of public school teachers are at least 49. Charters spend somewhat less per-pupil than traditional public schools in Boston, though their classes are smaller (spending differences likely reflect differences in student mix, such as the number of special education and limited English proficient students).[5] All public schools in Boston, including charter schools, qualify for Title I aid.

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[4]The six schools are Academy of the Pacific Rim, Boston Collegiate Charter School, Boston Preparatory Charter Public School, City on a Hill, Codman Academy Charter Public School, and Match Charter High School.

[5] The BPS average, for example, covers all students educated under district auspices, including out-of-district special education placements, and elementary school students.

Student Data

Massachusetts charter schools admit students by lottery when they have more applicants than seats. We collected lists of charter school applicants and information on the results of admissions lotteries from individual charter schools. Applicant lists were then matched to administrative records covering all Massachusetts public school students. Our analysis sample is limited to charter applicants who were enrolled in a Boston public school at the time they applied and applied for a charter school seat from Fall 2002 through Fall 2008. Additional information on applicant lotteries appears in the data appendix and especially Appendix Table A2.

We matched applicant records to administrative data using applicants' names and year and grade of application.[6] Among applicants eligible for our study, 95 percent were matched to state data.[7] Applicants were excluded from the lottery analysis if they were disqualified from the lottery they entered (disqualified applicants mostly applied to the wrong grade). We also omit siblings of current charter students, late applicants, and some out-of-area applicants. In addition to providing demographic information and scores on state assessments, state administrative records include AP and SAT scores for all public school students tested in Massachusetts.

Information on college enrollment and college choice comes from the National Student Clearinghouse (NSC). The Massachusetts Department of Elementary and Secondary Education routinely requests an NSC match for Massachusetts' high school graduates; we requested a supplemental match from the NSC for charter applicants in our lottery sample not covered by the state match. NSC data record enrollment spells at participating post-secondary institutions,

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[6] Birthdays, town of residence, race or ethnicity, and gender were used to distinguish duplicate matches.

[7] Match rates differ little by win/loss status. Results for applicant cohorts where match rate differentials are largest are similar to those for the larger sample.

which account for 94% of Massachusetts undergraduates. Missing institutions mostly run small vocational and technical programs.

Different types of outcomes generate different follow-up horizons, depending on when they occur. We define the relevant horizon based on each applicant cohort's projected senior year of high school.[8] The earliest information available on baseline (pre-application) characteristics is from the school year ending Spring 2002. Students projected to graduate from high school in Spring 2006 therefore generate the earliest outcomes. Outcome-specific samples range over projected senior years as follows:

- *MCAS scores:* These results are for students with projected senior years ending in Spring 2006 to Spring 2013; the outcome here is the 10th grade MCAS. Some students retake 10th-grade MCAS tests in a later grade, a score we also see. MCAS scores are standardized to the state score distribution by grade, year, and subject.
- *AP and SAT scores:* These results are for applicants with projected senior years 2007-2012, including tests taken earlier than senior year. AP and SAT scores are analyzed in their original units (AP scores run from 1-5; SAT subject scores run from 200-800).
- *High school graduation:* High school graduation data are for cohorts projected to finish in 2006-2011 (the most recent graduation year covered by state data is 2011).
- *College outcomes:* These are for students with projected senior years 2006-2010 (the most recent cohort for which we have NSC data is the high school class of 2010).

Applicants who apply in more than one grade appear only once in our analysis, with data reatined for the first application only. Baseline information for applicants for 9th grade charter

[8]The projected senior year equals the year in 8th grade plus 4 for applicants to City on a Hill, Codman Academy, and Match Charter High School (schools where applicants apply for 9th grade entry), year in 4th grade plus 8 for applicants to Boston Collegiate (where applicants apply for 5th grade entry), and year in 5th grade plus 7 for applicants to Academy of the Pacific Rim and Boston Preparatory (schools where applicants apply for 6th grade entry.)

entry comes from 8th grade; baseline information for applicants for 5th grade charter entry comes from 4th grade; baseline information for applicants for 6th grade charter entry comes from 4th grade for baseline test scores and 5th grade for demographic variables.

Table 1 compares charter applicants and the full sample of traditional BPS 9th graders. Applicants are disproportionately black, and have higher average baseline scores than the traditional BPS population. Limited-English proficient students are under-represented among charter applicants, but the proportion of applicants identified as qualifying for special education services is almost as high among applicants as in the traditional BPS population.

4 Empirical Framework

We estimate the effect of charter school attendance on high school graduation rates, measures of AP and SAT test-taking and scores, college enrollment, and college type. As a benchmark, we also report results for 10th grade MCAS scores. The MCAS results are extended to cover two competency thresholds in Massachusetts, one for high school graduation and one for the state's Adams Scholarship, a public university tuition waiver for public high school students.

Our lottery-based empirical strategy is motivated by the observation that charter attendance is a choice variable that may be correlated with motivation, ability, or family background. This leads to *selection bias*. Suppose, for example, that parents who chose to send their children are better informed or more educated themselves. Their children may therefore be more likely to go to college even in a world without charter schools. The selection bias here causes us to over-estimate the causal effect of charter attendance.

To eliminate selection bias, we use random offers of charter school seats to construct instrumental variables (IV) estimates. The idea behind IV is to compare outcomes between randomly selected lottery winners and losers, instead of comparing those who do and don't choose to enroll at a charter school. We then adjust this comparison (known in econometrics as *the reduced form*), by dividing it by the win/loss difference in charter school attendance rates (known in econometrics as *the first stage*). Assuming, as seems likely, that any gaps revealed by the reduced form estimates of charter offers on outcomes are caused by the corresponding differences in charter enrollment, the ratio of reduced form to first stage estimates captures the causal effect of charter attendance. Because the comparisons here are based on random assignment, IV estimates are purged of the selection bias that may contaminate other sorts of comparisons and estimates.

To see how IV works, consider a stylized study of applicants to a single charter school, say Match high school. Suppose (hypothetically) that 200 applicants applied for 100 Match seats in the Fall 2006. As a consequence of over-subscription at Match, 100 applicants were offered seats randomly (again, hypothetically). The reduced form in this case is the difference, say, in the 10th grade MCAS math scores of the 100 applicants offered a seat and the 10th grade MCAS scores of the 100 applicants not offered a seat. This might be a number like $.3\sigma$; in other words, those offered a seat at Match score three-tenths of a standard deviation higher on the 10th grade math test than those not offered a seat. Because offers are randomly assigned, the reduced form is very likely to be a good measure of the causal effect of a charter *offer*.

We could stop with an analysis of charter offers if everyone offered a seat takes it and no charter seats are obtained otherwise. In practice, however, not everyone offered a seat takes the offer; some applicants offered a seat at Match ultimately choose to go elsewhere, perhaps attending a public school closer to where they live. At the same time, some of those not immediately offered a seat are offered one later, by virtue of the fact that they were placed on a waiting list or applied again the following year. Suppose that 80% of those offered a seat at

Match take it, while 5% of those not offered a seat in this particular lottery nevertheless end up at Match eventually. The enrollment effect of an offer in Match's 2006 lottery is therefore $.8-.05=.75\%$. Because offers are randomly assigned, it seems fair to claim that the only reason those offered a seat at Match have higher scores is this 75 point difference in enrollment rates. The IV calculation therefore divides the reduced form effect of 3σ by the offer differential of .75. The resulting calculation produces

$$\text{Effect of charter attendance} = \frac{\text{Reduced Form}}{\text{First Stage}} = \frac{.3}{.75} = .4$$

Thus, we conclude that enrollment at Match boosts 10th grade math scores by four-tenths of a standard deviation.

Our empirical strategy is somewhat more involved than this stylized example suggests. The specific method used here, known as two-stage least squares (2SLS for short) is detailed in the technical appendix. Importantly, our 2SLS estimator makes use of two sources of variation in charter offers. Instead of a single variable indicating whether applicants were randomly offered a charter seat, we work with two such variables: the first, called the *initial offer* instrument, is a dummy variable indicating offers made immediately following a charter school lottery. In addition, because some applicants who don't receive offers on lottery day do so at a later date when their names are reached on a randomly ordered wait list, we also code a second instrument. The second instrument, which we call *ever offer*, indicates all applicants who eventually receive an offer, whether on lottery day or later. Applicants who eventually receive an offer have both instruments switched on, while those who receive later offers without an initial offer have only the *ever offer* instrument switched on. Our lottery-based estimation strategy therefore makes use of two pairs of reduced form and first stage estimates. In principle, the ratio of each reduced form estimate to each first stage estimate provides two alternative estimates of charter effects.

Our 2SLS procedure implicitly combines these two estimates into a single more precise estimate of the average causal effects of charter attendance.

Lottery Balance

The lottery-based empirical strategy is predicated on the notion that random assignment in admissions lotteries balances both the observed and unobserved characteristics of those who are and are not randomly offered charter seats. Whether this is indeed true is unknowable for unobserved characteristics such as motivation, but it's worth checking for balance in observed characteristics like race, special education status, and baseline (pre-application) test scores. Consistent with the presumed random assignment used in charter school admissions lotteries, the demographic characteristics of those who were and were not offered a seat in a charter lottery indeed appear to be similar. This is documented in Appendix Table A3, which reports descriptive statistics for the full sample of matched applicants, as well differences by offer status for the MCAS analysis sample. Columns (3) and (4) show that individual differences in mean characteristics by offer status are individually statistically insignificant; p-values for a joint test are high.

4.1 First Stage Estimates and an MCAS Benchmark

An admissions offer in a charter lottery boosts charter enrollment by an average of 23 percentage points. This can be seen in the *ever offer* first stage estimates reported in Table 2. The columns labeled *initial offer* show that if the offer is made right awy, the offer boosts charter enrollment by a further 14 points (we add the two first stage effects because the offer variables are defined so that everyone who receives an initial offer also has the *ever offer* variable switched on). The overall first stage is therefore close to 40 points for those who receive an offer on or immediately following lottery day.[9]

The relationship between lottery offers and charter enrollment - the size of the first stage estimates - is determined by the likelihood an applicant chooses to accept an offer (some accepted applicants choose to attend a traditional public school, including one of Boston's pilot schools, or an exam school). Similarly, some students who receive no offer in the lotteries for which we have data receive one at a later date. As always, 2SLS estimation adjusts for slippage between offers and enrollment on both sides, with the resulting estimates capturing causal effects for those who *comply* with (that is, enroll in a charter school in response to) the offers recorded in our data.

As a benchmark, Table 2 also estimates similar to those reported in our earlier Boston study (Abdulkadiroğlu et al., 2011), for 10th grade MCAS scores. These estimates were computed using the 2SLS procedure described in the appendix. Attendance at one of the charter high schools in our sample boosts 10th grade ELA scores by $.4\sigma$, that is, four-tenths of a standard deviation, while raising math scores by more than half of a standard deviation.[10]

As noted above, the analysis here covers varying sets of cohorts, with less data available for an analysis of longer term outcomes than for an analysis of MCAS scores. As a check on the representativeness of these subsamples, we also constructed 2SLS estimates of MCAS effects for the subsamples of applicants contributing to our AP/SAT and college-going analyses below. Estimates of effects on 10th grade MCAS scores in the AP/SAT and college-going samples (not

[9]First stage estimates differ slightly across outcomes due to small changes in sample composition.

[10]The estimates reported in Abdulkadiroğlu et al. (2011) are smaller than those reported here in Table 2, because the former are scaled to measure the effect of years of charter attendance, while those reported here show an overall charter enrollment effect, without putting these in per-year terms.

reported here) are similar to estimates for the full MCAS sample, suggesting that the short-run effects of charter attendance are similar for older and more recent cohorts.

5 College Preparation

5.1 MCAS Thresholds

Since 2003, high school graduation in Massachusetts has been determined in part by 10th grade MCAS scores. The initial state competency standard required students to pass the “Needs Improvement” threshold with a scaled score of 220 in both math and ELA; for the graduating class of 2010, standards were increased to require a “Proficient” score of at least 240 in math, ELA, and science.[11]

Beginning with the high school class of 2005, the state has also used the MCAS to determine qualification for public university tuition waivers, an award known as the Adams Scholarship. Qualification for an Adams Scholarship requires MCAS scores in the “Advanced” category in either ELA or math, a score that is at least “Proficient” in subjects where the Advanced standard isn't met, and a total MCAS score in the upper quartile of the distribution of scores in a scholarship candidate's home school district. Awardees qualify for tuition waivers at any Massachusetts public college or university.[12]

Charter school attendance has large effects on the likelihood applicants meet graduation competency standards and qualify for an Adams Scholarship. This can be seen in Table 3, which

[11]See http://www.doe.mass.edu/mcas/graduation.html for details. The new rules include an exception for students who pass the Needs Improvement threshold only and also meet personal goals. We ignore this exception here.

[12]Cohodes and Goodman (2013) estimate effects of Adams Scholarships on college enrollment and choice, showing these appear to increase enrollment in public universities in spite of the fact that they cover only a small portion of college costs.

reports estimates separately by subject (i.e., for whether students met a subject specific standard or qualification) and overall. Charter attendance boosts the likelihood of meeting competency standards on a first try by 16 percentage points; this falls to 13 points when looking whether applicants ever met competency standards. Competency gains are most dramatic for the likelihood of meeting the ELA standard. Consistent with these large gains in competency, charter attendance boosts the likelihood of qualifying for an Adams Scholarship by 18 points, a large and precisely estimated gain.[13]

Table 3 also suggests charter schools shift the MCAS distribution into the upper two score categories. Specifically, the table documents large and statistically significant gains in the likelihood charter applicants earn scores at a level deemed Proficient or Advanced. The gains here remain substantial whether measured by first attempts or final scores, though only first-attempt scores are shifted out of the lowest into the second-lowest (Needs Improvement) range.

The nature of the charter-induced shift in the distribution of MCAS scores emerges clearly in Figure 1. This figure plots estimated score distributions for a subsamples of applicants identified as being responsive to the offer of a charter seat. This group, known in econometric terminology as the group of *compliers*, consists of applicants defined as those who take a charter seat when offered one in a lottery, but enroll in a traditional public school otherwise. We plot distributions for compliers because, as with our 2SLS estimates, comparisons of distributions for compliers

[13]Charter school students can earn a scholarship in either the district of attendance (the charter school) or the district of residence (Boston). The two standards differ due to the requirement for a score in the upper quartile of the district score distribution. The Adams Scholarship cutoff is defined here using BPS thresholds.

are purged of the selection bias that contaminates comparisons between those who do and don't enroll in a charter school.[14]

The x-axis in Figure 1 marks MCAS score category cutoffs; these occur at 20 point intervals. Charter school attendance clearly pushes the first-attempt score distribution to the right, into the upper three score groups. The effect of charter attendance on ELA scores is most striking: very few non-charter students achieve at an Advanced level, while the distribution for those who enroll in a charter school has substantial numbers of compliers in the Advanced group. Formal statistical tests of distributional equality (not reported here) confirm that the distributional shifts documented in this figure are very unlikely to be merely a chance finding.

Figure 2 summarizes the average effect of charter attendance on MCAS categories and threshold. Gaps between charter and non-charter averages for each outcome in the figure are significantly different from zero.

5.2 AP Taking and Scores

Advanced Placement coursework allows high schoolers to experience the rigor of college-level courses and perhaps even earn college credit. Five of the six charter schools in our sample offer AP classes, and one school requires their students to pass AP tests to graduate. As shown in Table 4, charter school attendance increases the likelihood a student takes at least one AP test by 28 percentage points. Consequently, over half of charter students take at least one AP test, compared with about a quarter of the students in traditional public schools.

Charter attendance increases the number of AP tests taken by nearly a full additional exam, a result that can be seen in the second row of Table 4. At the same time, gains in AP *scores* are

[14]Complier distributions are estimated using a variation on the methods introduced by Abadie (2002; 2003). See the technical appendix for details.

more modest. Charter school attendance increases the likelihood of taking a test and earning a score of at least 2 by 15 percentage points, a statistically and quantitatively significant gain. But a score of 3 or better is required to earn college credit, and many colleges and universities require at least a 4. Charter attendance increases the probability of earning a score of 3 by a marginally significant 9.5 percentage points, but generates no significant increase in the likelihood of earning a 4 or 5. Note that by including zeros for non-takers in this analysis of score impact, we avoid bias from composition changes due to the large effect of charter attendance on the likelihood applicants ever take a test.

AP effects by subject, reported in columns 3-10 of Table 4, show a large increase in the likelihood charter applicants take tests in science, calculus, and history, 3 of the most commonly taken AP exams. Paralleling charter schools' large impact on MCAS math scores, the clearest AP score gains emerge for calculus. Charter attendances boosts the probability of taking the AP calculus test by 21 percentage points, and appears to boost the likelihood of earning a score of at least a 2 by nearly 9 points. The corresponding impact on the likelihood of earning a 3 on AP calculus is 7 percentage points, though the estimated increases in the likelihood of scoring 2 or 3 are only marginally statistically significant. Charter attendance increases test-taking in science and US history, with no corresponding impact on scores in these subjects. Charter schools have little effect on English test-taking or scores.

Figure 3 summarizes the effects of charter attendance on AP test taking and scores. For three out of four outcomes in the figure, the estimated effect of charter attendance is at least marginally significantly different from zero.

5.3 SAT Taking and Scores

The SAT is a major milestone for college bound high school students and, for many, a major hurdle on the path to college. Designed to be challenging for all students, low SAT scores are a special concern for poor and minority students. Gaps in SAT scores by race and socioeconomic status that might be attributable to family background and school quality are further accentuated by the willingness of higher income families to invest heavily in SAT preparation classes (see, e.g., Bowen and Bok (2002)).

Many of Boston's traditional public school students take the SAT, and charter attendance does little to increase this rate further. As can be seen in the first two columns of Table 5, among our applicants, close to two-thirds of non-charter students take the SAT, while the estimated effect of charter attendance on SAT taking is a modest 3 points, a gap far from statistical or economic significance.[15]

Although charter attendance has little effect on the rate at which applicants take the SAT, charter attendance raises the SAT scores applicants earn on the test. In particular, coding scores as zero for non-takers, charter attendances pushes the SAT composite score (the sum of math, verbal, and writing scores) above the bottom quartile of the state composite score distribution by 11 percentage points. Gains in math contribute most to the shift in composite scores; effects on verbal and writing scores are smaller (the estimated low-end shift in verbal scores is marginally significant). Charter attendance also raises the probability that applicants earn an SAT reasoning score (the sum of math and verbal) above the state median by 11 percentage points, with math again the largest contributor to this gain.

[15]Charter applicants are positively selected, that is, have somewhat higher baseline test scores than the general BPS population. Consequently, the SAT-taking rate among applicants of about .64 exceeds the SAT-taking rate of almost half in the overall non-charter BPS population.

Table 5 also reports estimates of effects on SAT scores, estimated in samples limited to those who take the test. Because charter attendance has little effect on the decision to take the SAT, such conditional comparisons are unlikely to be biased by compositional shifts. The conditional results show that Boston's charters have large, statistically significant effects on SAT scores, especially in math. Specifically, charter attendance boosts average math scores by 51 points, a gain that amounts to over four-tenths of a standard deviation in the US score distribution.[16] This is almost as large (in standard deviation units) as the MCAS math effect reported in Table 2, suggesting that the math skills demonstrated on the MCAS carry over to the SAT. Although charter attendance has smaller effects on verbal and writing scores, the composite SAT score gain is estimated to be a little over 100 points, a statistically significant result. The gain here amounts to almost one-third of a standard deviation in the US composite score distribution. The corresponding effect on the SAT reasoning score is 74 points, also a large gain.

The effect of charter attendance on the SAT score distribution is summarized in Figure 4, which plots the distribution of SAT scores for treated and untreated charter lottery compliers (again, the set of compliers consist of applicants who respond to the offer of a charter seat by enrolling; comparisons for this group have a causal interpretation). Charter school attendance causes a pronounced rightward shift in score distributions for all three SAT subjects, as well as for the distribution of composite scores. Formal statistical tests of distributional equality (not reported here) suggest these shifts are very unlikely to be a chance finding. On balance, Boston charters produce impressive gains on the SAT as well as the MCAS.

[16]Means (and standard deviations) of the 2012 US SAT distribution were 512 (117) in math, 496 (114) in verbal, 488 (114) in writing, 1010 (214) for SAT reasoning and 1498 (316) for the composite.

5.4 High school Graduation

As we saw in Table 3, charter attendance increases the likelihood that charter applicants meet the MCAS-based standard for a high school diploma and qualify for an Adams Scholarship at the University of Massachusetts. Does charter attendance also increase high school graduation rates? Perhaps surprisingly, the estimates in Table 6 suggest not, or at least, not be enough for any gain to be statistically significant.

The estimated effect of charter attendance on the likelihood a student graduates high school on time is a statistically insignificant (negative) effect of about -.10.[17] On the other hand, looking instead at whether applicants graduate within two years of their on time graduation date, charter attendance seems to produce an increase in this measure of graduation rates. The estimated increase in graduation rates omitting transfers and deceased students (and thereby following the official state definition of high school graduation rates) is about .10, though here too the estimates are not significantly different from zero.

Estimated effects of charter attendance on grade repetition (including partial grade repetition), also reported in Table 6, provide a possible explanation for why the gains in high school competency documented in Table 3 fail to generate clear and statistically significant gains in high school graduation rates in Table 6. Charter schools appear to be more likely than traditional public schools to hold their students back or to cause them to repeat a grade. Although grade retention effects are small (and, here too, not significantly different from zero), adding repetition effects to the within-two graduation effect comes close to accounting for the change in competency rates induced by charter attendance.

[17]On time graduation dates are determined by counting from the entry grade to grade 12.

6 College Enrollment and College Choice

Boston's charter high schools appear to boost their students' SAT scores, their AP calculus scores and AP participation rates, and the likelihood that students meet graduation standards and qualify for an Adams scholarship. These results suggest charters improve their students' preparation for college. We turn here to here to the effects of charter attendance on the likelihood that students go to college and the type of college they attend. The college sample is necessarily smaller than the sample used to analyze effects on earlier milestones, and the findings therefore less precise and more preliminary in nature.

To allow for the fact that charter schools may increase grade repetition, thereby delaying college applications, the college analysis looks at two sets of outcomes. The first set, with results reported in the first two columns of Table 7, measures outcomes assuming students graduate high school on time, that is, assuming no grade repetition. The second set, reported in columns 3-4 of the table, look at outcomes in a longer window, allowing for delayed college enrollment of up to two years. A consequence of stretching the follow-up period in this manner is a further reduction in sample size.

The estimates in column 2 of Table 7 suggest charter attendance increases college enrollment by about six percentage points in the on time sample, an estimate that increases to 13 points in the within two sample. Although substantial, neither estimate is statistically significantly different from zero; in other words, we can't rule out the possibility that these might be chance findings. The relative lack of precision here is a natural consequence of the fact that only about half of our charter applicants are old enough to have reached college enrollment milestones. Give the currently available sample size, enrollment effects would have to be very large indeed (on the order of 25-30 points) for us expect a statistically significant finding. In ongoing work, we're continuing to collect charter applicant data and plan to update published results accordingly.

Table 7 also reports results for enrollment in different sorts of post-secondary institutions (with students never enrolled at all coded as zero). Charter school attendance shifts many students toward four-year institutions. In the on-time enrollment sample, charter attendance reduces the likelihood that a student attends a two-year school by 10 percentage points while increasing the probability of four-year enrollment by 16 percentage points. In the within-two sample, the four year enrollment gain is 23 percentage points.

The estimates likewise show a large shift toward four year *public* colleges and universities, with an estimated gain of 19 percentage points in the on-time sample and 37 percentage points in the within-two sample. The gain here is partly due to the shift towards four-year from two-year schools, while also (to a lesser extent) reflecting a shift out of private schools in the within-two sample. Both the four-year shift and the shift towards public institutions are large enough to be significantly different from zero. The estimated decline in private enrollment in the within two sample is about 14 points, a decline that falls short of statistical significance, but nevertheless contributes to the public enrollment increase.

The last row of Panel A in Table 7 shows that much of the increase in four-year public enrollment occurs at *Massachusetts* public schools. This may be driven by the Adams Scholarship, which induces students to attend Massachusetts public universities; arlier, we noted that Boston charters significantly boosts the probability that students qualify for this scholarship. Consistent with these results, the institution with the largest enrollment of former charter students in our sample is the University of Massachusetts at Boston.

Panel B of Table 7 reports college enrollment effects by selectivity tier, as defined by the Barron's ranking system. In the within-two sample, we see that charters increase enrollment in the second-to-least selective Barron's tier ("competitive" colleges). These results provide weak evidence towards moderately more selective institutions. Specifically, charter attendance appears to increase the likelihood that students enroll in schools ranked in barron's second selectivity tier with two years of the expected date of high school graduation, with no other changes. This finding weighs against concerns that the shift towards public schools comes at the expense of selectivity.[18]

Figure 5 summarizes the effects of charter attendance on college attendance and institution type in the within-two sample. Significant results in the figure are for four-year enrollment variables only.

7 Additional Results

7.1 The Peer Channel

Charter schools are sometimes said to generate gains by selective retention of higher performing students (see, for example, Skinner (2009)). In other words, charters are said to kick out trouble-makers and stragglers, leaving a student population that's easier to teach. Importantly, the causal interpretation of our lottery-based estimation strategy is unaffected by selective retention because we follow all winners and losers, regardless of whether they stay in charter. Moreover, the charter enrollment variable is "switched on" even for students who spend only a single day enrolled in a charter school. Thus, outcomes for poor performing charter students who leave the school still "count" on the charter side of our IV estimation strategy.

[18]In a statewide sample, Cohodes and Goodman (2013) find the Adams Scholarship causes Massachusetts students to forgo more selective private campuses on average. But this results merges only for higher-income students.

At the same time, selective retention, if substantial, may lead to a favorable population mix that generates positive peer effects on students who remain enrolled in charter. In other words, charter school may do well for most of their students in part because a few bad apples who would otherwise be disruptive to all, or slow the class down, are encouraged to leave. While not invalidating the evidence of gains reported here, this *peer* channel has different policy implications than other explanations for charter effectiveness, such as differences in teacher quality or training.

We explore the peer channel by looking directly at school switching and peer composition. School switching is defined as being observed in two or more schools after a lottery application. Boston's high school population is highly mobile: over one-third of our applicant sample changes schools by this measure. It's of interest to know whether the switching rate is higher for charter students than others. Peer composition is measured as the average baseline scores of grade-mates at the start of 9th or 10th grade. Because charter applicants are positively selected (i.e., have higher baseline scores than other BPS students, on average), we expect to see some effect of charter enrollment on peer composition (recall that charter enrollment is defined here using data from 9th grade). The *evolution* of peer composition effects from 9th to 10th grades tells us how charter schools change the post-enrollment peer mix.

Charter enrollment raises the likelihood of school switching by about 12 percentage points, though this change is not significantly different from zero. As can be seen in column 2 of Table 8, however, the switching effect increase further to .143, a marginally significant finding, when switching is defined to omit natural transitional grades such as 6-to-7 (some charters have an unusual grade structure, a fact that might increase transition rates).

Might this evidence of differential switching account for the charter school gains reported here? Panel B assesses the explanatory power of the peer channel by showing the effect of charter enrollment on realized peer quality in 9th and 10th grade. Not surprisingly given the positive selection of charter applicants, charter enrollment is associated with sharp gains in peer achievement in 9th grade: the effect here is close to two-tenths of a standard deviation and significantly different from zero. The peer effect would be even large if not for the fact, documented in the last row of Panel A, that charter enrollment reduces exam school enrollment. In other words, the counterfactual for many charter students is an exam school, which also has positively selected peers.

Importantly, the effect of charter enrollment on peer quality falls for 10th grade peers, comparison with the effect of charter enrollment on 9th grade peers. This is apparent in the estimated peer effect of .1 for 10th grade peer, reported in column 4 of Table 8. In other words, the effect of charter attendance on students peer characteristics in 10th grade, presumably determined after the exit of "bad apples," is, in practice, *less* favorable than the effect on initial peer mix. This finding weighs against the notion that charter schools act to retain good peers, though clearly charter enrollment improves average peer composition initially.[19]

7.2 Effects on Special Education Students

[19] Our earlier study of Boston charters shows that *initial* peer composition is unlikely to account for positive charter effects on achievement: the interaction between school-specific gains and baseline peer achievement is negative. in other words, charters with the most value added have the worst initial peer mix.

One of the most important issues in the debate over school reform is how and whether students with special needs are served by schools of different types. Because charter seats are randomly assigned to applicants at oversubscribed schools, special education and LEP students are just as likely to be offered seats as are other applicants in our sample. Demographic differences in charter enrollment are therefore driven primarily by differences among applicants. There are too few LEP students in our applicant sample for a separate investigation of charter effects in this subpopulation to be fruitful, but special education students apply to charters at almost the same rate as other students in the district. We therefore ask explore the consequences of charter enrollment for the subsample of almost 20 percent of applicants identified as qualifying for special education services.[20]

The analysis here groups students by *baseline* special education status, that is, special education status as recorded in state administrative data in the same year that our baseline test scores were generated, before charter enrollment. We use a baseline definition of special education status out of a concern that charter schools might choose to reclassify students in one way or another. As it turns out, however, this concern is largely unfounded: the effect of charter enrollment on special education status is small and not significantly different from zero (see appendix Table A5 for details).

Estimates effects of charter enrollment by special education status show achievement gains at least as large for special education students as for others, as can be seen in Panel A of Table 9. Indeed, the overall effect of charter attendance meeting competency standards is almost entirely is due to the gains in the special education group. The gains in competency rates amount

[20]Low application rates in the LEP subpopulation may also be a concern. On the other hand, the Boston-area KIPP school evaluated in Angrist, et al. (2010 and 2012) enrolls many LEP students. Our earlier results suggest that KIPP enrollment generates substantially larger achievement gains for LEP students than for the general applicant population, especially in ELA.

special education students are an impressive 52 percentage points, in comparisons with an insignificant gain of about 9 points in competency among other students. Charter attendance also increases Adams Scholarship attainment in the special education group, though here the gains are larger for others. This is not surprising since most special education students are much farther from Adams qualification to start with.

Differences in the impact of charter enrollment by special education status are less clear for AP tests than for MCAS outcomes. Panel B of Table 9 charter enrollment affects AP taking similarly in the two subsamples, for example, though with a larger gain in calculus taking in the non special education group. Calculus score effects are also large for non special education students, though not large enough for differences in score effects by special education status to be statistically meaningful. Interestingly, however, panel C shows markedly larger score SAT score gains among special education students than for other applicants.

Special education students are significantly less likely to graduate high school on time than are other students, as can be seen in the mean graduation rates reported in columns 1 and 3 of Panel D. Charter attendance seems to hold some special education students back, reducing on time graduation rates in the special education subsample. The charter effect on within two graduation rates for special education students, however, is not significantly different from zero.

The sample of special education students available for a college going analysis is small, so the resulting estimates are necessarily imprecise. As can be seen in Panel E of Table 8, however, the estimated enrollment effects at schools of all types are much larger in the special education subsample than for other students. These results are highly imprecise and should be seen as preliminary and suggestive; we'll expand the analysis here as more data become available. Even now, however, findings in other areas seem reasonably conclusive: charter attendance increases the rate at which special education students meet state competency standards markedly, and appears to generate increased human capital for special education students, as evidenced by especially large gains in MCAS and SAT scores.

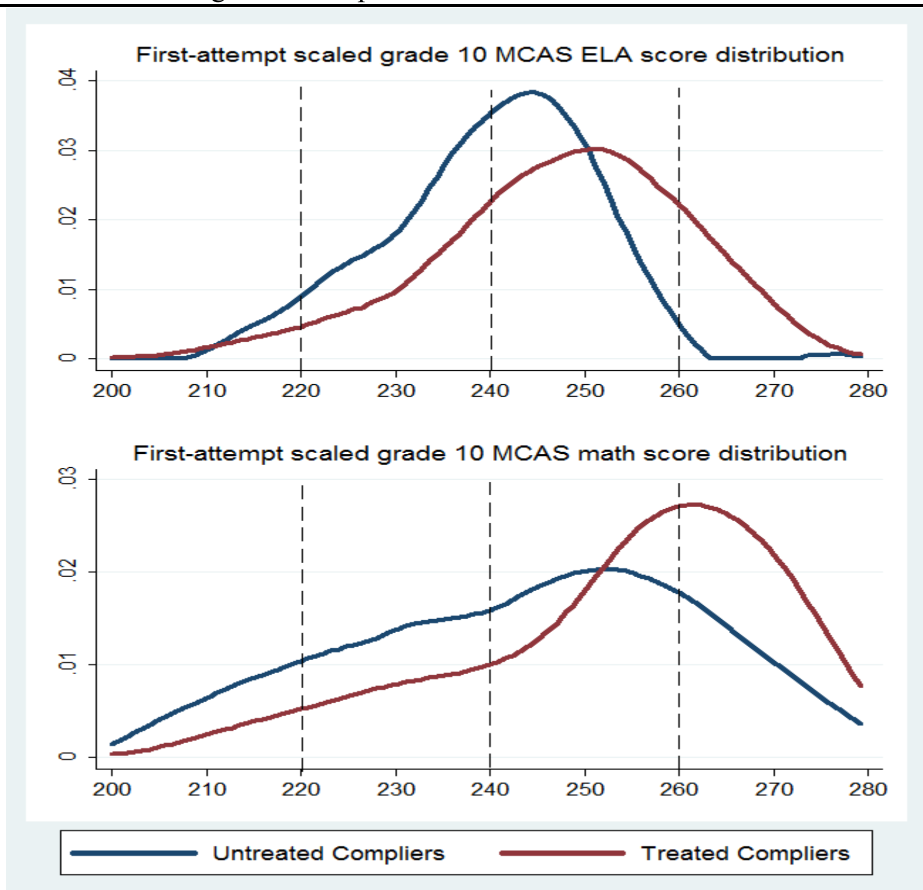
8 Summary and Conclusions

Studies of many educational interventions show promising short-run gains, followed by discouragingly fast fadeout. This paper uses randomized entrance lotteries to ask whether the substantial short-run test score effects of Boston's charter high schools translate into gains on longer-run outcomes like Advanced Placement test-taking and scores, SAT scores, college attendance, and college choice. Our estimates suggest that the effects of Boston's charters are remarkably persistent. Specifically, charter attendance raises the probability that students pass high-stakes exams required for high-school graduation, boosts the likelihood that students qualify for an exam-based college scholarship, increases the frequency of AP test-taking, substantially increases SAT scores, and shifts students away from attending two-year institutions and towards four-year attendance. The effect of charter attendance on the probability of attending a four-year public institution in Massachusetts is particularly large.

We explore a possible explanation for these gains in the form of school switching and peer effects. Charter attendance increases switching outside of transitional grades, but this does not accentuate the effect of charter enrollment on peer composition. If anything, charter peers become more like other peers as students progress from 9th grade to 10th. Motivated by concerns about how charters serve special needs students, we report estimates for a special education subsample, a group well represented at Boston’s charter high schools. With the exception of Adams Scholarship qualification and a possible delay in high school graduation, special education students seem to get at least as much out of charter attendance as does the general applicant population.

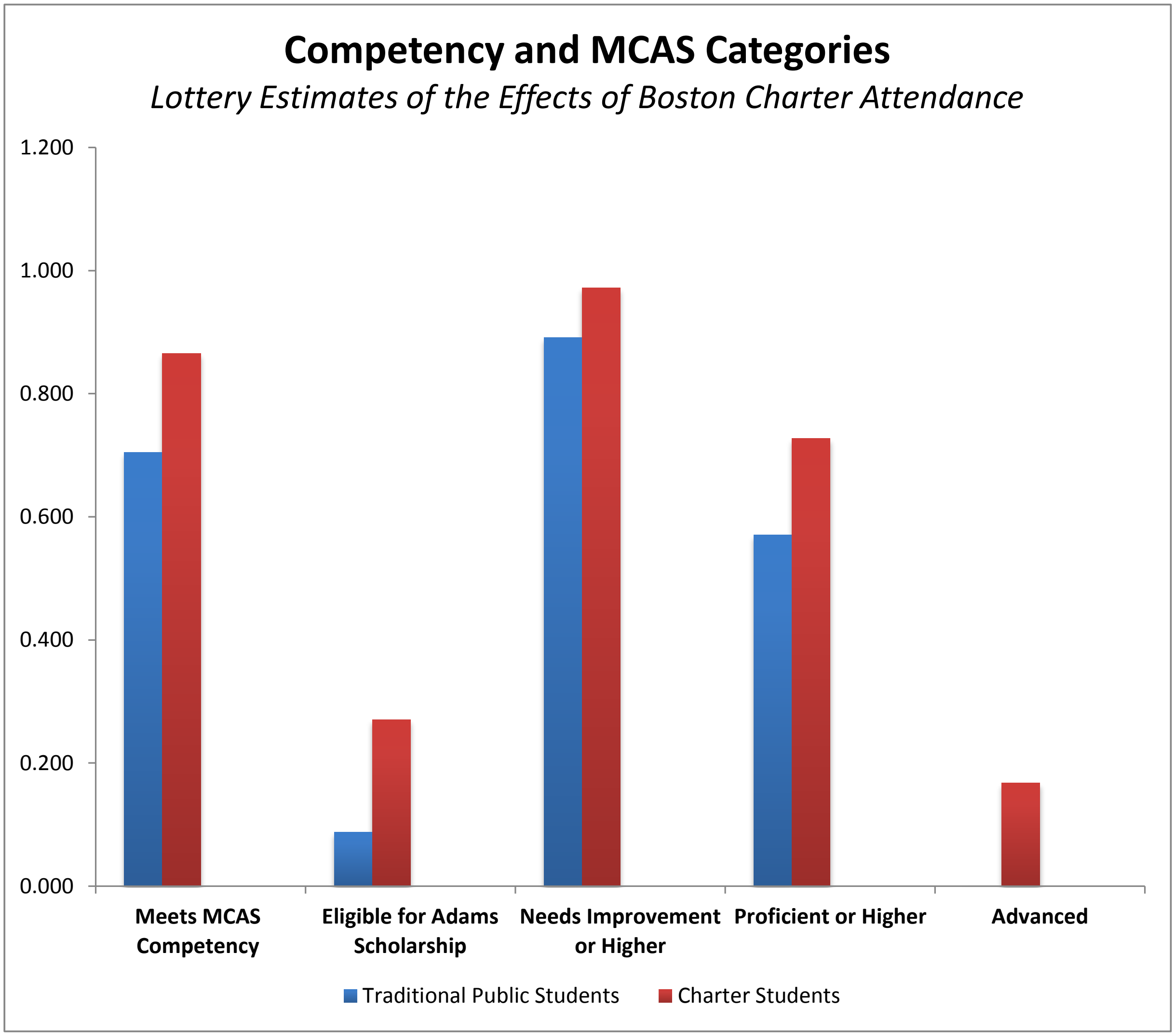
These results suggest that the short-run test score impacts reported in our previous work on Boston's charter schools are not driven by short-run gaming or teaching to the test; rather, they seem to represent increases in underlying human capital, with effects that generalize to a number of other contexts. The cohorts of lottery applicants in our sample are too young to generate reliable estimates of effects on college persistence or graduation. In future work, we plan to investigate the effects of Boston's charter schools on these outcomes, as well as longer-run labor market outcomes like employment and earnings.

Figure 1: Complier Distributions for MCAS Scaled Scores



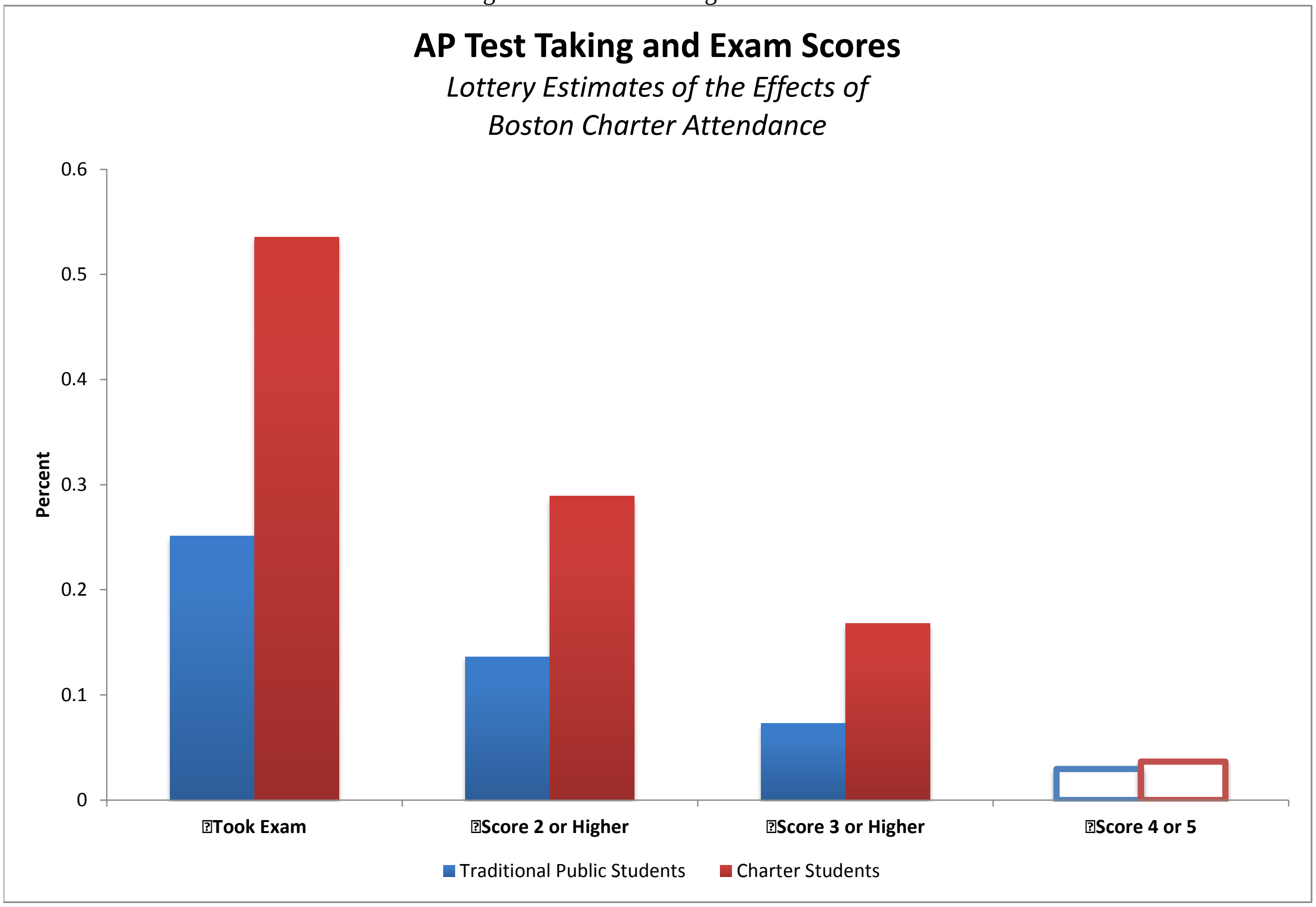
Notes: This figure plots smoothed MCAS scaled score distributions for treated and untreated compliers. The sample is restricted to lottery applicants projected to graduate between 2006 and 2013 assuming normal academic progress from baseline. Dotted vertical lines at scaled score 220 mark MCAS needs improvement thresholds, 240 for MCAS proficiency thresholds, and 260 for MCAS advanced thresholds.

Figure 2: Competency and MCAS Categories



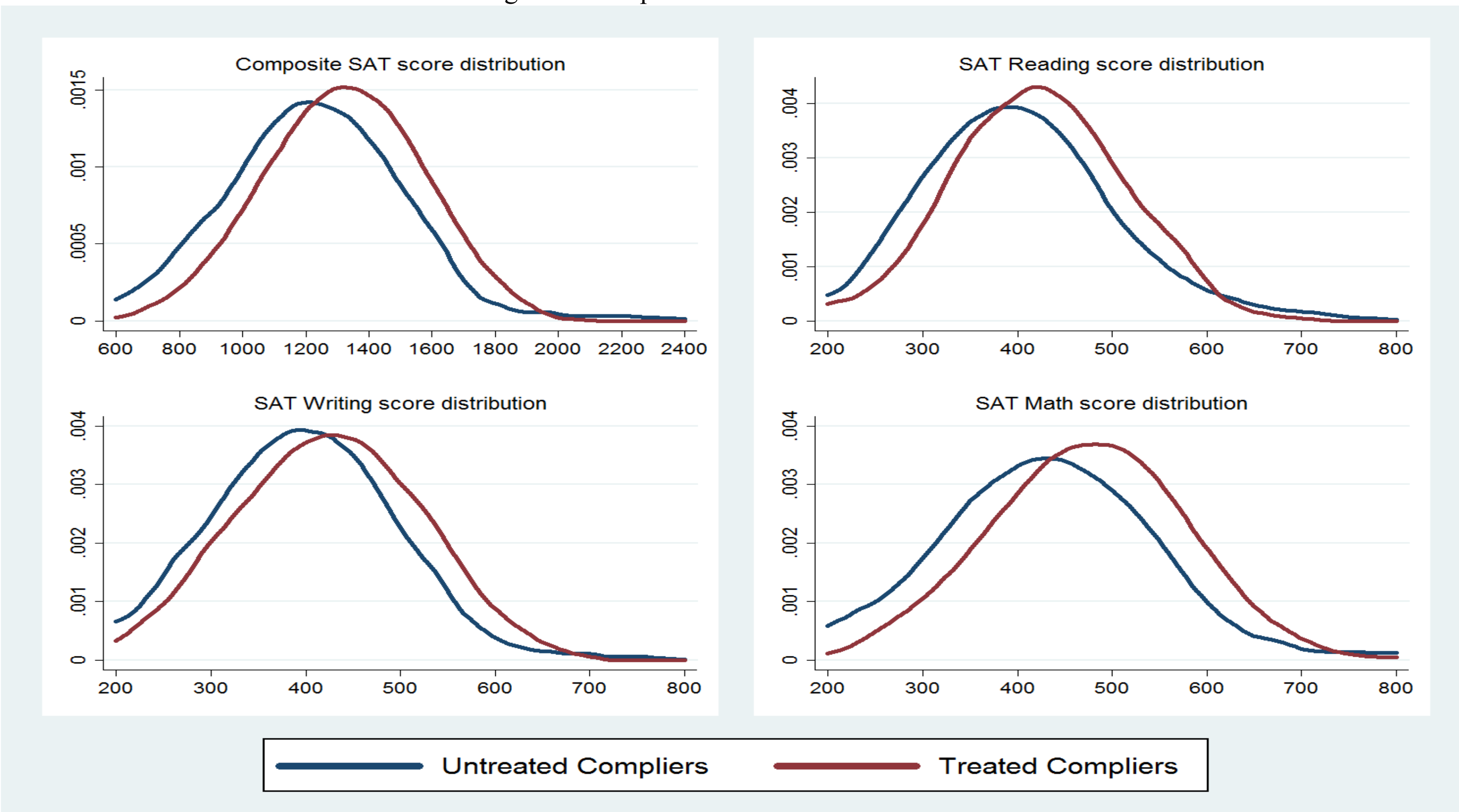
NOTE: Solid bars indicate statistically significant differences.

Figure 3: AP Test Taking and Exam Scores



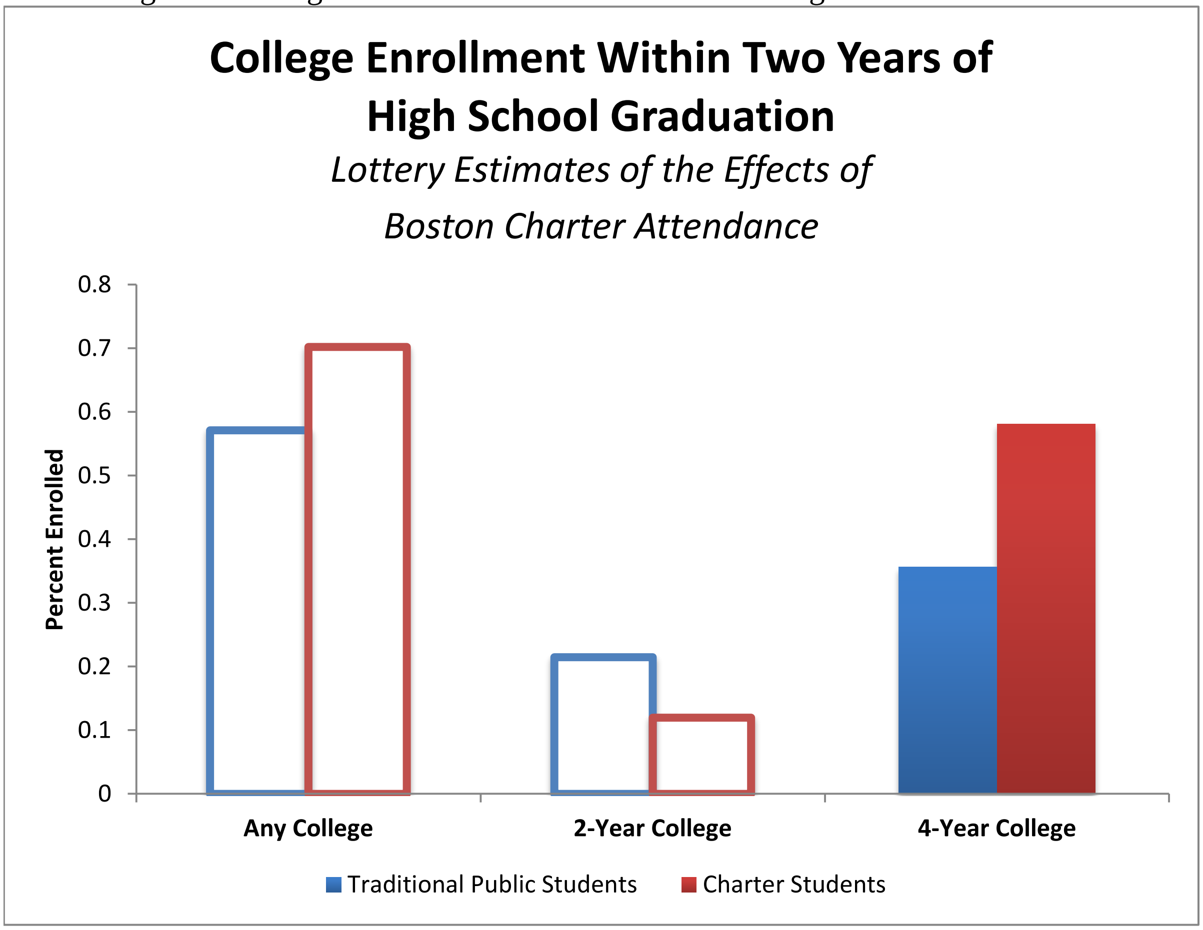
NOTE: Solid bars indicate statistically significant differences.

Figure 4: Complier Distributions for SAT Scores



Notes: This figure plots smoothed SAT score distributions for treated and untreated compliers. The sample is restricted to lottery applicants projected to graduate between 2007 and 2012.

Figure 5: College Enrollment Within Two Years of High School Graduation



NOTE: Solid bars indicate statistically significant differences.

Table 1: Descriptive Statistics

	Projected Senior Year					
	2006-13 (MCAS outcome sample)		2007-12 (AP/SAT outcome sample)		2006-10 (NSC outcome sample)	
	BPS 9th Graders	Lottery Applicants	BPS 9th Graders	Lottery Applicants	BPS 9th Graders	Lottery Applicants
	Mean (1)	Mean (2)	Mean (3)	Mean (4)	Mean (5)	Mean (6)
Female	0.496	0.546	0.497	0.537	0.499	0.541
Black	0.421	0.615	0.419	0.606	0.436	0.657
Hispanic	0.307	0.252	0.310	0.262	0.300	0.226
Asian	0.101	0.034	0.100	0.033	0.099	0.037
Subsidized Lunch	0.742	0.733	0.749	0.737	0.744	0.738
Special Education	0.205	0.177	0.199	0.178	0.201	0.169
Limited English Proficiency	0.119	0.035	0.112	0.037	0.118	0.026
Baseline MCAS ELA	-0.488	-0.286	-0.473	-0.339	-0.450	-0.268
Baseline MCAS Math	-0.426	-0.302	-0.411	-0.329	-0.406	-0.340
Took any AP	-		0.267	0.313	-	
Took SAT	-		0.493	0.643	-	
On-time enrollment	-		-		0.367	0.481
Charter Attendance		0.294		0.281		0.301
Ever Offer		0.644		0.638		0.663
Initial Offer		0.289		0.310		0.298
N	29933	3527	22476	2946	19675	1886

Notes: This table shows descriptive statistics for charter lottery applicants and Boston public school (BPS) students. Column (1) shows means for BPS attendees projected to graduate between 2006 and 2013 assuming normal academic progress from baseline. Column (2) shows means for charter lottery applicants in the same projected graduation year range. Column (4) shows means for the AP/SAT outcome sample restricted to students projected to graduate between 2007 and 2012. Column (3) shows means for BPS attendees projected to graduate in the same year range. Column (6) shows means for the National Student Clearinghouse (NSC) outcome sample, which is restricted to students projected to graduate between 2006 and 2010. Column (5) shows means for BPS attendees projected to graduate in the same year range. Baseline grade is defined as 4th grade for Boston Collegiate, 5th grade for Boston Preparatory and Academy of the Pacific Rim, and 8th grade for Match, Codman Academy and City on a Hill Charter. Baseline grade for BPS 9th graders is 8th grade.

*significant at 10%; **significant at 5%; ***significant at 1%

Table 2: Lottery Estimates of Effects on 10th-Grade MCAS Scores

	First Stage		Outcome Mean	
	Ever Offer	Initial Offer	[s.d.]	Effect
Subject	(1)	(2)	(3)	(4)
Standardized ELA	0.230***	0.140***	-0.289	0.397***
	(0.042)	(0.031)	[0.825]	(0.106)
N	3527			
First-stage F	28.8			
Standardized Math	0.232***	0.140***	-0.237	0.545***
	(0.041)	(0.031)	[0.900]	(0.122)
N	3474			
First-stage F	28.8			

Notes: This table reports 2SLS estimates of the effects of Boston charter attendance on 10th-grade MCAS test scores. The sample includes students projected to graduate between 2006 and 2013. The endogenous variable is charter attendance in 9th or 10th grade. The instruments are ever offer and initial offer dummies. Initial offer is equal to one when a student is offered a seat in any of the charter schools immediately following the lottery, while ever offer is equal to one for students offered seats at any time. Means and standard deviations in column (3) are for non-charter students. All 2SLS regressions control for risk sets, 10th grade calendar year dummies, race, sex, special education, limited English proficiency, subsidized lunch status, and a female by minority dummy. Standard errors are clustered at the school-year level in 10th grade.

*significant at 10%; **significant at 5%; ***significant at 1%

Table 3: Lottery Estimates of Effects on MCAS Performance Categories

	ELA				Math				Combined			
	First Attempt		Ever		First Attempt		Ever		First Attempt		Ever	
	Mean	Effect	Mean	Effect	Mean	Effect	Mean	Effect	Mean	Effect	Mean	Effect
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Panel A: Consequential Score Outcomes												
Meets Competency Determination Requirement	0.814	0.162*** (0.053)	0.831	0.148*** (0.053)	0.760	0.112* (0.059)	0.803	0.082 (0.058)	0.697	0.161** (0.067)	0.744	0.132* (0.068)
Eligible for Adams Scholarship Using BPS Cutoffs									0.151	0.183*** (0.062)		
Panel B: MCAS Categories												
Needs Improvement or Higher	0.965	-0.009 (0.024)	0.990	-0.004 (0.011)	0.915	0.081** (0.034)	0.978	0.029* (0.015)	0.904	0.081** (0.036)	0.976	0.022 (0.016)
Proficient or Higher	0.656	0.167*** (0.062)	0.658	0.162*** (0.062)	0.641	0.153** (0.066)	0.645	0.132** (0.067)	0.538	0.157** (0.073)	0.540	0.152** (0.075)
Advanced or Higher	0.083	0.188*** (0.036)	0.083	0.188*** (0.036)	0.314	0.260*** (0.062)	0.314	0.260*** (0.062)	0.068	0.167*** (0.035)	0.068	0.167*** (0.035)
N				3523				3471				3448

Notes: This table reports 2SLS estimates of the effects of Boston charter attendance on passing Massachusetts' 10th-grade MCAS requirements for high school graduation. The Competency Determination requires scores of 220 for both ELA and math for the classes of 2006-2009, and scores of 240 for both tests for the classes of 2010-2013. A student is eligible for the Adams Scholarship if he is proficient on both tests, advanced in either subject, and scores among the top 25% of the Boston district on his first attempt. A student "needs improvement" if he scores at or above 220 on both tests; "is proficient" if he scores at or above 240 on both tests; "is advanced" if he scores at or above 260 on both tests. See Table 2 notes for detailed regression specifications.

*significant at 10%; **significant at 5%; ***significant at 1%

Table 4: Lottery Estimates of Effects on Advanced Placement Test-taking and Scores

	All AP Exams		Science		Calculus		US History		English	
	Mean	Effect	Mean	Effect	Mean	Effect	Mean	Effect	Mean	Effect
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Took Exam	0.267	0.284***	0.100	0.323***	0.062	0.210***	0.034	0.177*	0.148	0.075
		(0.073)		(0.060)		(0.070)		(0.093)		(0.078)
Number of Exams	0.513	0.954***	0.113	0.312***						
		(0.274)		(0.069)						
Score 2 or Higher	0.137	0.153**	0.028	0.043	0.018	0.086*	0.023	0.056	0.087	0.070
		(0.068)		(0.032)		(0.045)		(0.048)		(0.053)
Score 3 or Higher	0.070	0.095*	0.016	0.020	0.015	0.072*	0.014	0.027	0.024	0.034
		(0.051)		(0.014)		(0.040)		(0.019)		(0.027)
Score 4 or 5	0.039	0.007	0.009	-0.001	0.008	0.021	0.007	-0.010	0.009	0.003
		(0.033)		(0.012)		(0.019)		(0.011)		(0.012)
AP Slugging (Sum of all scores)	0.732	0.699	0.104	0.128						
		(0.472)		(0.120)						
N										2946

Notes: This table reports 2SLS estimates of the effects of Boston charter attendance on AP test-taking and scores. The sample includes students projected to graduate between 2007 and 2012. Outcomes are equal to zero for students who never took AP exams. AP Slugging is equal to the sum of all available test scores, and AP score of 1 is coded as 0 in this outcome. Science subjects include Biology, Chemistry, Physics B, Physics Mechanics, Physics Electricity/Magnetism, Computer Science A, Computer Science AB, and Environmental Science. Outcomes for Calculus combine Calculus AB and Calculus BC. Outcomes for English combine English Literature and English Language. See Table 2 notes for detailed regression specifications.

*significant at 10%; **significant at 5%; ***significant at 1%

Table 5: Lottery Estimates of Effects on SAT Test-taking and Scores

	Taking		Reasoning (1600)		Composite (2400)	
	Mean [s.d.] (1)	Effect (2)	Mean [s.d.] (3)	Effect (4)	Mean [s.d.] (5)	Effect (6)
Took SAT	0.636	0.028				
	[0.481]	(0.078)				
Score Above MA Bottom Quartile			0.254	0.133**	0.254	0.115*
			[0.436]	(0.066)	[0.436]	(0.067)
Score Above MA Median			0.093	0.112**	0.083	0.099**
			[0.290]	(0.049)	[0.275]	(0.040)
Score In MA Top Quartile			0.026	0.000	0.019	-0.010
			[0.160]	(0.016)	[0.138]	(0.017)
N						2946
Average Score			846.8	74.0**	1254.7	100.7**
(For takers)			[166.5]	(29.1)	[240.0]	(43.0)
N						1895

	Math (800)		Verbal (800)		Writing (800)	
	Mean [s.d.] (1)	Effect (2)	Mean [s.d.] (3)	Effect (4)	Mean [s.d.] (5)	Effect (6)
Score Above MA Bottom Quartile	0.301	0.162**	0.264	0.120**	0.279	0.106
	[0.459]	(0.080)	[0.441]	(0.060)	[0.449]	(0.067)
Score Above MA Median	0.117	0.143**	0.102	0.063	0.096	0.053
	[0.321]	(0.057)	[0.303]	(0.046)	[0.295]	(0.041)
Score In MA Top Quartile	0.033	0.046	0.025	-0.019	0.022	0.010
	[0.178]	(0.028)	[0.158]	(0.021)	[0.147]	(0.021)
N						2946
Average Score	434.3	51.1***	412.5	22.8	408.0	26.7*
(For takers)	[95.5]	(17.0)	[87.3]	(15.7)	[86.7]	(16.2)
N						1895

Notes: This table reports 2SLS estimates of the effects of Boston charter attendance on SAT test-taking and scores. The sample includes students projected to graduate between 2007 and 2012. Outcomes are based on the last SAT scores available. Means and standard deviations are for non-charter students. The average score outcomes restrict the sample to SAT takers. All other outcomes are equal to zero for non-SAT takers. The maximum SAT scores are shown in parenthesis next to outcome labels. US average and standard deviations for 2012 are 512 (117) for math; 496 (114) for verbal; 488 (114) for writing; 1010 (214) for reasoning; 1498 (316) for composite. See Table 2 notes for detailed regression specifications.
*significant at 10%; **significant at 5%; ***significant at 1%

Table 6: Lottery Estimates of Effects on High School Graduation and Grade Repetition

			Excl. Transferred and Deceased	
	Mean (1)	Effect (2)	Mean (3)	Effect (4)
Panel A: Graduation Outcome				
Graduate On-time	0.685	-0.107	0.726	-0.089
		(0.069)		(0.071)
N		2597		2444
Graduate Within Two	0.787	0.043	0.828	0.099
		(0.073)		(0.074)
Repeat grade for at least one semester	0.203	0.078	0.193	0.068
		(0.074)		(0.075)
Repeat at least one entire grade, or repeat more than one grade	0.142	0.060	0.141	0.057
		(0.061)		(0.063)
N		1886		1777
Panel B: On-time 10th-Grade MCAS Test Taking				
Take ELA on-time	0.919	0.008	-	
		(0.021)		
N		3523		
Take Math on-time	0.924	0.005	-	
		(0.022)		
N		3471		
Take Both on-time	0.925	0.011	-	
		(0.020)		
N		3448		

Notes: This table reports 2SLS estimates of the effects of Boston charter attendance on high school graduation and grade repetition. On-time graduation is equal to one if a student graduates before or in the year of his projected graduation year. The sample for on-time graduation includes students projected to graduate between 2006 and 2011. Graduate within two is equal to one if a student graduates by the year following projected graduation year. Grade repetition outcomes are defined in two ways: is equal to one if a student repeats a grade for at least one semester of any grade; repeats entire grade at least once or repeating more than one grade. The sample for graduate within two and grade repetition includes students projected to graduate by Spring 2011. Taking 10th-grade MCAS on-time is equal to one if a student takes first MCAS test before or in the projected 10th grade based on normal academic progress from baseline. Columns (3) and (4) remove transferred or deceased applicants. See Table 2 notes for detailed regression specifications.
*significant at 10%; **significant at 5%; ***significant at 1%

Table 7: Lottery Estimates of Effects on College Enrollment

	Enrolled On-time		Enrolled Within Two	
	Mean	Effect	Mean	Effect
	(1)	(2)	(3)	(4)
Panel A: Attendance at Any NSC-Covered School				
Any	0.491	0.059	0.607	0.131
		(0.083)		(0.120)
Two-year	0.121	-0.104*	0.198	-0.095
		(0.055)		(0.093)
Four-year	0.370	0.163**	0.409	0.225**
		(0.079)		(0.110)
Four-year Public	0.135	0.185***	0.129	0.367***
		(0.068)		(0.113)
Four-year Private	0.235	-0.022	0.279	-0.142
		(0.086)		(0.151)
Four-year Public In MA	0.114	0.140**	0.105	0.284***
		(0.061)		(0.100)
Panel B: Attendance at Barron's-Ranked Schools				
Lowest Selectivity Tier Only	0.208	-0.009	0.305	-0.043
		(0.063)		(0.103)
Second Lowest Selectivity Tier Only	0.193	0.052	0.188	0.183*
		(0.070)		(0.098)
Top Three Selectivity Tiers	0.090	0.016	0.114	-0.009
		(0.047)		(0.080)
N		1886		1382

Notes: This table reports 2SLS estimates of the effects of Boston charter school attendance on college enrollment. On-time enrollment is defined as enrolling by the semester after projected high school graduation, while enrollment within two years is defined as enrolling within two fall semesters after projected high school graduation. The on-time enrollment sample includes students projected to graduate in 2010 or earlier. The within-two sample is restricted to students projected to graduate in 2009 or earlier, so that within-two enrollment can be observed. See Table 2 notes for detailed regression specifications.

*significant at 10%; **significant at 5%; ***significant at 1%

Table 8: Estimates of Effects on School Switching and Realized Peer Quality

	Mean (1)	Effect (2)	Mean (3)	Effect (4)
Panel A: School Switching				
Any Switch to observed schools	0.358	0.116	-	
		(0.085)		
N		3074		
Switch to observed schools without a transitional grade	0.329	0.143*	-	
		(0.081)		
N		3064		
Ever attend an exam school	0.145	-0.099**	-	
		(0.042)		
N		3194		
Panel B: Realized Peer Quality in 9th Grade and 10th Grade				
	Grade 9		Grade 10	
Peer Baseline ELA	-0.382	0.177***	-0.355	0.103
		(0.065)		(0.066)
N		3664		3730
Peer Baseline Math	-0.378	0.164**	-0.341	0.112
		(0.071)		(0.070)
N		3672		3742
Peer Baseline Sum of ELA and Math	-0.745	0.318**	-0.680	0.205
		(0.132)		(0.132)
N		3663		3727

Notes: This table reports 2SLS estimates of the effects of Boston charter attendance on school switching and realized peer quality. School-switching estimates are based on the sample of applicants projected to graduate between 2006 and 2012, and realized peer quality estimates are based on the MCAS outcome sample. A student switches to an observed school if he is observed to be in two schools in any grades after lottery application. Exam school attendance is equal to one if a student is observed attending an exam school any time after the lottery and zero otherwise. Realized peer quality is measured as the average baseline scores of other students in the same school and year. See Table 2 notes for detailed regression specifications.
*significant at 10%; **significant at 5%; ***significant at 1%

Table 9: Estimates of Effects by Baseline Special Education Classifications

	Not Special Ed		Special Ed	
	Mean	Effect	Mean	Effect
	(1)	(2)	(3)	(4)
Panel A: 10th- Grade MCAS				
Standardized ELA	-0.144	0.349***	-1.007	0.572**
		(0.110)		(0.262)
Standardized Math	-0.106	0.522***	-0.896	0.679***
		(0.131)		(0.245)
Meets Competency Determination Requirement (First Attempt)	0.763	0.089	0.363	0.510***
		(0.072)		(0.131)
Adams Scholarship Eligibility	0.174	0.198***	0.035	0.094*
		(0.074)		(0.052)
N		2850		598
Panel B: AP Outcomes				
Took any AP	0.309	0.276***	0.064	0.280***
		(0.083)		(0.107)
Took AP Calculus	0.071	0.227***	0.019	0.130*
		(0.077)		(0.078)
Score 3 or Higher, any AP	0.082	0.108	0.014	0.014
		(0.065)		(0.058)
Score 3 or Higher, Calculus	0.016	0.090*	0.006	0.004
		(0.050)		(0.042)
AP Slugging (Sum of all scores)	0.846	0.829	0.178	0.150
		(0.570)		(0.490)
N		2423		523
Panel C: SAT Outcomes				
Took SAT	0.673	0.067	0.458	-0.165
		(0.080)		(0.175)
N		2423		523
SAT Math (800)	443.5	50.9***	368.1	49.9
		19.1		34.3
SAT Reasoning (1600)	863.6	66.0**	726.4	103.7*
		31.3		58.3
SAT Composite (2400)	1280.4	90.0**	1070.5	164.0**
		45.4		82.3
N		1648		247
Panel D: High School Graduation				
Graduate On-time	0.705	-0.072	0.586	-0.375**
		(0.075)		(0.179)
N		2145		452
Graduate Within Two	0.805	0.062	0.690	-0.111
		(0.076)		(0.219)
N		1568		318
Panel E: College Enrollment Within Two				
Any	0.635	0.092	0.441	0.522
		(0.121)		(0.697)
4-year	0.440	0.178	0.224	0.874
		(0.123)		(0.672)
4-year Public	0.147	0.348***	0.028	0.614*
		(0.121)		(0.367)
N		1158		224

Notes: This table reports 2SLS estimates of the effects of Boston charter attendance by baseline special education classifications. See Table 2 notes for detailed regression specifications.
*significant at 10%; **significant at 5%; ***significant at 1%

Table A1: Boston School Characteristics

	Public High Schools	Charters Serving Grade 9-12	Charters Serving Grade 9-12 Only	Charters in the Study
	Mean	Mean	Mean	Mean
	(1)	(2)	(3)	(4)
Panel A: Charter School Characteristics				
Number of years open	-	14	15	14
Days per year	180	190	189	191
Average minutes per day	389	478	477	489
Have Saturday school	-	0.71	0.75	0.83
Avg. math instructions (min)	-	92.0	83.5	97.3
Avg. reading instruction (min)	-	92.0	89.8	97.3
No Excuses	-	0.71	0.75	0.83
Panel B: Comparison with Traditional Boston Public Schools				
Number of teachers	45	27	19	28
Student/teacher ratio	14.6	13.0	13.6	13.3
Proportion of teachers licensed in teaching assignment	0.97	0.63	0.71	0.58
Proportion of teachers 32 and younger	0.28	0.71	0.71	0.76
Proportion of teachers 49 and older	0.35	0.09	0.10	0.05
Proportion of core classes taught by highly qualified teachers	0.93	0.97	0.98	0.97
Avg. per-pupil expenditure	$14,614*	$14,277	$15,313	$13,990
Title I eligible	1	1	1	1
N (schools)	21	7	4	6

Notes: This table reports characteristics of Boston charter schools and Boston public schools operating in academic calendar year 2012-13. Charter school characteristics are obtained from a survey of school administrators. Panel B compares Boston charter high schools to Boston public high schools. Data on public schools are from http:\\www.doe.mass.edu. Boston public high schools include Another Course to College, Boston Arts Academy, Boston Community Leadership Academy, Boston Latin Academy, Boston Latin School, Brighton High, Boston International High, Burke High, Charlestown High, Community Academy of Science and Health, Dorchester Academy, East Boston High, The English High, Excel High, Fenway High, Greater Egleston High, New Mission High, O'Bryant School of Math and Science, Quincy Upper, Snowden International High, Urban Science Academy. Data for West Roxbury Academy and TechBoston Aacdemy are missing. Boston charters serving grade 9-12 include Academy of the Pacific Rim, Boston Preparatory, City on a Hill, Codman Academy, Boston Collegiate High, Health Careers Academy, and Match. Boston charter high schools serving grade 9-12 only are City on a Hill, Codman Academy, Match, Health Careers Academy. Statistics are based on data from 2011. *Average per-pupil expenditure is the mean of FY2010 and FY2012 per-pupil expenditures (data acquired from annual "At A Glance" BPS publications) for all Boston Public Schools, including middle schools and elementary schools. The statistic includes all salaries, instructional costs, and support services costs; it excludes all capital costs.

Table A2: Lottery Records

	Panel A: Lottery Records								
Projected Senior Year	2006	2007	2008	2009	2010	2011	2012	2013	All
Total number of records	600	450	940	883	1117	1533	1753	1564	8840
Excluding disqualified applicants	600	450	940	883	1117	1530	1753	1553	8826
Excluding late applicants	590	446	930	880	1117	1530	1733	1553	8779
Excluding applicants from outside of area	590	446	930	880	1114	1529	1733	1535	8757
Excluding siblings	570	437	905	864	1101	1482	1642	1454	8455
Excluding records not matched to the SIMS	509	419	858	816	1055	1395	1547	1354	7953
Reshaping to one record per student	437	419	632	594	799	1025	1100	966	5972
Excluding repeat applications	437	419	629	589	778	1005	1029	914	5800
In Boston schools at baseline	289	337	511	481	605	847	751	690	4511
Excluding applicants without outcome scores	232	268	419	382	483	667	568	529	3548

Panel B: Comparison of Ever Offer and Initial Offer Records by Schools and Cohorts

Application Year/School		Boston Preparatory	Academy of Pacific Rim	Boston Collegiate	City on a Hill	Codman Academy	Match
2002	Ever			Yes	No Variation	-	Yes
	Initial			Yes	Yes	-	Yes
2003	Ever			Yes	-	-	Yes
	Initial			Yes	-	-	Yes
2004	Ever			Yes	No Variation	Yes	Yes
	Initial			Yes	Yes	Yes	Yes
2005	Ever	No Variation	Yes	Yes	Yes	-	Yes
	Initial	Yes	Yes	Yes	Yes	-	Yes
2006	Ever				Yes	-	Yes
	Initial				Yes	-	Yes
2007	Ever				Yes	-	Yes
	Initial				Yes	-	Yes
2008	Ever				No Variation	Yes	Yes
	Initial				Yes	Yes	Yes*
2009	Ever				Yes	Yes	Yes
	Initial				Yes	Yes	Yes
N(applicants)		84	86	273	2035	161	2498

Notes: Panel A summarizes the sample restrictions imposed for the lottery analysis. Disqualified applications are duplicate records and applications to the wrong grade. In Panel B, blank space indicates cohorts irrelevant to the analysis and years before schools opened. "Dash" shows schools and years for which lottery records were unavailable. "No Variation" indicates that every applicant received an offer. "Yes" means that lottery records with non-missing information on ever offer and initial offer were available, and that not every applicant gets an offer or initial offer in that school year. Number of applicants is based on the MCAS outcome sample. *For Match 2008 applicants, we impute initial offer using the 2007 Match initial offer cutoff.

Table A3: Covariate Balance

	Ever offer (1)	Initial offer (2)
Female	0.004	0.028
	(0.021)	(0.020)
Black	-0.005	0.008
	(0.021)	(0.019)
Hispanic	0.000	-0.006
	(0.018)	(0.017)
Asian	0.000	-0.005
	(0.008)	(0.006)
Subsidized Lunch	0.019	0.016
	(0.019)	(0.018)
Special Education	-0.005	0.015
	(0.017)	(0.016)
Limited English Proficiency	0.006	0.004
	(0.007)	(0.007)
Baseline MCAS ELA	-0.009	-0.038
	(0.037)	(0.036)
Baseline MCAS Math	0.004	-0.032
	(0.038)	(0.036)
P-Value	0.971	0.799
N	3391	3391

Notes: This table reports coefficients from regressions of observed characteristics on lottery offers, controlling for risk sets. Estimates are based on the MCAS outcome sample. P-values are from tests of the hypothesis that all coefficients are zero.
*significant at 10%; **significant at 5%; ***significant at 1%

Table A4: Grade 10 and Grade 12 Attrition

	Panel A: Observed 10th-Grade MCAS Scores and Grade 12 In MA Status				*Panel B: Attrition Differentials by Ever Offer and Initial Offer*					
	Either Math or ELA	ELA	Math	Grade 12 MA	ELA		Math		Grade 12 MA	
Projected Senior Year	Mean	Mean	Mean	Mean	Ever Offer	Initial Offer	Ever Offer	Initial Offer	Ever Offer	Initial Offer
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
2006	0.803	0.803	0.803	0.747	0.108	0.031	0.108	0.031	0.015	0.068
					(0.083)	(0.053)	(0.083)	(0.053)	(0.079)	(0.062)
2007	0.795	0.792	0.789	0.774	-0.038	-0.063	-0.034	-0.036	0.011	0.017
					(0.058)	(0.066)	(0.058)	(0.065)	(0.057)	(0.062)
2008	0.820	0.812	0.800	0.765	0.100	-0.034	0.072	-0.035	0.028	-0.011
					(0.064)	(0.043)	(0.066)	(0.045)	(0.070)	(0.050)
2009	0.794	0.786	0.771	0.763	-0.033	-0.061	-0.020	-0.048	-0.037	-0.050
					(0.042)	(0.042)	(0.044)	(0.043)	(0.044)	(0.043)
2010	0.798	0.795	0.785	0.765	0.036	-0.010	0.028	-0.015	-0.033	-0.040
					(0.044)	(0.040)	(0.045)	(0.041)	(0.046)	(0.042)
2011	0.787	0.784	0.762	0.730	-0.005	0.039	-0.003	0.050	0.014	0.034
					(0.031)	(0.032)	(0.032)	(0.033)	(0.033)	(0.035)
2012	0.756	0.750	0.743	0.610	0.027	-0.016	0.048	-0.007	-0.038	-0.059
					(0.052)	(0.036)	(0.052)	(0.037)	(0.057)	(0.041)
2013	0.767	0.764	0.751	-	-0.014	0.038	-0.015	0.054	-	
					(0.036)	(0.043)	(0.037)	(0.044)		
All Cohorts	0.787	0.782	0.770	0.726	0.007	-0.002	0.008	0.006	-0.010	-0.010
					(0.016)	(0.015)	(0.016)	(0.015)	(0.015)	(0.017)
N (All Cohorts)						4511		4511		3821

Notes: This table summarizes attrition for 10th-grade MCAS scores and 12th-grade Massachusetts status for charter school lottery applicants. Columns (1), (2) and (3) show the percentage of observed MCAS scores in samples expected to have post-lottery 10th-grade MCAS test scores given normal academic progress after the lottery. Column (4) shows the percentage of students in Massachusetts in 12th grade among lottery applicants. Columns (5) and (6) report coefficients on ever offer and initial offer dummies from regressions in which the dependent variable is an indicator equal to one if a student has a follow-up 10th-grade ELA test score. The dependent variable in columns (7) and (8) is an indicator equal to one if a student has a follow-up 10th-grade math test score. The dependent variable in columns (9) and (10) is an indicator equal to one if a student is observed in Massachusetts in 12th grade. All regressions control for risk set dummies.

*significant at 10%; **significant at 5%; ***significant at 1%

Table A5: Estimates of Effects on Special Education Classifications

	Grade 10		Grade 11		Grade 12	
	Mean	Effect	Mean	Effect	Mean	Effect
	(1)	(2)	(3)	(4)	(5)	(6)
Special Education Status	0.156	-0.034	0.146	-0.019	0.138	-0.040
		(0.028)		(0.033)		(0.034)
N		3194		2874		2680

Notes: This table reports 2SLS estimates of the effects of Boston charter attendance on high school special education classifications in 10th grade through 12th grade. Estimates are based on the sample of students projected to graduate between 2006 and 2012. See Table 2 notes for detailed regression specifications.
*significant at 10%; **significant at 5%; ***significant at 1%

Data Appendix

The data used for this study come from several sources. Lists of charter applicants and lottery winners are constructed from records provided by individual charter schools. Information on schools attended and student demographics come from the Student Information Management System (SIMS), a centralized database that covers all public school students in Massachusetts. Test scores are from the Massachusetts Comprehensive Assessment System (MCAS). Advanced Placement (AP) and Scholastic Aptitude Test (SAT) scores are provided by the College Board. College attendance information comes from the National Student Clearinghouse (NSC). This Appendix describes each data source and details the procedures used to clean and match them.

Lottery Data

Data description and sample restrictions

Our sample of applicants is obtained from records of lotteries held at 6 Massachusetts charter schools between 2002 and 2009. The participating schools and lottery years are listed in Table A2. A total of 23 school-specific entry cohorts are included in the analysis. Lotteries for three participating schools, Match, Codman Academy, and City on a Hill, were conducted for entry to 9th grade; two schools, Boston Preparatory and Academy of the Pacific Rim, held lotteries for 6th grade entry. Records for Boston Collegiate are from 5th grade lotteries.

The raw lottery records typically include applicants' names, dates of birth, contact information, and other information used to define lottery groups, such as sibling status. The first five rows in Table A2 show the sample restrictions we impose on the raw lottery records. We exclude duplicate applicants and applicants listed as applying to the wrong entry grade. We also drop late applicants, out-of-area applicants, and sibling applicants, as these groups are typically not included in the standard lottery process. Imposing these restrictions reduces the number of lottery records from 8,840 to 8,455.

Lottery offers

In addition to the data described above, the lottery records also include information regarding offered seats. We used this information to reconstruct indicator variables for whether lottery participants received randomized offers. We make use of two sources of variation in charter offers, which differ in timing. The *initial offer* instrument captures offers made on the day of the charter school lottery. The *ever offer* instrument captures offers made initially or later, as a consequence of movement down a randomly sequenced waiting list. The pattern of instrument availability across schools and applicant cohorts is documented in Panel B of Appendix Table A2. In some years, all applicants eventually received offers, in which case only the initial offer instrument contributes to the analysis; these cases are listed as "No Variation" for the ever offer instrument. As documented in Table 1, initial and ever offer rates were 29 and 64 percent in our MCAS analysis sample, and these rates were similar in the samples for other outcomes.

SIMS Data

Data description

Our study uses SIMS data from the 2001-2002 school year through the 2011-2012 school year. Each year of data includes an October file and an end-of-year file. The SIMS records information on demographics and schools attended for all students in Massachusetts' public schools. An observation in the SIMS refers to a student in a school in a year, though there are some student-school-year duplicates for students that switch grades or programs within a school and year. The SIMS includes a unique student identifier known as the SASID, which is used to match students from other data sources as described below.

Coding of demographics and attendance

The SIMS variables used in our analysis include grade, year, name, town of residence, date of birth, sex, race, special education and limited English proficiency status, free or reduced price lunch, and school attended. We constructed a wide-format data set that captures demographic and attendance information for every student in each year in which he or she is present in Massachusetts' public schools. This file uses information from the longest-attended school in the first calendar year spent in each grade. Attendance ties were broken at random; this affects only 0.007 percent of records. Students classified as special education, limited English proficiency, or free/reduced price lunch in any record within a school-year-grade retain that designation for the entire school-year-grade. The SIMS also includes exit codes for the final time a student is observed in the database. These codes are used to determine high school graduates and transfers.

We measure charter school attendance in 9th grade. A student is coded as attending a charter in her 9th-grade year when there is any SIMS record reporting charter attendance in that year. Students who attend more than one charter school within a year are assigned to the charter they attended longest.

MCAS Data

We use MCAS data from the 2001-2002 school year through the 2011-2012 school year. Each observation in the MCAS database corresponds to a student's test results in a particular grade and year. The MCAS outcomes of interest are math and English Language Arts (ELA) tests in grade 10. We also use baseline tests taken prior to charter application, which are from 4th grade or 8th grade depending on a student's application grade. The raw test score variables are standardized to have mean zero and standard deviation one within a subject-grade-year in Massachusetts. We also make use of scaled scores, which are used to determine whether students meet MCAS competency thresholds. Unless otherwise noted, we only use the first test taken in a particular subject and grade.

AP and SAT Data

We use AP and SAT data files provided to the Massachusetts Department of Elementary and Secondary Education by College Board. The AP and SAT files include scores on all AP exams and SAT tests for graduation cohorts 2007 and 2012; for student who took the SAT more than once, the file includes only the score for the most recent exam. The AP and SAT files also include SASID identifiers, which are used to merge these outcomes with the SIMS database.

NSC Data

Data on college outcomes comes from the National Student Clearinghouse (NSC) database, which captures enrollment for 94% of undergraduates in Massachusetts. We combine information from three separate searches of the NSC database:

- A 2010 search for all students in the SIMS database between 2002 and 2009 with projected graduation years earlier than 2014, assuming normal academic progress from the last observed grade and year. Note that this search was not restricted to students who graduated high school.
- A 2011 search of students who graduated from Massachusetts public high schools in the class of 2010.
- A 2012 search of all students who graduated from Massachusetts public high schools in the classes of 2003 through 2010.

All students in our charter applicant sample were included in the 2010 NSC search, and Massachusetts high school graduates were included in multiple searches. College types are coded using the first attended college after the last date a student is observed in the SIMS. NSC searches were conducted using criteria like name and date of birth; the NSC files also include SASIDs, which are used to merge the college outcomes with the SIMS database.

Matching Data Sets

The MCAS, AP, SAT, and NSC datafiles are merged to the master SIMS data file using the unique SASID identifier. The lottery records do not include SASIDs; these records are matched manually to the SIMS by name, application year, and application grade. In some cases, this procedure did not produce a unique match. We accepted some matches based on fewer criteria where the information on grade, year and town of residence seemed to make sense.

Our matching procedure successfully located most applicants in the SIMS database. The sixth row of Panel A of Table A2 reports the number of applicant records matched to the SIMS in each applicant cohort. The overall match rate across all cohorts was 94 percent (7,953/8,455).

Once matched to the SIMS, each student is associated with a unique SASID; at this point, we can therefore determine which students applied to multiple schools in our lottery sample. Following the match, we reshape the lottery data set to contain a single record for each student. If students applied in more than one year, we keep only records associated with the earliest year of application. Our lottery analysis also excludes students who did not attend a Boston Public Schools (BPS) school at baseline, as students applying from private schools have lower followup rates. This restriction eliminates 22 percent of charter applicants. Of the remaining 4,511 charter applicants, 3,548 (78 percent) contribute a score to our MCAS analysis.

Technical Appendix

Two-Stage Least Squares

Our empirical strategy uses randomly assigned charter lottery offers to estimate causal effects of attending charter schools. As described in the data appendix, we make use of two sources of variation in charter offers, which differ in timing. The *initial offer* instrument, Z_{i1}, is a dummy variable indicating offers made on the day of the charter school lottery. The *ever offer* instrument, Z_{i2}, is a dummy variable indicating offers made initially or later, as a consequence of movement down a randomly sequenced waiting list. The first stage using both instruments comes from estimating a linear model linking lottery offers and charter attendance. Specifically, we estimate

$$C_{it} = \lambda_t + \sum_j \mu_j d_{ij} + \beta' X_i + \pi_1 Z_{i1} + \pi_2 Z_{i2} + \eta_{it},$$

where C_{it} is a dummy indicating attendance by student i in applicant cohort t, at any of the 6 charter schools in our lottery sample in 9th or 10th grade. [21]

In addition to capturing the effect of initial and eventual offers in two separate parameters, π_1 and π_2, this first stage model controls for differences in application patterns across students through a of application "risk set" dummies, d_{ij}. These indicate each unique combination of charter school applications in a particular year. We include risk set effects because the application mix determines the probability of receiving an offer even when offers at each school are randomly assigned.[22] Missing values for either instrument are coded as no offer. Because the model controls for the pattern of schools and cohorts with lottery data of each type through

[21] Our definition of charter attendance is time-invariant, but the first stage equation allows parameters to vary by outcome year, hence we write C_{it}.

[22] For example, in a world with three charter schools, there are 7 risk sets: all schools, each school, and any two.

application risk sets, this convention is innocuous. The lottery analysis omits siblings of current applicants as well as applicants who apply after a school's initial admissions lottery (such applicants are often offered seats non-randomly). We also control for a vector of baseline demographic variables, X_i.

Because our IV estimation strategy involves more than one instrument and takes account of risk sets and other covariates, we use an IV procedure known as Two-Stage Least Squares (2SLS). This procedure is an econometric generalization of the simple "ratio of differences" calculation in our stylized example. 2SLS begins with the first stage equation above. The fitted values from this model then replace observed charter attendance (C_{it}) in a "second stage equation" that links charter school attendance with outcomes as follows:

$$y_{it} = \alpha_t + \sum_j \delta_j d_{ij} + \gamma' X_i + \rho C_{it} + \varepsilon_{it}$$

Here, y_{it} is the outcome of interest; the parameter α_t captures a cohort effect; ε_{it} is an error term; and ρ is the causal effect of interest. The second stage controls for the same risk set dummies and demographic variables as the first stage. With two instruments used to estimate a single causal effect, we can interpret 2SLS estimates as a statistically efficient weighted average of what we'd get from a simpler calculation using the instruments one at a time, as in the stylized example in the text.

Complier Distributions

Our 2SLS procedure recovers causal effects for charter lottery compliers, students who are induced to attend charter schools by lottery offers and would otherwise attend traditional public schools. In figures 1 and 2, we also plot test score distributions for compliers in the treated (charter) and untreated (traditional public school) states. To produce these figures, we apply

Abadie's (2002, 2003) method of recovering marginal treated and untreated outcome distributions for compliers. Specifically, for any value v of SAT or MCAS scores (denoted y_i) and omitting time subscripts for simplicity, we estimate equations of the form

$$K_h(v - y_i)C_i = \sum_j \kappa_{0j}(v)d_{ij} + \gamma_0(v)C_i + \eta_{0iv}$$

$$K_h(v - y_i)(1 - C_i) = \sum_j \kappa_{1j}(v)d_{ij} + \gamma_1(v)(1 - C_i) + \eta_{1iv},$$

where charter attendance, C_i, is treated as an endogenous regressor and instrumented with lottery offers. Here $K_h(v) = \frac{1}{h}K(\frac{v}{h})$, $K(v)$ is an Epanechnikov kernel function, and h is a bandwidth. Estimates of γ_0 and γ_1 for different values of v trace out densities for treated and untreated compliers. We estimate these equations for every percentile of the observed MCAS and SAT distributions. We use bandwidths that are twice Silverman's (1986) rule-of-thumb, which takes the form

$$h^* = 2.34\hat{\sigma}\hat{n}^{-1/5}$$

Here $\hat{\sigma}$ and $\hat{n}$ are estimated standard errors and counts for the treated and untreated complier distributions.

References

Abadie, A. (2002). Bootstrap tests for distributional treatment effects in instrumental variables models. *Journal of the American Statistical Association*, 97(457).

Abadie, A. (2003). Semiparametric instrumental variable estimation of treatment response models. *Journal of Econometrics*, 113(2).

Abdulkadiroğlu, A., Angrist, J., Dynarski, S., Kane, T. J., and Pathak, P. (2011). Accountability and flexibility in public schools: Evidence from Boston's charters and pilots. *Quarterly Journal of Economics*, 126(2):699-748.

Anderson, M. L. (2008). Multiple inference and gender differences in the effects of early intervention: A reevaluation of the abecedarian, perry preschool, and early training projects. *Journal of the American statistical Association*, 103(484):1481-1495.

Andrabi, T., Das, J., Ijaz Khwaja, A., and Zajonc, T. (2011). Do value-added estimates add value? accounting for learning dynamics. *American Economic Journal: Applied Economics*, 3(3):29-54.

Angrist, J. D., Cohodes, S. R., Dynarski, S. M., Fullerton, J., Kane, T. J., Pathak, P. A., and Walters, C. R. (2011a). Student achievement in Massachusetts' charter schools. Center for Education Policy Research at Harvard University.

Angrist, J. D., Dynarski, S. M., Kane, T. J., Pathak, P. A., and Walters, C. R. (2010). Inputs and impacts in charter schools: KIPP Lynn. *American Economic Review*, 100(2):239-243.

Angrist, J. D., Dynarski, S. M., Kane, T. J., Pathak, P. A., and Walters, C. R. (2012). Who benefits from KIPP? *Journal of Policy Analysis and Management*, 31(4):837-860.

Angrist, J. D., Pathak, P. A., and Walters, C. R. (2011b). Explaining charter school effectiveness. Working Paper 17332, National Bureau of Economic Research, Cambridge, MA.

Banerjee, A. V., Cole, S., Duo, E., and Linden, L. (2007). Remedying education: Evidence from two randomized experiments in India. *Quarterly Journal of Economics*, 122(3):1235-1264.

Booker, K., Sass, T. R., Gill, B., and Zimmer, R. (2008). Going beyond test scores: Evaluating charter school impact on educational attainment in Chicago and Florida. RAND, Santa Monica, CA.

Bowen, W. and Bok, D. (2000). The Shape of the River: Long-Term Consequences of Considering Race in College and University Admissions. Princeton University Press, Princeton, NJ.

Chetty, R., Friedman, J. N., Hilger, N., Saez, E., Schanzenbach, D. W., and Yagan, D. (2011). How Does Your Kindergarten Classroom Affect Your Earnings? Evidence From Project STAR. *Quarterly Journal of Economics*, 126(4):1593-1660.

Cohodes, S. and Goodman, J. (2013). Merit aid, college quality, and college completion: Massachusetts' Adams scholarship as an in-kind subsidy. HKS Faculty Research Working Paper Series RWP13-005.

Cunha, F., Heckman, J. J., and Schennach, S. M. (2010). Estimating the Technology of Cognitive and Noncognitive Skill Formation. *Econometrica*, 78(3):883-931.

Currie, J. and Thomas, D. (2000). School quality and the longer-term effects of head start. *The Journal of Human Resources*, 35(4):755.

Deming, D. (2009). Early childhood intervention and life-cycle skill development: Evidence from Head Start. *American Economic Journal: Applied Economics*, 1(3):111-134.

Deming, D. and Dynarski, S. M. (2010). Into College, Out of Poverty? Policies to Increase the Postsecondary Attainment of the Poor. In *Targeting Investments in Children: Fighting Poverty When Resources are Limited*. Ed. Philip Levine and David Zimmerman. University of Chicago Press, Chicago, IL.

Dobbie, W. and Fryer, R. G. (2011a). Are high-quality schools enough to increase achievement among the poor? Evidence from the Harlem Children's Zone. *American Economic Journal: Applied Economics*, 3(3):158-187.

Dobbie, W. and Fryer, R. G. (2011b). Getting beneath the veil of effective schools: Evidence from New York City. Technical Report NBER Working Paper No. 17632, National Bureau of Economic Research, Cambridge, MA.

Dobbie, W. and Fryer, R. G. (2012). Are high quality schools enough to reduce social disparities? Evidence from the Harlem Children's Zone. Unpublished manuscript, Harvard University.

Dynarski, M. and Gleason, P. (2002). How can we help? what we have learned from recent federal dropout prevention evaluations. *Journal of Education for Students Placed At Risk*, 7(1):43-69.

Dynarski, M., Gleason, P., Rangarajan, A., and Wood, R. (1998). Impacts of dropout prevention programs. Technical report, Mathematica Policy Research, Inc., Princeton, NJ.

Dynarski, M. and Wood, R. (1997). Helping high-risk youths: Results for the alternative schools demonstration program. Mathematica Policy Research, Inc. Princeton, NJ.

Dynarski, S. M., Hyman, J. M., and Schanzenbach, D. W. (2011). Experimental evidence on the effect of childhood investments on postsecondary degree attainment and degree completion. Working Paper 17553, National Bureau of Economic Research, Cambridge, MA.

Garces, E., Thomas, D., and Currie, J. (2002). Longer-term effects of head start. *American Economic Review*, 92(4):999-1012.

Jacob, B. A. (2007). Test-based accountability and student achievement: An investigation of differential performance on NAEP and state assessment. Working Paper 12817, National Bureau of Economic Research, Cambridge, MA.

Jacob, B. A., Lefgren, L., and Sims, D. P. (2010). The persistence of teacher-induced learning. *The Journal of Human Resources*, 45(4):915-943.

Jacob, B. A. and Levitt, S. D. (2003). Rotten apples: An investigation of the prevalence and predictors of teacher cheating. *Quarterly Journal of Economics*, 118(3):843-877.

Kane, T. J. and Staiger, D. O. (2008). Estimating teacher impacts on student achievement: An experimental evaluation. Technical Report Working Paper 14607, National Bureau of Economic Research, Cambridge, MA.

Kemple, J. and Snipes, J. (2000). Career academies: Impacts on students' engagement and performance in high school. MDRC. New York, NY.

Neal, D. and Schanzenbach, D. W. (2010). Left behind by design: Proficiency counts and test based accountability. *Review of Economics and Statistics*, 92(2):263-283.

Skinner, K. J. (2009). Charter school success or selective out-migration of low achievers? Effects of enrollment management on student achievement. Massachusetts Teachers Association, Boston, MA.

Thernstrom, A. M. and Thernstrom, S. (2003). *No excuses: Closing the racial gap in learning*. Simon & Schuster, New York, NY.

Tuttle, C. C., Gill, B., Gleason, P., Knechtel, V., Nichols-Barrer, I., and Resch, A. (2013). KIPP middle schools: Impacts on achievement and other outcomes. Mathematica Policy Research, Inc., Princeton, NJ.