The Effects of Charter Schools on Traditional Public School Students in North Carolina

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Abstract

National support and growth of school choice has raised concerns about disadvantaged students left behind. The recent shift in North Carolina (NC) charter schools to serving higher-achieving students supports this concern, but the effect on those left in traditional public schools is unclear. Using panel data covering all public school students in NC from 1997 to 2016, I examine charter effects on traditional public school student test scores, and how effects vary by the relative achievement of schools. I control for time-invariant determinants of selection and trends using student-school spell effects and linear school trends, and show evidence that remaining time-varying determinants do not bias effects. Results show competition from higher-achieving charters has small positive effects and does not increase achievement gaps for disadvantaged students in traditional public schools. Lower-achieving charter competition has zero to small negative effects and increases achievement gaps for some disadvantaged populations. This suggests that the growth of higher-achieving charters does not negatively affect student achievement or disadvantaged students left behind, and may even be beneficial.

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1 Introduction

Charter schools are privately run public schools with open enrollment policies, and have significant flexibility in the use of funding, hiring practices, and curriculum choice compared to traditional public schools. The charter school model is based on the principle that schools should be held accountable for student success while having the freedom to innovate and adjust learning environments. National growth in the charter sector, since its inception in 1992, to over seven percent of all public schools in 2016 has raised concerns over the students left behind, particularly disadvantaged students. Proponents of charter schools often argue that increased competition will induce traditional public schools to increase productivity while opponents worry that charters may drain traditional public school resources and talent. Implicit in these arguments is that effects on traditional public school students may depend on the relative achievement of charter and traditional public schools, which has largely been ignored in the literature. In North Carolina, between 1997 and 2005 (period 1), charter schools enrolled lower-achieving students relative to nearby traditional public schools, but between 2006 and 2016 (period 2) enrolled more white and higher-achieving students, which supports concerns over disadvantaged students left behind. In order to understand the effects of this new generation of charter schools, this paper evaluates whether competitive effects differ by the relative achievement of charter and traditional public schools, and whether disadvantaged students are differentially affected.

Competitive pressure is an often cited mechanism through which charter schools can affect traditional public school students, and it stems from two sources. First, students lost to charter schools decrease traditional public school district revenue because state and local per pupil allotments are transferred from districts to charters. Lost revenue may result in staffing reductions, program cuts, or school shutdown which implies a financial incentive for traditional public schools that are not overcrowded to keep students. Overcrowded schools might not face the same financial incentive, and possibly benefit from the opening of charter schools that save districts the cost of a new school.

Second, charter schools may skim higher-performing students or teachers from traditional public schools. This might increase difficulty in attaining desired achievement levels or meeting accountability standards which implies an academic incentive for traditional public schools to retain talented teachers and students. This incentive may be stronger for schools facing competition from charter schools with relatively higher average lagged student test scores that may recruit high-quality teachers and students from traditional public schools. In response to these competitive pressures, traditional public schools can possibly re-allocate resources, cut inefficient teachers or programs, induce staff to increase productivity, or improve school-family connections.[1] In turn,

[1] Ericson et al. (2001) survey district administrators in a non-random sample of 49 districts across 5 states in 1999 and find, in response to charters, some districts form specialty schools, implement gifted or at-risk programs, after school programs, specialized curriculum, or parental involvement activities. Administrators report tracking students that leave for charters and comparing student achievement with charters. Zimmer and Buddin (2009) survey traditional public school principals in California in 2002 and find that 20% of principals who indicate students in their local attendance area attend a charter change at least one of the following: teacher compensation, teacher hiring/firing/discipline policies, curriculum, instructional practices, or professional development.

these steps might have positive effects on student achievement in traditional public schools.

Even absent a response to competitive pressure, traditional public school students might be affected by charter schools through a re-allocation of students, teachers, and funding. If higher or lower-achieving students sort into charter schools, there may be negative or positive peer effects on students in traditional public schools. Similarly, if higher or lower-performing teachers sort into charter schools, there may be negative or positive teacher effects on students in traditional public schools.[2] These effects may be exacerbated by higher-achieving charters if they have recruited higher-performing students and teachers from traditional public schools. Finally, the financial effect is ambiguous depending on the overcrowdedness of the district. Because of the different mechanisms at play, the overall competitive effect is an empirical question.

There are two primary challenges when estimating the effects of charter schools on students in traditional public schools. First, competitive effects may be confounded by student selection. For example, in a school level analysis, if higher-achieving students select into charter schools, average traditional public school achievement goes down regardless of any competitive effects.[3] Second, charter school location may be based on unobservable traditional public school characteristics that are also related to student achievement. For example, charter schools may locate near high-quality traditional public schools. Even if there is no competitive effect, a failure to account for endogenous locational decisions creates upwardly biased estimates because traditional public school quality is positively correlated with proximity to a charter school and student achievement.

Empirically, I model student test score gains as a function of competition and control for student-school spell fixed effects in order to account for the most likely contributors to the endogeneity of measures of competition.[4] Spell fixed effects account for student selection based on time-invariant student or family characteristics which is preferable to studies utilizing alternative strategies relying on school-level data, which may suffer from student selection bias (Holmes et al., 2003; Hoxby, 2003; Bettinger, 2005; Ni, 2009). Spell fixed effects also account for the non-random location of charter schools based on time-invariant characteristics.

I contribute to the existing literature in several ways. First, I assess whether effects vary based on the relative achievement of charter and traditional public schools. Cremata and Raymond (2014) and Cordes (forthcoming) allow effects to vary based on charter school achievement, but do not measure achievement relative to competing traditional public schools. Relative achievement is central because the degree of competitive pressure and allocative effects depend on the relationship

[2]Carruthers (2012) and Jackson (2012) find that teachers who move from traditional public to charter schools in North Carolina are less effective in terms of value added and have weaker credentials.

[3]Researchers are primarily concerned with the effect of charter schools on students in traditional public schools (TPS), but the effect on average TPS achievement is not without policy relevance. For example, state accountability standards are not adjusted based on the competitive environment. Since 2014 in North Carolina, schools have been given a performance grade that is based on school achievement (80%) and student growth (20%). Since the grade is largely based on achievement, a loss of high-achieving students to charters has a negative effect on the performance grade even if the TPS remains just as efficient in terms of growth.

[4]A student-school spell fixed effect is defined as the set of observations for a student while at a particular school. Spell fixed effects are an alternative to controlling separately for school and student fixed effects. For example, demeaning with respect to a spell fixed effect is an alternative to explicitly including hundreds of school dummy variables in a regression and demeaning with respect to student fixed effects.

between a traditional public school and competing charter schools. Additionally, both papers focus on large urban centers which may limit external validity. Second, I contribute to studies of charter schools in North Carolina by considering the new generation of charters which differ substantially from those that have been studied, given the shift toward higher-achieving students (Holmes et al., 2003; Bifulco and Ladd, 2006; Mehta, 2012; Jinnai, 2014; Gao and Semykina, 2017).

Third, I implement two strategies to test whether spell fixed effects alleviate endogeneity concerns. The first strategy includes school-specific linear trends in estimation to allow for the possibility that charter schools locate based on underlying trends in achievement. This adds to the literature that employs spell fixed effect models but does not control for trends (Sass, 2006; Bifulco and Ladd, 2006; Booker et al., 2008; Zimmer et al., 2009; Zimmer and Buddin, 2009; Winters, 2012; Jinnai, 2014). The second strategy exploits the timing of the charter school applications and uses lagged school achievement and other lagged school characteristics to capture relevant shocks to traditional public schools at the time of application. The timing and arduous nature of the application process make it likely that charter schools locate based on persistent unobservable characteristics, but locating based on time-varying shocks is possible. These two strategies are particularly useful because instrumental variables that are robust to time-varying unobservable confounders are difficult to obtain, and my evidence suggests that panel models may be sufficient.[5] Fourth, I bound competitive estimates by estimating effects over a range of persistence parameter values between zero and one. This relaxes the implausible assumption often maintained in the literature that what a student learned in the previous year is fully retained in the current year.[6,7] If this assumption fails and lagged achievement is correlated with competition, estimates will be biased.

Results show that charter schools have no effect on math test scores, but have a small positive effect on reading test scores. Additionally, charter schools with higher average lagged student achievement than traditional public schools have small positive effects on traditional public school students while lower-achieving charter competition has zero to small negative effects. This indicates that differences in relative charter and traditional public school achievement across settings may partially explain why the literature has found divergent results. Higher-achieving competition differentially benefits Hispanic and economically disadvantaged students in math relative to their counterparts, which reduces achievement gaps. Lower-achieving competition differentially hurts Hispanic, economically disadvantaged, limited English proficient, and disabled students in reading relative to their counterparts, which augments achievement gaps. This suggests that higher-achieving competition, at the least, does not negatively affect traditional public school students and may even be beneficial. Estimates are insensitive to the inclusion of school trends, lagged school achievement and other lagged school characteristics, which suggests that spell fixed effects may be adequate to control for endogeneity concerns. Estimates are sensitive to the persistence assumption with effects weakening in magnitude with lower persistence; however, the sign and significance of

[5] Several papers utilize instrumental variable estimation in order to account for selection on time-varying unobservables (Bettinger, 2005; Imberman, 2011; Gao and Semykina, 2017).

[6] Zimmer and Buddin (2009) assume the opposite extreme - that there is no persistence in test scores.

[7] Booker et al. (2008) acknowledge these concerns.

effects is almost always preserved between high and low persistence values.

The rest of the paper proceeds as follows. Section 2 gives background information on charter schools in North Carolina. Section 3 describes the construction of the competition measures and summarizes the data. Section 4 discusses the empirical model, endogeneity concerns, and robustness checks. Section 5 provides the main empirical results and results of the robustness checks. Section 6 concludes.

2 Background

Charter schools are operated by independent non-profit boards of directors and are freed from many of the regulations facing traditional public schools, but still must participate in the state accountability program. Charter schools do not have class size restrictions, curriculum requirements, and are not required to have all teachers licensed. Additionally, charter schools do not have to provide transportation and do not have to provide free and reduced price lunch to low income students. They have open enrollment policies, cannot charge tuition, and cannot be religiously affiliated. Oversubscribed schools must hold lotteries to randomly determine student entrants.

Funding policies vary by state, but in North Carolina charter schools receive state funding for each student that is equal to the per pupil allocation for average daily membership in the local education agency (LEA) in which the charter resides. Additional state funds are appropriated based on the number of students with disabilities and that are classified as limited English proficient. The LEA in which the charter student resides is required to transfer an amount equal to the per pupil local current expense appropriation fund of the LEA. In short, local and state funds follow the student so a local education agency that loses a student is also losing the funding that is attached to that student. Unlike traditional public schools, charter schools do not receive separate capital funding for school building construction or renovation.

Charter schools first opened in North Carolina in the 1997-1998 school year with the passage of the Charter School Act, and sole authority of charter school authorization was given to the State Board of Education.[8] Originally, a 100 school cap was placed on the total number of charter schools allowed in operation, but that cap was lifted in 2011. This created a situation in which the majority of growth in the charter school sector occurred from 1998 to 2002 and from 2013 to 2016. The final column of Table 1 shows the growth of the charter sector over time. Of all charter school openings between 1998 and 2016, 53% occurred between 1998 and 2002 and 33% between 2013 and 2016. In 1998, 34 charter schools were in operation comprising 1.7% of all public schools. By 2016, a total of 157 charter schools were in operation or about 6.1% of all public schools.

[8] Throughout the paper, school years will be referred to by the spring year. For example, the 1997-1998 school year will be referenced as 1998.

3 Data

The North Carolina Department of Public Instruction (NCDPI) collects administrative data on all students in North Carolina public schools, and this information is made available through the North Carolina Education Research Data Center (NCERDC). Individual students are linked across years and linked to teachers and schools. The data contains student demographic information including sex, race, limited English proficiency, economically disadvantaged status, disability status, and academically gifted status. In addition, North Carolina requires end of grade exams in grades 3 through 8 for all students in math and reading. Test scores are reported in developmental scale scores and are designed to measure a student's growth in math and reading comprehension as he or she progresses through school. In order to account for differential scales across years and grades, and to ease interpretation, math and reading test scores are standardized by grade-year.[9] School level data files from NCDPI contain latitudes and longitudes for charter and traditional public schools in North Carolina. I link each traditional public school to every charter school and calculate distances between each pair to create distance based measures of competition.[10]

3.1 Time Periods

I consider two time periods: period 1 (1997-2005) and period 2 (2006-2016). The cut-off year is chosen as 2006 because the majority of previous studies in North Carolina are restricted to time periods before 2006. Additionally, charter schools in period 1 differ substantially in size and student composition from those in period 2. This relates to competitive mechanisms such as the degree of competitive pressure a traditional public school faces and allocative effects resulting from non-random teacher and student sorting between schools. Therefore, I extend the literature examining North Carolina charter schools by analyzing this new generation of charter schools in period 2.

3.2 Measures of Competition

Attrition Measures

One of the main challenges facing an empirical analysis of competitive effects is identifying reliable measures of which traditional public schools are competing with charter schools. Perhaps the strongest measure is the attrition rate to charter schools. This measure of competition is less common in the literature, but is used by Cremata and Raymond (2014) and Winters (2012). I define the traditional public school attrition rate as the number of students that non-structurally switch from the traditional public school to any charter school before the begining of the current year divided by the traditional public school's prior enrollment. The analysis is restricted to schools serving grades 3 through 8 so attrition rates are restricted to student moves between those grades. I define non-structural switchers as students that switch schools when they could have

[9] I conduct standardization by subtracting the average score for a particular grade-year and dividing by the standard deviation of scores in that grade-year. Standardized test scores within grade-year have a mean of zero and standard deviation of one. Charter school students are included in the standardization.

[10] See Appendix A for more details on the geocoding process.

stayed an additional year at their prior school.[11] In order to account for potential non-linearities in competitive effects, the main attrition competition measures are dummy variables for attrition rates strictly greater than 0 and less than or equal to 1%, and attrition rates strictly greater than 1%.[12] This also allows effects to vary based on the degree of competition. I define school-year observations with zero percent attrition as not competing, and this is the omitted category in the analysis. Table 2 defines the main set of competition measures used throughout this paper.

Distance Measures

In addition to attrition measures of competition, I construct several distance based measures that count the number of charter schools within a certain radius of a traditional public school. Distance based measures of competition must strike a balance; a larger distance band may include schools that are not competing in the treatment group, and a small band may exclude some schools that do compete. Overall, 75% of non-structural student moves from traditional public to charter schools are less than 10 miles apart which implies schools farther than 10 miles from a charter are unlikely to face a significant degree of competition. Based on this information, I construct distance measures of competition using a maximum 10 mile radius.

There is an additional complication because students switching to charters in urban areas travel smaller distances than in rural areas. The first row of Table 3 shows that in urban areas the median distance between schools for students making non-structural moves from a traditional public school to a charter school is 4.25 miles while in rural areas it is 7.81. In order to account for this, I add the restriction that competing traditional public schools be one of the closest 10 traditional public schools to a charter. In practice, this allows the distance band defining which schools compete to be flexible based on the density of schools in an area.[13] The fifth row of Table 3 shows the average distance of charter schools to the 10th nearest traditional public school by urbanicity. The table shows that, on average, the 10th closest traditional public school to a charter in urban areas is 4.4 miles, and in rural areas is 11.7 miles. With this in mind, I define distance based competition as an indicator that is one if a traditional public school is within 10 miles of a charter school and is one of the 10 nearest traditional public schools to a charter.[14] Several papers employ distance based measures of competition, but do not allow distance bands to vary based on urbanicity (Bifulco and Ladd, 2006; Booker et al., 2008; Sass, 2006).

[11] Some students move residence which implies a traditional public school may be counted as competing with a charter school many miles away. In order to limit this problem, attrition rates are only calculated based on students that switch schools within 20 miles of one another. This restriction excludes 5% of non-structural student moves from traditional public schools to charter schools.

[12] This cutoff point is chosen to allow effects to vary based on the degree of competition while leaving enough observations in the high attrition category to detect effects. Among traditional public schools facing attrition, 75% have attrition rates below 1%, and 25% have attrition rates above 1%.

[13] Certain charter schools in urban areas are nearby a large number of traditional public schools. For example, one charter school in an urban area in period 2 is within 5 miles of 69 traditional public schools. Allowing all of these schools into the treatment group would give a large amount of weight to the effects of this one charter school.

[14] There is an added complexity because traditional public schools (TPSs) open and close. Then a TPS could move in and out of treatment based on the closing and opening of other TPSs that are closer to the charter. In order to account for this, all restricted measures of competition have the added restriction that if a TPS is ever one of the nearest 10 TPSs to a charter within a period, it is always counted as one of the nearest 10 in that period.

Attrition vs Distance Measures

I choose attrition measures of competition as the main competition measures because they are more likely to correctly identify which schools are competing, and because they do not rely on arbitrary distance bands and other restrictions as the distance measures do. However, traditional public schools not facing attrition, but nearby charter schools, may still be affected if the threat of competition is enough to induce a competitive response. Additionally, the impact of charter schools on traditional public school attrition may be large upon charter entry and then taper in later years. This may result in attrition measures not considering a traditional public school as competing even though it is still nearby a charter school. For these reasons, I show results using distance based measures as a check. Additionally, specifications using attrition based measures of competition also control for traditional public schools within 10 miles of a charter but not facing attrition as a check for whether distance measures capture effects that attrition measures do not.

Relative Achievement Measures

One purpose of this paper is to assess whether competitive effects depend on the relative achievement of traditional public and charter schools. In order to test this hypothesis, I create variables for both attrition and distance competition measures to indicate if competing charter schools have higher average achievement than a traditional public school. In the case of attrition, I define a traditional public school as competing with higher-achieving charter schools if the average lagged standardized test scores of students in charter schools to which the traditional public school students have attrited is greater than the average lagged standardized test scores of students in the traditional public school.[15] The charter school average is weighted by the number of attriters so that charter schools competing more heavily with a traditional public school are given more weight. I construct the relative achievement measures separately for math and reading. When math test scores are the dependent variable of interest, I use the relative math achievement measures to define relative achievement. When reading test scores are the dependent variable of interest, I use the relative reading achievement measures to define relative achievement. I use a similar process for distance based measures except the charter school average is taken over charter schools within a certain distance and is weighted by charter school membership.

3.3 Summary Statistics

Summary statistics are computed for period 1 and period 2 separately and are displayed in Panel A and B of Table 4, respectively. Math and reading test scores are only available for grades 3 through 8, so the sample is restricted to students in those grade levels. Columns 1 and 4 include traditional public schools that do not face attrition to charter schools, columns 2 and 5 include traditional

[15]I use the lagged test scores of current students instead of the lagged school average because new charter schools do not have a lagged school average. A portion of the identifying variation in the analysis comes from entering charter schools so it is useful to have a measure of relative achievement that is available for traditional public schools competing with entering charter schools. This implies that, for new charter schools, the measure of achievement is based solely on student test scores while at a different school.

public schools that face attrition to charter schools, and columns 3 and 6 include charter schools. Significant differences between groups within each period are starred at the $p < .05$ level and are always relative to the attrition group (within panel comparisons). Significant differences between the same group across time periods are lettered at the $p < .05$ level in Panel A (between panel comparisons). The top half of the table weights statistics by school membership and the bottom half does not.

In period 1 and period 2, schools not facing attrition do not statistically significantly differ in terms of math and reading test scores compared to schools facing attrition. In both periods, schools facing attrition have higher proportions of black, Hispanic, and gifted students, but lower proportions of white students than schools not facing attrition. Additionally, traditional public schools facing attrition have higher enrollment and are more likely to be urban middle schools than traditional public schools not facing attrition. This indicates that schools facing attrition and those not differ along several observable dimensions possibly correlated with achievement, which implies they should be controlled in the analysis.

The characteristics of charter schools relative to traditional public schools facing attrition in each period are more striking. Period 1 charters have lower math and reading test scores than competing traditional public schools, but period 2 charters have higher math and reading scores. In terms of ethnicity, period 1 charters relative to competing traditional public schools are relatively balanced although Hispanic students are under-represented in charters. Period 2 charters are significantly more likely to be white and less likely to be Hispanic than competing traditional public schools. In both periods, charters have lower proportions of limited English proficient students, and period 2 charters have lower proportions of disabled students than competing traditional public schools.[16] Overall, charter schools have lower enrollment than competing traditional public schools and are more likely to offer grade levels spanning combinations of elementary, middle, and high school grades.

So far I have made comparisons within Panel A and Panel B of Table 4, but it is also useful to compare charter schools across time periods (columns 3 and 6). Significant differences between time periods for charter schools are marked with the letter, a, in Panel A. Period 1 charters have significantly lower test scores in math and reading than period 2 charters. They also have lower proportions of Hispanic and limited English proficient students. Urbanicity does not differ between periods, but charters in period 1 are significantly smaller than those in period 2.[17]

In order to further explore how the relative achievement of charter schools has shifted over time, Table 5 gives the proportion of traditional public schools that are competing with lower or higher-achieving charters for both math and reading by period. The first row shows that 32% of period 1 traditional public schools facing attrition have lower average lagged student math scores than charter schools to which the traditional public school students attrite. By period 2, 55%

[16]There is some concern about charter school reporting of academically gifted and free lunch eligible students so these measures should not be compared between traditional public and charter schools.

[17]This is because charter schools that opened in period 1 grew significantly in terms of enrollment by period 2, and because the initial enrollment of opening charter schools is much higher in period 2 than in period 1.

have lower achievement than competing charters. A similar pattern emerges in reading with 49% of traditional public schools facing competition from higher-achieving charter schools in period 1, and 66% in period 2. This indicates that, in both math and reading, traditional public schools are more likely to face higher-achieving competition in period 2 than in period 1. If competitive effects depend on relative achievement, this shift may result in differential effects between periods.

4 Empirical Strategy

4.1 Empirical Model

I use a value added model of student test scores in math and reading to estimate the effects of charter schools on traditional public school student achievement. Current traditional public school student test scores are modeled as a function of lagged test scores which serve as a proxy for unobserved historical school and family inputs for a student.[18] The lagged value added model of achievement is given by

$$q_{ijt} = \beta_0 + \lambda q_{ij,t-1} + \boldsymbol{c}_{jt}\boldsymbol{\beta}_1 + \boldsymbol{w}_{ijt}\boldsymbol{\beta}_2 + \boldsymbol{x}_{j,t-1}\boldsymbol{\beta}_3 + \mu_i + \gamma_j + \theta_t + \phi_j t + \epsilon_{ijt}, \tag{1}$$

where q_{ijt} is either standardized math or reading test score for student i in school j at time t. The vector $\boldsymbol{c}_{jt}$ includes measures of competition, $\boldsymbol{w}_{ijt}$ is a vector of contemporaneous student and school-level control variables, $\boldsymbol{x}_{j,t-1}$ is a vector of lagged school-level control variables, μ_i is student unobserved heterogeneity, γ_j is school unobserved heterogeneity, θ_t is year-grade unobserved shocks, $\phi_j t$ is a school specific linear time trend, and ϵ_{ijt} is an idiosyncratic error. I assume that measures of competition $\boldsymbol{c}_{jt}$ may be correlated with both student and school heterogeneity.

Equation 1 can not be consistently estimated using fixed effect or first difference estimation to remove student heterogeneity without further assumptions. For example, fixed effect estimation, depending on the approach, implicitly or explicitly time demeans all variables with respect to each cross-section. The new time demeaned error $(\epsilon_{ijt} - \bar{\epsilon}_i)$ is correlated with time demeaned lagged achievement $(q_{ij,t-1} - \bar{q}_i)$ because $\bar{\epsilon}_i$ is a function of $\epsilon_{ij,t-1}$ which is correlated with $q_{ij,t-1}$ by construction. Additionally, $\bar{q}_i$ is a function of q_{ijt} for all t and so is correlated with both ϵ_{ijt} and $\bar{\epsilon}_i$. In order to avoid this problem, I assume that persistence in achievement is one ($\lambda = 1$) and write a gains-score model as

$$\Delta q_{ijt} = \beta_0 + \boldsymbol{c}_{jt}\boldsymbol{\beta}_1 + \boldsymbol{w}_{ijt}\boldsymbol{\beta}_2 + \boldsymbol{x}_{j,t-1}\boldsymbol{\beta}_3 + \mu_i + \gamma_j + \theta_t + \phi_j t + \epsilon_{ijt}. \tag{2}$$

Without lagged achievement on the right hand side, standard fixed effect or first difference estimation can be applied to remove student heterogeneity. However, the perfect persistence assumption

[18] See Todd and Wolpin (2003) for a detailed derivation. In order for lagged test scores to serve as an appropriate proxy, it is assumed that the education production function does not change over time, that the effect of inputs declines as the distance in time from current achievement increases, and that the rate of decline is uniform across inputs.

is unlikely to hold in student achievement because what a student learned in the previous year is unlikely to be fully retained in the current year. If competition is correlated with lagged achievement and λ is not one, the estimator for $\boldsymbol{\beta}_1$ will be inconsistent because a portion of lagged achievement is effectively left in the error term.[19] In order to account for this, I utilize persistence parameters in increments of 0.01 from 0 to 1 and provide lower and upper bounded competition estimates based on these results.[20] I report main results assuming persistence of one, and secondary results assuming alternative persistence values.

Controlling for student and school fixed effects addresses many factors that may bias estimates of the effect of competition on student test scores. The primary endogeneity concern comes from the non-random location of charter schools that may be correlated with unobserved traditional public school characteristics that are also correlated with achievement. I include school fixed effects to control for any fixed unobservable school characteristics correlated with charter school location. This removes bias from fixed unobservables such as charter location decisions made based on relatively constant factors such as urbanicity or local school quality. Of secondary concern is that student school choice decisions may be based on unobservable student characteristics that create a correlation between proximity to a charter school and these unobservables. Student fixed effects control for any constant factors such as student ability or family characteristics that may be correlated with competition.

I include time-varying control variables to account for factors at the student and school level that may be correlated with student achievement and competition. The contemporaneous control variables are an indicator for being within 5 miles of a closing traditional public school, being within 5 miles of an opening traditional public school, whether the school has increased its grade span, and whether a school has decreased its grade span. I include these controls because charter school location may be correlated with restructuring in local school districts, and shifting resources, teachers, and students may affect student achievement. Additional contemporaneous control variables include an indicator for cohort student moves between schools, non-cohort moves, and grade repetition. Charter school location may be correlated with student turnover in a local area and switching schools may be associated with a drop in test scores.[21] A cohort move is defined as a stu-

[19] If persistence is not one, imposing perfect persistence in a gain-score model leaves $(\lambda - 1)$ proportion of lagged achievement in the error term: $q_{ijt} - q_{ij,t-1} = \beta_0 + \boldsymbol{c}_{jt}\boldsymbol{\beta}_1 + \boldsymbol{w}_{ijt}\boldsymbol{\beta}_2 + \boldsymbol{x}_{j,t-1}\boldsymbol{\beta}_3 + \mu_i + \gamma_j + \theta_t + \phi_j t + [(\lambda - 1)q_{ij,t-1} + \epsilon_{ijt}]$.

[20] An alternative is to leave lagged achievement on the right hand side and estimate equation 1 using an Arellano-Bond approach. In practice, the equation includes school dummy variables and is first differenced with respect to student fixed effects. By construction, first differenced lagged achievement is correlated with the first differenced error term. In order to account for this endogeneity, further lags of achievement are used as instruments for first differenced lagged achievement. The main concern with this approach is that the second lag of achievement, which is commonly used as an instrument, is likely to be endogenous because of measurement error in test scores and autocorrelation in the error term. To avoid this problem, the third or later lag of achievement can be used as the instrument, but this is a heavy data requirement and the third lag may be a weak instrument. A final alternative is to use alternative tests as instruments. For example, twice lagged reading test scores can be used as an instrument for first differenced lagged math test scores. This approach requires the assumption that shocks to math and reading test scores are uncorrelated which seems unlikely to hold in practice. See Andrabi et al. (2011) for a more detailed discussion.

[21] Contemporaneous control variables may be viewed as mediators depending on the extent to which charter schools cause them. For example, other school openings and closings, changing grade spans, or turnover could, to a certain degree, be caused by charter schools and so these variables could be mediators. I am more concerned that charter

dent switching schools when at least 15% of his or her cohort in the previous school also made the same move. All other student moves between schools are considered non-cohort. The one period lagged control variables are school enrollment, proportions of disabled, limited English proficient, gifted, white, black, and Hispanic students which are meant to control for school characteristics that are possibly correlated with charter school location and achievement. A complete list of control variables with definitions is presented in Table 6.

Estimation of equation 2 is problematic because student effects, school effects, and linear trends enter the model separately. One possibility is to time demean the model with respect to student effects and explicitly include school dummy variables and school dummy variables interacted with a linear time trend. This approach is computationally infeasible because it requires the inclusion of thousands of covariates. Instead, I define student-school spell effects as $\psi_{ij} = \mu_i + \lambda_j$. In the dummy variable context, a spell fixed effect could be eliminated using the interaction of school and student dummy variables. First differencing or time demeaning with respect to student-school spells greatly simplifies estimation. The use of spell fixed effects provides a consistent estimator under strict exogeneity but is less efficient than including student and school effects separately.[22] Because of the large sample size, loss of precision is less of a concern, and in practice I do not have a problem detecting effects. In order to additionally control for linear school trends, I first difference equation 2 with respect to spell effects. This eliminates student and school heterogeneity, and because the first difference is with respect to the student-school spell effect, linear trends reduce to school effects ($\phi_j t - \phi_j(t-1) = \phi_j$).

$$\Delta\Delta q_{ijt} = \Delta \boldsymbol{c}_{jt}\boldsymbol{\beta}_1 + \Delta \boldsymbol{w}_{ijt}\boldsymbol{\beta}_2 + \Delta \boldsymbol{x}_{j,t-1}\boldsymbol{\beta}_3 + \Delta\theta_t + \phi_j + \Delta\epsilon_{ijt}. \tag{3}$$

Consistent estimation of equation 3 using pooled ordinary least squares (POLS) requires that $\boldsymbol{c}_{jt}$ is uncorrelated with $\epsilon_{ij,t-1}$, ϵ_{ijt}, and $\epsilon_{ij,t+1}$. I estimate whether results are robust to the inclusion of school trends, but I report the main set of results using POLS on equation 3 omitting ϕ_j, and explicitly including the first differenced grade-year dummy variables to eliminate $\Delta\theta_t$. In order to estimate equation 3 with trends, I estimate a school fixed effect regression to remove ϕ_j. I am interested in how effects differ between periods so in practice all control variables are interacted with a dummy variable for period 2, and school time trends are allowed to vary by period. Finally, standard errors are clustered at the school level to account for correlation in error terms within schools.

schools choose to locate in areas with higher turnover, closings, etc and so view these variables as confounds. I have purposely excluded school inputs as contemporaneous covariates because these may respond to competition. For example, I exclude peer composition because charter schools may cause a shift in peer composition and so peer characteristics mediate the charter school effect.

[22]See Abowd et al. (1999) for a more detailed discussion.

4.2 Estimation Sample and Identifying Variation

Equation 3 makes it clear that only students with 2 consecutive non-missing test score gains will be included in the estimation sample. Additionally, because first differences are taken with respect to student-school spells, only two consecutive gains in the same school are valid. Between 1997 and 2016 about 4 million observations meet this criteria. The majority of traditional public schools in North Carolina follow traditional grade spans with elementary (K through 5) and middle (6 through 8). A student in 6th grade in a middle school still has a test score gain between 5th and 6th grade even if 5th grade was at a different school because I construct test score gains without considering which school a student attends.[23] This implies that the majority of students in the estimation sample are in 5th grade, 7th grade, and 8th grade (about 95%) because these students potentially have two test score gains while in the same school. Some 4th and 6th graders are also included in the estimation sample because of grade repetition or because some traditional public schools serve non-traditional grade spans with both elementary and middle grade levels.

Equation 3 also makes clear that identification of competitive effects relies on variation in $\boldsymbol{c}_{jt}$ within a student-school spell. Attrition and distance measures of competition may vary based on the opening, closing, expanding, or moving of charter schools. For attrition, identification relies on students in schools facing attrition in one period and not in another. About 30% of students with two valid test score gains in the estimation sample experience variation between no attrition, 0-1% attrition, or >1% attrition. Identification does not come from students moving from an area without a charter to an area with a charter because first differences are with respect to a student while at a particular school. Identification of the effect of higher-achieving competition relative to lower-achieving competition comes from changes in relative achievement within a student-school over time even if the level of attrition does not vary. In other words, school level attrition can be constant and the difference in competitive effects between higher and lower-achieving competition is still identified as long as relative achievement changes over time.

4.3 Robustness Checks

The primary threat to identification after controlling for fixed unobservable student and school level confounders is based on unobservable trends or time-varying shocks correlated with competition and student achievement.

Trends

First, I check robustness to the inclusion of linear school trends. Including non-linear trends in estimation is computationally demanding; instead, I allow linear trends to vary between periods. In estimation, this requires that I separately define two school fixed effects for the same school: one for period 1 and the other for period 2. If competition measures are biased by correlation with

[23] This is why controls are included in the model for student moves between schools. If student test score gains were constructed only using observations for a student while at a particular school, there would be no need to control for student moves.

time-varying unobservable traditional public school characteristics, we expect competitive effect estimates to be sensitive to the addition of school trends.

Time-Varying Unobservables

Unobserved shocks correlated with charter school location decisions are less of a concern because of the charter school approval process. Considering the timing and length of the application process, it seems conservative to assume that the decision to apply likely responds to shocks that occurred two or more years before the planned opening year but not one year before.[24] For this to be a threat to my identification strategy, shocks two or more years prior have to be correlated with current achievement and current measures of competition. Fortunately, given the first difference estimation strategy, I can include school average student test score gains lagged three periods in the model to capture lagged shocks. More specifically, write equation 2 with spell fixed effects, but without school trends as

$$\Delta q_{ijt} = \beta_0 + \boldsymbol{c}_{jt}\boldsymbol{\beta}_1 + \boldsymbol{w}_{ijt}\boldsymbol{\beta}_2 + \boldsymbol{x}_{j,t-1}\boldsymbol{\beta}_3 + \psi_{ij} + \theta_t + [\zeta\bar{\epsilon}_{j,t-3} + \tilde{\epsilon}_{ijt}], \tag{4}$$

where the error term is divided into an average lagged school component representing relevant shocks at the time of application and an idiosyncratic student component ($\epsilon_{ijt} = \zeta\bar{\epsilon}_{j,t-3} + \tilde{\epsilon}_{ijt}$). Furthermore, aggregate equation 2, with spell fixed effects but without school trends, to the school level and lag three periods.

$$\Delta \bar{q}_{j,t-3} = \beta_0 + \boldsymbol{c}_{j,t-3}\boldsymbol{\beta}_1 + \bar{\boldsymbol{w}}_{j,t-3}\boldsymbol{\beta}_2 + \boldsymbol{x}_{j,t-4}\boldsymbol{\beta}_3 + \bar{\psi}_j + \theta_{t-3} + \bar{\epsilon}_{j,t-3}. \tag{5}$$

Then we can solve for $\bar{\epsilon}_{j,t-3}$ in equation 5 and plug into equation 4. In practice, this implies including thrice lagged average student test score gains, thrice lagged school control variables, and thrice lagged competition measures in estimation. The $\bar{\psi}_j$ and θ_{t-3} are subsumed by spell fixed effects and time effects in equation 4. If shocks three periods ago are correlated with current charter school location and current achievement, the addition of these lagged covariates may affect the competition estimates. Sensitivity of the estimate for $\boldsymbol{\beta}_1$ to the addition of thrice lagged covariates may suggest that shocks near the time of application are relevant to test scores at time t and correlated with current competition measures, which implies a biased competitive effect estimate.

Fixed Effect Estimation

First differences (FD) and fixed effect (FE) estimation methods are able to remove student and school heterogeneity combined into a student-school spell effect. First differences is the main estimation strategy used in this paper; however, it is useful to compare FD estimates to FE estimates for the main set of results as a test of strict exogeneity (Wooldridge, 2010). If strict exogeneity is

[24] In North Carolina, the charter school application process is arduous and lengthy. Deadlines have varied across time, but in general applications are due at least one year before a school opens. For a specific example, charter schools planning to open in the 2014-2015 school year had an application deadline of March 1, 2013. Additionally, letters of intent were due January 4, 2013 and a letter of intent is required for the application to be considered.

violated such that competition is correlated with ϵ_{ijt} from any time period, FD and FE estimators generally have different probability limits. Thus, large differences between FD and FE estimates may suggest a violation of this assumption.

Distance Based Competition Measures

So far I have generally focused my discussion on the endogeneity of competition measures based on where charter schools locate which is appropriate for distance based measures of competition. Attrition, however, is determined both by proximity to a charter and the decision of students to move to that charter. This adds an additional concern for attrition based measures of competition because attrition rates may be correlated with unobserved time-varying school characteristics. I compare results using distance and attrition based measures of competition as a check of this potential source of bias.

Distance and Private School Controls

In addition to separately running specifications with distance based measures of competition, I also estimate a specification that combines distance and attrition measures. There is some concern that traditional public schools not facing attrition but nearby charter schools should be treated differently from schools not facing attrition and not nearby charter schools. In order to account for this, I add an indicator to the main specification using attrition measures of competition that is one for traditional public schools not facing attrition but within 10 miles of any charter school. This separately identifies the effect of traditional public schools nearby a charter that are not facing attrition from traditional public schools facing attrition. Estimated effects are then relative to the omitted category of schools that are not facing attrition and are not within 10 miles of any charter school.

Charter school entry, exit, and expansion may be correlated with the presence of private schools. It is also possible that charter schools affect the opening and closing of private schools. I obtain private school information from the National Center for Education Statistics Private School Universe Survey from 1996 to 2014. This survey is conducted every other year. It does not contain exact private school location information in every year, but does always contain mailing city and zipcode. I convert mailing city and zipcodes to latitudes and longitudes and compute distances between private schools and traditional public schools to construct indicators for whether a traditional public school is within 5 miles of an opening or closing private school. These measures are much cruder than my competition measures because the addresses are not physical addresses, addresses are not at the street level, and the survey suffers from non-response. However, this is the only private school data available, and I check the sensitivity of competition estimates to the inclusion of these private school control variables.

Relative Achievement Instrumental Variable

Considering heterogeneity in competitive effects introduces another layer of challenge because relative achievement measures of competition are a function of lagged student test scores, which introduces additional endogeneity concerns. More specifically, the relative achievement measure for attrition is defined as

$$H_{jt}(\bar{q}_{j,t-1}) = 1[\bar{q}_{j,t-1} < \bar{CH}_{j,t-1}], \tag{6}$$

which is an indicator that is one if the average lagged test scores of students in a traditional public school are lower than the average lagged test scores of students in competing charter schools. The average lagged achievement of students in traditional public school j at time t is defined as

$$\bar{q}_{j,t-1} = \frac{1}{N_{jt}} \sum_{i \in j,t} q_{i,t-1},$$

where $q_{i,t-1}$ is the lagged standardized math or reading test score of student i in school j at time t whether or not the student attended school j at time $t-1$.

The average lagged student achievement of competing charter schools is defined as

$$\bar{CH}_{j,t-1} = \frac{N_1 \bar{q}_{1,t-1} + ... + N_{M_{jt}} \bar{q}_{M_{jt},t-1}}{N_1 + ... + N_{M_{jt}}}.$$

The $\bar{q}_{m,t-1}$ are average lagged student test scores for charter school m competing with traditional public school j (constructed in the same way as the traditional public school average). Charter schools are indexed by m and run $1, ..., M_{jt}$. The number of competitors M_{jt} can vary for traditional public school j at time t. For charter competitors, the N_m is not charter school size but rather is the number of students that attrited from TPS j to charter school m. Charter students are not in the estimation sample, but are used to construct average charter school test scores for this competition measure.

Essentially, specifications that account for relative achievement include dummy variables for each level of attrition (0-1% or >1%), and interact these dummy variables with a dummy variable for facing higher-achieving competition ($H_{jt}(\bar{q}_{j,t-1})$). Consider the main estimating equation 3 but ignore school effects ϕ_j.[25] In practice, results are insensitive to the inclusion of trends. Competition measures are first differenced, and I have argued that attrition is uncorrelated with $\epsilon_{ij,t-1}$, ϵ_{ijt}, and $\epsilon_{ij,t+1}$, which implies that first differenced attrition is uncorrelated with $\Delta\epsilon_{ijt}$ from the estimating equation 3. However, the interactions with relative achievement measures are correlated with the first differenced error through $H_{jt}(\bar{q}_{j,t-1})$ because relative achievement for school j is a function of $q_{i,t-1}$ for students i in school j at time t which is correlated with $\epsilon_{ij,t-1}$.

Whether or not the size of the correlation between relative achievement measures and the error is significant depends on the dependence in ϵ_{ijt} and how many observations we are averaging over for school j at time t. If there are many students and errors are independent, the school average of achievement converges to a deterministic value that is uncorrelated with $\epsilon_{ij,t-1}$. If schools on average are small, the error may be strongly correlated with the average of lagged student achievement.

[25]School fixed effects implicitly time demean all variables and the error term with respect to school averages. The IV strategy relies on further lags of $\bar{q}_{jt-1}$ so including school fixed effects will introduce a correlation between the demeaned instrument and the demeaned error in the first stage.

Finally, if the errors are strongly correlated within schools even a large number of students does not get rid of the correlation between $\bar{q}_{j,t-1}$ and $\epsilon_{ij,t-1}$. On average, schools in the estimation sample have around 600 students so the main concern is the possibility that individual errors are strongly correlated within school.

In order to test for this potential source of bias, I construct instruments that are uncorrelated with the error term in equation 3 ($\phi_j + \Delta\epsilon_{ijt}$), but correlated with the first difference of relative achievement measures of competition interacted with attrition dummy variables. The instruments are constructed using the lagged test scores of students in school j at time $t-2$. Student test scores lagged three periods are unlikely to be correlated with the first differenced error unless there is significant serial correlation in the errors. More specifically the instruments are interactions of attrition dummy variables with

$$H_{jt}(\bar{q}_{j,t-3}) = 1[\bar{q}_{j,t-3} < \bar{CH}_{j,t-1}], \quad (7)$$

where

$$\bar{q}_{j,t-3} = \frac{1}{N_{j,t-2}} \sum_{i \in j,t-2} q_{i,t-3}.$$

The only difference between the instrumental variable and the competition measure is that the instrument is based on a comparison of charter school achievement relative to the traditional public school lagged student test scores from two periods ago rather than lagged test scores from the current period.[26] Instruments enter in levels in the first differenced estimating equation 3.

4.4 Heterogeneity by School Type

Competitive effects may vary based on the relative characteristics of charter and traditional public schools. I have already defined the main relative achievement measures of competition, but I define an additional relative achievement measure as an indicator that is one if competing charter schools have higher average lagged student test scores than the district in which the traditional public school resides. This tests whether results are sensitive to how broadly relative achievement is defined. I also define an indicator for whether charter schools competing with a traditional public school have higher average lagged student test scores than other charter schools. This measure does not depend on the relative achievement of traditional public schools, and tests whether this is an important consideration. Finally, I also explore heterogeneity in treatment effects by defining indicators for whether a traditional public school has lower proportions of white students, disabled students, or limited English proficient students than competing charter schools.

[26] Charter school lagged student test scores may include the test scores of students in traditional public schools the period before switching to a charter. Then charter school average lagged student achievement could be correlated with shocks at the traditional public school in $t-1$. Except for charter schools that just opened, the majority of student lags will not be from a traditional public school, but from the charter school itself, which limits this concern. However, in the first year of operation charter school student lagged test scores are solely based on traditional public schools. A later robustness check removes traditional public schools competing with charter schools in their first year of operation from the analysis and indicates that this is not a concern.

4.5 Heterogeneity by Student Type

Effects may also vary based on the characteristics of individual students. For example, when faced with higher-achieving competition, traditional public schools may focus more on moving lower-achieving students into proficiency. On the other hand, the loss of higher-achieving students may induce traditional public schools to shift effort and resources to these types of students in order to prevent further attrition. From the allocative side, lower or higher-achieving charters may recruit certain types of teachers and students from traditional public schools resulting in differential effects on disadvantaged students left behind. In order to explore these possibilities, I interact competition measures with student ethnicity (black, Hispanic), limited English proficiency, academically gifted status, disability status, and economically disadvantaged status. Considering the shift in the charter school sector to serving more high-achieving white students, it is important to consider the spillover effects on students traditionally more at-risk of academic failure left in traditional public schools.

5 Results

5.1 Main Results

Table 7 presents the main results using attrition measures of competition. All specifications assume a persistence parameter of one. Columns 1 through 3 present results for math test scores and columns 4 through 6 for reading. This table addresses whether effects depend on the relative achievement of charter and traditional public schools and whether effects differ by period. Column 1 divides traditional public schools into those facing 0-1% attrition (low), those facing attrition >1% (high), and those facing no attrition which is the excluded category. Effects in column 1 are statistically insignificant and close to zero indicating no effect of competition on math test scores.

Column 2 interacts the attrition measures from column 1 with indicators for whether the lagged student test scores of the traditional public school are lower on average than the lagged student test scores of charter schools to which the traditional public school students are attriting. Results indicate that students in traditional public schools competing with lower-achieving charter schools relative to students in schools facing no attrition lose -0.007 and -0.016 standard deviations in math test scores for 0-1% and >1% attrition levels, respectively. Alternatively, students in traditional public schools facing 0-1% attrition from higher-achieving charter schools gain a statistically significant 0.027 standard deviations in math test scores relative to those facing lower-achieving competition, and those facing >1% attrition gain 0.043 standard deviations. The effect of higher-achieving competition relative to students in schools experiencing no attrition is 0.020 standard deviations for 0-1% attrition, and 0.027 standard deviations for >1% attrition.

Column 3 additionally interacts the competition variables from column 2 with period 2 indicators to assess whether effects vary by period. The first four rows are the effects in period 1 and indicate that lower-achieving charter competition has small, statistically insignificant negative effects while higher-achieving charter competition has positive effects around 0.025 standard deviations relative to students in schools facing no attrition. The effect of lower-achieving competition in period 2 relative to students in schools facing no attrition, is the sum of the coefficients in rows 1 and 2 and the coefficients in rows 5 and 6. This indicates there are slightly more negative effects from >1% attrition from lower-achieving charters in period 2, around -0.026 standard deviations, than in period 1. Finally, the effects from higher-achieving competition relative to no competition in period 2 are the sum of all odd rows for attrition 0-1% and even rows for >1% attrition, and indicate small positive effects from higher-achieving competition of 0.016 and 0.025 standard deviations for 0-1% and >1% attrition, respectively. Overall, this suggests effects are similar between periods for math.

Column 4 of Table 7 displays results for reading test scores and indicates that students in traditional public schools facing 0-1% attrition gain 0.004 standard deviations, and those facing more than 1% attrition gain 0.009 standard deviations relative to students in schools facing no attrition to charter schools. Column 5 shows that the positive effects are driven by competition with higher-achieving charter schools. Additionally, column 6 indicates that in both period 1 and period 2 higher-achieving competition has positive effects in reading, and lower achieving competition has zero to small negative effects. The main difference in reading is that effects from lower-achieving competition are slightly more negative in period 1 than in period 2. Relative achievement effects in reading are slightly smaller in magnitude than math but reflect a similar pattern. Overall, the main results suggest that higher-achieving charter competition has small positive effects in math and reading, but overall effects are close to zero in math and very small and positive in reading.

Because effects between periods are similar in both math and reading, future tables will omit the period interactions and focus on relative achievement. To aid interpretation, Figures 1 and 2 display effects for math and reading for each group based on combinations of attrition levels and relative achievement. Estimates can be interpreted as the difference in test scores between each group relative to students in traditional public schools facing no attrition. Panel A in each figure displays results for the main specification and reflects results in Table 7. The remaining panels display results from various specification checks discussed in future sections.

5.2 Persistence Results

The main set of results in Table 7 use a persistence parameter of one. Figure 3 demonstrates the effect of different persistence parameters on competitive effect estimates for math test scores. Estimates are displayed for the main relative achievement competition groups: attrition 0-1% lower-achieving charter competition, attrition 0-1% higher-achieving charter competition, attrition >1% lower-achieving charter competition, and attrition >1% higher-achieving charter competition. The x-axis is persistence values ranging from 0 to 1 in increments of 0.01. The graph demonstrates that there is a strong linear relationship between assumed persistence parameters and competition estimates with effects increasing in magnitude with larger persistence values. However, the sign and significance of effects is generally preserved regardless of the persistence value. Confidence intervals are not displayed in the graph, but even assuming persistence of zero still gives statistically significant positive effects for higher-achieving competition in both math and reading which I show in Panel B in Figures 1 and 2 and Table 8 which all assume zero persistence.

5.3 Robustness Check Results

Trend Results

I test for sensitivity to the inclusion of linear school trends because charter schools may locate based on underlying trends in traditional public school achievement. Results in Table 9 with the inclusion of school trends are very similar to estimates in Table 7. This suggests that competition measures are not significantly biased by unobservable trends in school achievement.

Time-Varying Unobservable Results

As discussed in Section 4.3, charter schools may respond to local shocks around the time of application. If this is the case, estimates might be affected by the addition of thrice lagged school average student test score gains, thrice lagged school characteristics, and thrice lagged competition measures as additional regressors. Table 10 shows results with the inclusion of these additional covariates and demonstrate that this is not a concern because estimates are largely unchanged.

Fixed Effect Estimation Results

Differences between fixed effect and first difference estimates may suggest a violation of strict exogeneity. Results using spell fixed effects without controlling for school trends are presented in Table 11 and can be compared to Table 7. Estimates are almost identical between methods and alleviate concern about violations of strict exogeneity.

Distance Based Competition Measure Results

Distance based measures of competition serve as a useful check of bias in attrition measures due to student schooling decisions based on local or school level shocks. Results using distance based measures are presented in Table 12. As with attrition, there is a positive gap between effects from higher-achieving and lower-achieving competition. Effect sizes are generally larger in magnitude using the distance based measures, but largely reflect results using attrition which indicates that this is not a major concern.

Distance and Private School Control Results

Charter schools may affect or respond to the opening or closing of private schools in an area, and private school openings and closings may also affect traditional public school student achievement. Columns 2 and 5 of Table 13 present results including private school controls and are very similar to columns 1 and 4 without private school controls. Interestingly, the private school coefficients are statistically significant and indicate that closing private schools have very small negative effects on traditional public school student math and reading test scores, and that opening private schools have small positive effects on reading test scores.

Additionally, traditional public schools within 10 miles of a charter school that are not experiencing attrition may still experience competitive effects. Columns 3 and 6 of Table 13 present results including an indicator for students in schools within 10 miles of any charter but not facing attrition. The addition of this indicator does not affect competition estimates, and is statistically insignificant and close to zero. This suggests the attrition measures of competition are not missing competitive effects by excluding schools that are nearby charter schools but not experiencing attrition.

Relative Achievement Instrumental Variable Results

As discussed in Section 4.3, relative achievement competition measures are possibly correlated with the first differenced error term because I define relative achievement based on lagged student test scores which are correlated with lagged error terms by construction. In order to test for the extent of this bias, instrumental variables are constructed for relative achievement based on average lagged student test scores using twice lagged average lagged student test scores, which are plausibly exogenous. Theoretically, when math is the outcome, I could use two instruments constructed from twice lagged average lagged student test scores: one interacted with attrition 0-1% and the other interacted with attrition >1%. However, I can also construct instruments based on reading test scores. The specifications in Table 14 include all four instruments based on math and reading interacted with the two attrition levels. This over-identifies the model and allows for tests of over-identifying restrictions.

Before analyzing the coefficients, note that first stage F tests of the excluded instruments indicate that the instruments are strongly correlated with the endogenous variables. The Hansen J P-value is the p-value associated with a test of the joint null hypothesis that the instruments are valid. The null is marginally not rejected in the case of math (p=0.10) and not rejected in the case of reading (p=0.53). This does raise some suspicion about the validity of the instruments in specifications with math as the dependent variable. However, the large amount of data used in estimation and that this is not a strong rejection may alleviate concerns. Additionally, the instruments may be identifying different local average treatment effects which would also cause a rejection of the null.

The coefficient estimates in column 1 and 2 for math and reading largely reflect the premium associated with higher-achieving competition. Estimates for attrition between 0-1% are slightly larger in magnitude when compared to the main results. The largest difference comes from a sizable increase in the magnitude of effects for attrition greater than 1%. In math, students in schools facing attrition >1% from lower-achieving charters see a drop in gains of -0.055 standard deviations (compared to OLS of -0.007); among the IV results, this is the largest deviation from the main results. Those facing higher-achieving charters see gains in math of 0.055 standard deviations (compared to OLS of 0.026), relative to schools with no attrition. In reading, the IV results for attrition greater than 1% are also larger in magnitude than the main results, but to a lesser degree.

Although results are not displayed, I run specifications using variations of the instruments such as only including instruments constructed from math scores in math regressions and using further lags of achievement to construct the instruments. Results generally reflect those presented in Table 14. Overall, IV results suggest that, if anything, bias in the OLS model is toward zero so that the main OLS estimates are understating the true effect. Instrumental variable results are not reported as the main results because I can not include linear trends in the IV models and because the Hansen test of over-identifying restrictions is marginally passed in the math specifications. Additionally, depending on the construction of the instruments, estimates are not always statistically significantly different from zero in the reading IV specifications, although they are always greater in magnitude than the OLS estimates.

5.4 Heterogeneity by School Type Results

Although I have shown effects depend on relative school achievement, it is possible that broader definitions of relative achievement or relative school demographics are also important. Table 15 presents results for various measures of relative charter and traditional public school achievement and demographics. Attrition group dummy variables are interacted with indicators for whether competing charter schools have higher average lagged student test scores than the twice lagged average lagged student test scores of the traditional public school. Essentially this uses the instrumental variable for relative achievement developed in a prior section as the measure of competition. The relative achievement premium is reduced in math and eliminated in reading which suggests that further lags of achievement are less relevant than current lags in constructing relevant achievement measures. The next set of interactions use an indicator if competing charter school average lagged student achievement is greater than the average lagged student achievement of the district in which the traditional public school resides. For low levels of attrition, a relative achievement premium exists but is weakened relative to the main results. This suggests that measuring achievement relative to the traditional public is more relevant than measuring relative to the district.

Next, attrition levels are interacted with a dummy variable indicating whether a charter school has higher average lagged student test scores than the average of all charter schools. This removes any relation to traditional public schools and results show a small premium in math for the 0-1% attrition level, but all other groups have no effect. Finally, attrition level dummy variables are interacted with indicators if competing charter schools have higher proportion of white, disabled, or limited English proficient students than the traditional public school. None of these interactions are statistically significant. Overall, these results suggest that heterogeneous treatment effects are driven by differences in relative achievement, and that, although I find small effects using different definitions of relative achievement, the largest effects are found using relative achievement based on lagged student test scores which I use for the main set of results throughout this paper.

5.5 Heterogeneity by Student Type Results

As discussed in section 4.5, traditional public schools may respond to charter competition in ways that differentially affect different types of students. Similarly, allocative effects from shifting students, teachers, and resources may differentially affect different types of students. Table 16 presents results that interact relative achievement measures of competition with student demographic characteristics. Rows 4-8 display the interaction coefficients, but note that the variable definitions change with the column headings. For example, columns 1 and 2 interact competition measures with an indicator if a student is black. Columns 3 and 4 interact competition measures with an indicator if a student is Hispanic. In order to avoid the use of a triple interaction term, the relative achievement interactions are replaced with group indicator variables for each combination of attrition level and relative achievement: attrition 0-1% lower-achieving charter competition, attrition 0-1% higher-achieving charter competition, attrition >1% lower-achieving charter competition, and attrition >1% higher-achieving charter competition. These group indicators are then interacted with student demographics.

For math test scores, the interaction terms indicate that in general groups are very similar. The exceptions are higher gains for Hispanic and economically disadvantaged students relative to non-Hispanic and non-economically disadvantaged students in schools facing 0-1% attrition from higher-achieving charter schools (columns 3 and 11). This suggest, at the least, that higher-achieving competition does not differentially hurt disadvantaged students left behind. In reading, Hispanic, limited English proficient, disabled, non-gifted, and economically disadvantaged students experience more negative effects than their counterparts from lower achieving competition. This suggests that achievement gaps for disadvantaged students are augmented in schools facing lower-achieving charter competition. Additionally, the interaction terms range from -0.028 to -0.046 standard deviations for Hispanic, limited English proficient, and economically disadvantaged students which are not inconsequential. This indicates that higher-achieving competition does not negatively affect disadvantaged students and may even be beneficial, while lower-achieving competition negatively affects disadvantaged students more than their counterparts, although the effects are small.

5.6 Effects in Context

Studies in states other than North Carolina following a similar empirical strategy to that employed in this paper find mixed results. Sass (2006) finds a positive effect on math test scores and no effect on reading in Florida. Zimmer et al. (2009) analyze effects across eight geographic locations and generally find no significant effects apart from a small positive effect in Texas. In North Carolina, previous results have also been mixed. Bifulco and Ladd (2006) find no effect on student test scores, although effects are generally positive, while Holmes et al. (2003) find a small positive effect using a school level analysis. Jinnai (2014) finds a small positive effect and shows that defining competition at the grade level rather than the school level increases effect sizes. Mehta (2012) finds a small positive spillover effect when estimating a model of charter and traditional public school competition that models charter school entry, school inputs, and student school choices.

All the studies mentioned that are conducted in North Carolina are estimated using data between 1996 and 2005 and use distance based measures of competition. Using distance based measures of competition in period 1 (1997-2005), I confirm the general finding of small positive effects in math and reading. The attrition measures I employ do not confirm this finding, but the specifications I use also include a control for traditional public schools facing no attrition within 10 miles of a charter school, and the coefficient is statically insignificant and close to zero. This suggests that schools facing attrition that are not within 10 miles of any charter are responsible for the slightly divergent findings.

Comparing effect sizes to other studies is complicated by differences in competition measures and differences in the construction of outcome measures. Perhaps most directly comparable is Cremata and Raymond (2014) which use standardized test score gains as the outcome and attrition measures of competition interacted with charter achievement as the treatment. They define high-achieving competition as an indicator that is one if the average achievement of charter competitors of a traditional public school is above the district average. In Washington DC, where charter enrollment was over 40% of public school enrollment by 2012, they find high-achieving competition improves math scores by 0.04-0.08 (when significant) and reading test scores by 0.06 to 0.15 relative to low-achieving competition. Cordes (forthcoming) also allows effects to vary by charter school achievement, and defines high-achieving competition in New York City as an indicator if the average proficiency of competing charters is above the 75th percentile of the city in the prior year. She finds no premium to high-achieving competition in math, but in reading finds a premium of 0.017 standard deviations. I generally find higher-achieving competition increases test score gains by 0.01-0.03 standard deviations which falls between the effect sizes in these two studies.

Finally, it is useful to compare effect sizes to other policy interventions. Of particular, importance are the estimated effects of charter schools on charter school students as these studies often rely on the assumption of no spillover effects on traditional public schools. The CREDO National Charter School Study includes the analysis of charter schools in 27 states and generally finds aggregate effect sizes between -0.03 and 0.03 standard deviations (CREDO, 2013). Finally, Ladd et al. (2016) find effects between 0 and -0.03 standard deviations in North Carolina using a student fixed effects approach.

6 Conclusion

This paper examines the effects of charter schools on traditional public school students in North Carolina and finds that, on average, charter schools in North Carolina have no effect on math test scores, and a very small positive effect on reading test scores. Also, I examine whether effects differ by the relative achievement of traditional public and charter schools, and find higher-achieving competition has small positive effects, while lower-achieving competition has zero to small negative effects. Interactions with student characteristics suggest that more disadvantaged students left behind in traditional public schools facing lower-achieving charter competition generally experience the same or more negative effects in reading than their counterparts. Additionally, the cases of more positive effects on math test scores for disadvantaged students relative to their counterparts occur in schools facing higher-achieving competition. This suggests that the shift in charter schools to serving higher-achieving students has, at the very least, not hurt disadvantaged students left behind and may even be beneficial.

Charter schools may locate based on trends in traditional public school achievement, or based on relevant shocks near the time of charter school application. Linear school trends and lagged school controls are strategies to address these concerns, and results are insensitive to their inclusion. This suggests that controlling for time-invariant student and school heterogeneity may be adequate to control for endogeneity concerns. Results are somewhat sensitive to the persistence assumption, but effects are generally the same sign and significance regardless of assuming perfect or zero persistence in student test scores.

The findings of this paper have implications for research on the competitive effects of charter schools on traditional public school students. Although the effect sizes I find are small, the literature, when effects are significant, generally finds small positive or negative effects. Differential effects based on the relative achievement levels of competitors may explain differences in competitive effects across previous competition studies, and even competition studies based on the same state if characteristics of the charter school sector change over time within a state. This suggests that future work examining the effects of charter schools on traditional public school students should consider heterogeneous treatment effects based on the relative characteristics of traditional public and charter schools.

The findings of this study also have implications for research on the competitive effects of charter schools on charter school students. Studies of charter school productivity often employ local matching techniques or use lottery information to compare students lotteried in and those lotteried out of an oversubscribed charter school. The methods assume that charter schools have no spillover effects on traditional public schools which has been shown here to depend on the relative achievement of competitors. This may be especially relevant for lottery based studies where oversubscribed charter schools are possibly in high demand because of their high achievement.

Future work will examine the mechanisms through which charter schools affect traditional public school students. For example, changes in class size, student composition, and teacher composition may partially explain the observed effects on traditional public school students. As higher-achieving charter schools have grown in North Carolina, it is also important to understand which types of charter schools are approved by the State Board of Education, where these charter schools locate, and whether they are accessible to students from all backgrounds. Future research will use information collected from individual charter school applications to address these questions.

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Table 1: Traditional Public Schools, Charter Schools, and New Charter Schools by Year

Year	Traditional Public School Count	Charter School Count	Charter Schools % of All Public	New Charter School Count	Growth in Charter Schools
1995	1,952	0	0.0%	0	-
1996	1,967	0	0.0%	0	-
1997	1,989	0	0.0%	0	-
1998	2,006	34	1.7%	34	-
1999	2,028	59	2.8%	26	76.5%
2000	2,063	77	3.6%	23	39.0%
2001	2,096	90	4.1%	15	19.5%
2002	2,125	93	4.2%	8	8.9%
2003	2,145	93	4.2%	5	5.4%
2004	2,160	93	4.1%	2	2.2%
2005	2,178	97	4.3%	5	5.4%
2006	2,232	99	4.2%	2	2.1%
2007	2,288	93	3.9%	1	1.0%
2008	2,349	98	4.0%	7	7.5%
2009	2,380	97	3.9%	2	2.0%
2010	2,413	96	3.8%	0	0.0%
2011	2,424	99	3.9%	3	3.1%
2012	2,409	100	4.0%	1	1.0%
2013	2,414	108	4.3%	9	9.0%
2014	2,424	128	5.0%	22	20.4%
2015	2,431	149	5.8%	23	18.0%
2016	2,437	157	6.1%	12	8.1%

All public schools are included, and there is no restriction on school type or grade levels served. Traditional public schools include magnet schools. The growth in charter schools is defined as the number of new charter schools divided by the number of charter schools in operation the previous year.

Table 2: Competition Measure Definitions

Competition Measure	Definition
Attrition Based Measures	
Attrition 0%	Indicates if a TPS has 0% of prior year enrollment non-structurally switch to any charter in the current year (base)
Attrition 0-1%	Indicates if a TPS has 0-1% of prior year enrollment non-structurally switch to any charter in the current year
Attrition >1%	Indicates if a TPS has >1% of prior year enrollment non-structurally switch to any charter in the current year
Higher-Achieving Charter	Indicates if the average lagged test scores of students in charter schools from which a TPS faces attrition are higher than the average lagged test scores of the TPS students
Distance Based Measures	
Within 10 Miles 0 Charter	Indicates if a TPS is not within 10 miles of any charter and not one of the closest 10 TPSs to any charter (base)
Within 10 Miles 1 Charter	Indicates if a TPS is within 10 miles of one charter and one of the closest 10 TPSs to that charter
Within 10 Miles 2 or More Charters	Indicates if a TPS is within 10 miles of 2 or more charters and one of the closest 10 TPSs to those charters
Higher-Achieving Charter	Indicates if the average lagged test scores of students in charter schools within 10 miles of the TPS are higher than the average lagged test scores of the TPS students

TPS refers to traditional public school, and CH refers to charter school. All competition measures have the added restriction that schools can compete only if they serve at least one grade level that is the same. I define non-structural switchers as students that switch schools when they could have stayed an additional year at their prior school. Attrition based measures of competition have the added restriction that non-structural moves are only counted toward attrition if the distance between schools is less than 20 miles. All distance competition measures have the added restriction that a traditional public school be one of the closest 10 traditional public schools to a charter school. Distances between schools are straight line distances.

Table 3: Summary of Distances between Traditional Public and Charter Schools by Urbanicity

	Urban	Suburban	Town	Rural
Non-Structural Student Moves From TPSs to Charters:				
Median Distance Between Schools	4.25	5.66	3.29	7.81
75th Percentile Distance Between Schools	6.80	9.25	7.65	12.21
Number of Switchers	14,719	6,904	4,828	13,333
Average Distance of Charter Schools to the:				
5th Closest TPS	2.7	4.4	7.2	7.9
10th Closest TPS	4.4	6.8	13.3	11.7
15th Closest TPS	6.0	8.9	17.3	15.3

TPS refers to traditional public school. Pooled for years 1998-2016. Distances are in miles. Student moves are restricted to grade levels between 3 and 13. Average distance between schools only considers schools that overlap in at least one grade level. Non-structural switchers are defined as students that switch schools when they could have stayed an additional year at their prior school.

Table 4: Charter and Traditional Public School Characteristics by Attrition Status and Period

	Panel A: Period 1 (1997-2005)			Panel B: Period 2 (2006-2016)		
	(1) TPS No Attrition	(2) TPS Attrition	(3) Charter	(4) TPS No Attrition	(5) TPS Attrition	(6) Charter
Math Std	-0.00[a]	0.01[a]	-0.19*[a]	-0.01	-0.01	0.09
Read Std	-0.01	0.01[a]	-0.06[a]	-0.01	-0.02	0.21*
Black	0.28*[a]	0.35[a]	0.36[a]	0.24*	0.31	0.28
Hispanic	0.05*[a]	0.06[a]	0.02*[a]	0.12*	0.14	0.06*
White	0.63*[a]	0.54[a]	0.58	0.56*	0.47	0.60*
Free Lunch	0.36[a]	0.35[a]	0.12*[a]	0.45*	0.46	0.26*
Lim Eng Prof	0.03*[a]	0.03[a]	0.00*[a]	0.06	0.06	0.02*
Disability	0.14[a]	0.14[a]	0.14	0.15*	0.14	0.13*
Gifted	0.12*[a]	0.15	0.06*[a]	0.14*	0.16	0.02*
Enrollment	507.61*[a]	627.43[a]	210.05*[a]	497.73*	612.30	432.72*
Urban	0.21*[a]	0.39[a]	0.41	0.20*	0.35	0.41
Rural	0.45*[a]	0.32[a]	0.28	0.50*	0.36	0.29
Suburban	0.18[a]	0.18	0.13	0.15*	0.18	0.14
Town	0.16*	0.11	0.19*	0.15*	0.11	0.15
Elementary	0.61[a]	0.60	0.20*[a]	0.63	0.61	0.12*
Middle	0.19*	0.28	0.09*[a]	0.20*	0.29	0.04*
Elem-Middle	0.13*[a]	0.10[a]	0.48*	0.10*	0.07	0.53*
Middle-High	0.05*	0.02	0.11*	0.05*	0.02	0.06*
Elem-Mid-High	0.02*	0.01	0.13*[a]	0.02*	0.01	0.26*
Observations	10188	3488	565	13766	6941	1125

TPS refers to traditional public school. TPS Attrition includes TPSs that are facing any amount of attrition to charter schools that are no more than 20 miles away from the TPSs. All groups are restricted to schools serving a grade level between 3 and 8. Statistics are weighted by school membership in grades 3 through 8 for the top panel and unweighted for the bottom panel. Standard errors are clustered at the school level. Significant differences relative to TPS Attrition within each period are starred, *, for $p < 0.05$. Significant differences between periods for each group are lettered, [a], for $p < 0.05$ in Panel A.

Table 5: Count and Proportion of Traditional Public Schools Experiencing Attrition to Higher or Lower-Achieving Charter Schools for Period 1 and Period 2 in Math and Reading

	Lower-Achieving Charter Competition	Higher-Achieving Charter Competition	Total
Math			
Period 1	2,316 (68%)	1,103 (32%)	3,419 (100%)
Period 2 Full	3,067 (45%)	3,734 (55%)	6,801 (100%)
Period 2 Split	937 (39%)	1,454 (61%)	2,391 (100%)
Reading			
Period 1	2,047 (60%)	1,372 (40%)	3,419 (100%)
Period 2 Full	2,320 (34%)	4,481 (66%)	6,801 (100%)
Period 2 Split	712 (30%)	1,679 (70%)	2,391 (100%)

Sample is restricted to traditional public schools (TPSs) facing attrition. Higher-achieving charter competition includes TPSs facing attrition and the lagged test scores of the TPS students are lower on average than that of the lagged test scores of students in charter schools from which the TPS is facing attrition. Full includes TPSs facing attrition from charter schools operating in period 2 that opened in period 1 or period 2. Split isolates TPSs facing attrition from charter schools operating in period 2 that opened in period 2 and does not count charter schools that opened in period 1 in defining competition. Period 1 ranges from 1997-2005, and period 2 from 2006-2016.

Table 6: Control Variable Definitions

Name	Definition
Student Level	
Cohort Switcher*	Indicates Student Moves with > 15% of Cohort to a New School
Non-Cohort Switcher*	Indicates a Non-Cohort Switcher Move
Grade Repeater*	Indicates a Student Repeats a Grade
School Level	
Within 5 Miles Closed*	Indicates a School is Within 5 Miles of a Closing TPS
Within 5 Miles Open*	Indicates a School is Within 5 Miles of an Opening TPS
Grade Decrease*	Indicates a School Decreases Grade Span
Grade Increase*	Indicates a School Increases Grade Span
Enrollment	Number of Students Attending a School
Disabled	Proportion of Disabled Students in a School
Limited English Proficient	Proportion of Limited English Proficient Students in a School
Gifted	Proportion of Gifted Students in a School
White	Proportion of White Students in a School
Black	Proportion of Black Students in a School
Hispanic	Proportion of Hispanic Students in a School

*Indicates covariates that are included contemporaneously with the dependent variable. All other covariates are lagged one period in regressions.

Table 7: First Differenced Regressions of Standardized Student Test Score Gains on Attrition Competition Measures Interacted with Relative Achievement and Period for Years 1997-2016: No School Trends, High Persistence

VARIABLES	(1) Math	(2) Math	(3) Math	(4) Read	(5) Read	(6) Read
Attrition 0-1%	0.003	-0.007***	-0.007	0.004**	-0.002	-0.008**
	(0.002)	(0.003)	(0.004)	(0.002)	(0.003)	(0.004)
Attrition >1%	0.005	-0.016**	-0.004	0.009**	-0.001	-0.005
	(0.005)	(0.007)	(0.010)	(0.004)	(0.006)	(0.008)
Attrition 0-1% * Higher-Achieve CH		0.027***	0.032***		0.011***	0.017***
		(0.004)	(0.007)		(0.003)	(0.005)
Attrition >1% * Higher-Achieve CH		0.043***	0.030*		0.017**	0.021**
		(0.009)	(0.016)		(0.007)	(0.010)
Attrition 0-1% * Period2			-0.000			0.011**
			(0.006)			(0.005)
Attrition >1% * Period2			-0.022*			0.005
			(0.013)			(0.011)
Attrition 0-1% * Higher-Achieve CH * Period2			-0.007			-0.009
			(0.008)			(0.006)
Attrition >1% * Higher-Achieve CH * Period2			0.021			-0.006
			(0.018)			(0.013)
Observations	4,016,929	4,016,929	4,016,929	3,994,994	3,994,994	3,994,994

TPS refers to traditional public school, and CH refers to charter school. Dependent variables are standardized traditional public school student test score gains in math or reading. All regressions include grade-year dummy variables, controls for student switching, grade repetition, and school level covariates. Attrition 0-1% indicates if a TPS has strictly greater than 0% but less than or equal to 1% of prior year enrollment non-structurally switch to any CH in the current year. Attrition >1% indicates if a TPS has >1% of prior year enrollment non-structurally switch to any charter in the current year. Attrition equal to zero is the omitted category. Non-structural switchers are students that switch schools when they could have stayed an additional year at their prior school. Higher-Achieve CH indicators are one if the average lagged test scores of students in a TPS are lower than the average lagged test scores of students in charter schools from which the TPS is facing attrition. Period2 is an indicator for years between 2006 and 2016. Dependent and independent variables are first differenced with respect to student-school spells to remove student and school heterogeneity, and the resulting equation is estimated using OLS. High persistence assumes that persistence in test scores is 1, and low assumes 0 persistence. Period 1 ranges from 1997-2005, and period 2 from 2006-2016. Standard errors are clustered at the school level.

Table 8: First Differenced Regressions of Standardized Student Test Score Gains on Attrition Competition Measures Interacted with Relative Achievement for Years 1997-2016: No School Trends, Low Persistence

VARIABLES	(1) Math	(2) Math	(3) Read	(4) Read
Attrition 0-1%	0.001	-0.002	0.002	0.000
	(0.001)	(0.002)	(0.001)	(0.001)
Attrition >1%	0.002	-0.003	0.005**	0.002
	(0.003)	(0.004)	(0.002)	(0.003)
Attrition 0-1% * Higher-Achieve CH		0.008***		0.004*
		(0.002)		(0.002)
Attrition >1% * Higher-Achieve CH		0.011**		0.005
		(0.005)		(0.004)
Observations	4,016,929	4,016,929	3,994,994	3,994,994

TPS refers to traditional public school, and CH refers to charter school. Dependent variables are standardized traditional public school student test score gains in math or reading. All regressions include grade-year dummy variables, controls for student switching, grade repetition, and school level covariates. Attrition 0-1% indicates if a TPS has strictly greater than 0% but less than or equal to 1% of prior year enrollment non-structurally switch to any CH in the current year. Attrition >1% indicates if a TPS has >1% of prior year enrollment non-structurally switch to any charter in the current year. Attrition equal to zero is the omitted category. Non-structural switchers are students that switch schools when they could have stayed an additional year at their prior school. Higher-Achieve CH indicators are one if the average lagged test scores of students in a TPS are lower than the average lagged test scores of students in charter schools from which the TPS is facing attrition. Dependent and independent variables are first differenced with respect to student-school spells to remove student and school heterogeneity, and the resulting equation is estimated using OLS. High persistence assumes that persistence in test scores is 1, and low assumes 0 persistence. Standard errors are clustered at the school level.

Table 9: First Differenced Regressions of Standardized Student Test Score Gains on Attrition Competition Measures Interacted with Relative Achievement for Years 1997-2016: School Trends, High Persistence

VARIABLES	(1) Math	(2) Math	(3) Read	(4) Read
Attrition 0-1%	0.002	-0.007***	0.004**	-0.002
	(0.002)	(0.003)	(0.002)	(0.003)
Attrition >1%	0.004	-0.018***	0.008**	-0.002
	(0.005)	(0.007)	(0.004)	(0.006)
Attrition 0-1% * Higher-Achieve CH		0.026***		0.012***
		(0.004)		(0.003)
Attrition >1% * Higher-Achieve CH		0.043***		0.016**
		(0.009)		(0.007)
Observations	4,016,929	4,016,929	3,994,994	3,994,994

TPS refers to traditional public school, and CH refers to charter school. Dependent variables are standardized traditional public school student test score gains in math or reading. All regressions include grade-year dummy variables, controls for student switching, grade repetition, and school level covariates. Attrition 0-1% indicates if a TPS has strictly greater than 0% but less than or equal to 1% of prior year enrollment non-structurally switch to any CH in the current year. Attrition >1% indicates if a TPS has >1% of prior year enrollment non-structurally switch to any charter in the current year. Attrition equal to zero is the omitted category. Non-structural switchers are students that switch schools when they could have stayed an additional year at their prior school. Higher-Achieve CH indicators are one if the average lagged test scores of students in a TPS are lower than the average lagged test scores of students in charter schools from which the TPS is facing attrition. Dependent and independent variables are first differenced with respect to student-school spells to remove student and school heterogeneity, and the resulting equation is estimated using school fixed effect estimation to control for school trends. High persistence assumes that persistence in test scores is 1, and low assumes 0 persistence. Standard errors are clustered at the school level.

Table 10: First Differenced Regressions of Standardized Student Test Score Gains on Attrition Competition Measures Interacted with Relative Achievement for Years 1997-2016: No School Trends, High Persistence, Time-Varying Unobservables

VARIABLES	(1) Math	(2) Math	(3) Read	(4) Read
Attrition 0-1%	0.003	-0.007**	0.005**	-0.000
	(0.003)	(0.003)	(0.002)	(0.003)
Attrition >1%	0.007	-0.019**	0.012***	0.004
	(0.006)	(0.008)	(0.004)	(0.007)
Attrition 0-1% * Higher-Achieve CH		0.024***		0.010***
		(0.005)		(0.004)
Attrition >1% * Higher-Achieve CH		0.047***		0.012
		(0.010)		(0.008)
Observations	3,185,595	3,185,417	3,166,835	3,166,660

TPS refers to traditional public school, and CH refers to charter school. Dependent variables are standardized traditional public school student test score gains in math or reading. All regressions include grade-year dummy variables, controls for student switching, grade repetition, and school level covariates. Attrition 0-1% indicates if a TPS has strictly greater than 0% but less than or equal to 1% of prior year enrollment non-structurally switch to any CH in the current year. Attrition >1% indicates if a TPS has >1% of prior year enrollment non-structurally switch to any charter in the current year. Attrition equal to zero is the omitted category. Non-structural switchers are students that switch schools when they could have stayed an additional year at their prior school. Higher-Achieve CH indicators are one if the average lagged test scores of students in a TPS are lower than the average lagged test scores of students in charter schools from which the TPS is facing attrition. Dependent and independent variables are first differenced with respect to student-school spells to remove student and school heterogeneity, and the resulting equation is estimated using OLS. High persistence assumes that persistence in test scores is 1, and low assumes 0 persistence. Standard errors are clustered at the school level. I include thrice lagged school average student test scores gains in math and reading, thrice lagged school level control variables, and thrice lagged competition measures as additional covariates.

Table 11: Fixed Effect Regressions of Standardized Student Test Score Gains on Attrition Competition Measures Interacted with Relative Achievement for Years 1997-2016: No School Trends, High Persistence

VARIABLES	(1) Math	(2) Math	(3) Read	(4) Read
Attrition 0-1%	0.002	-0.009***	0.004**	-0.001
	(0.002)	(0.003)	(0.002)	(0.002)
Attrition >1%	0.004	-0.018***	0.010***	-0.000
	(0.005)	(0.007)	(0.003)	(0.005)
Attrition 0-1% * Higher-Achieve CH		0.029***		0.010***
		(0.004)		(0.003)
Attrition >1% * Higher-Achieve CH		0.043***		0.017***
		(0.009)		(0.006)
Observations	8,735,199	8,734,975	8,694,404	8,694,180

TPS refers to traditional public school, and CH refers to charter school. Dependent variables are standardized traditional public school student test score gains in math or reading. All regressions include grade-year dummy variables, controls for student switching, grade repetition, and school level covariates. Attrition 0-1% indicates if a TPS has strictly greater than 0% but less than or equal to 1% of prior year enrollment non-structurally switch to any CH in the current year. Attrition >1% indicates if a TPS has >1% of prior year enrollment non-structurally switch to any charter in the current year. Attrition equal to zero is the omitted category. Non-structural switchers are students that switch schools when they could have stayed an additional year at their prior school. Higher-Achieve CH indicators are one if the average lagged test scores of students in a TPS are lower than the average lagged test scores of students in charter schools from which the TPS is facing attrition. Dependent and independent variables are in levels. Spell fixed effects are included to control for student and school heterogeneity, and models are estimated using fixed effect estimation. High persistence assumes that persistence in test scores is 1, and low assumes 0 persistence. Standard errors are clustered at the school level.

Table 12: First Differenced Regressions of Standardized Student Test Score Gains on Distance Competition Measures Interacted with Relative Achievement for Years 1997-2016: No School Trends, High Persistence

VARIABLES	(1) Math	(2) Math	(3) Read	(4) Read
Within 10 1 CH	0.002	-0.018**	0.005	-0.010*
	(0.006)	(0.008)	(0.005)	(0.005)
Within 10 2 or More CH	0.019*	-0.006	0.015**	-0.001
	(0.010)	(0.011)	(0.007)	(0.007)
Within 10 1 CH * Higher-Achieve CH		0.044***		0.027***
		(0.006)		(0.004)
Within 10 2 or More CH * Higher-Achieve CH		0.057***		0.031***
		(0.011)		(0.007)
Observations	4,015,639	3,969,834	3,993,715	3,948,171

TPS refers to traditional public school, and CH refers to charter school. Dependent variables are standardized traditional public school student test score gains in math or reading. All regressions include grade-year dummy variables, controls for student switching, grade repetition, and school level covariates. Within 10 1 CH indicates if a TPS is within 10 miles of one charter school and one of the closest 10 TPSs to that charter. Within 10 2 or More CH indicates if a TPS is within 10 miles of more than one charter school and one of the closest 10 TPSs to those charter schools. Within 10 miles of no charter school is the omitted category. Higher-Achieve CH indicators are one if the average lagged test scores of students in a TPS are lower than the average lagged test scores of students in charter schools within 10 miles. Dependent and independent variables are first differenced with respect to student-school spells to remove student and school heterogeneity, and the resulting equation is estimated using OLS. High persistence assumes that persistence in test scores is 1, and low assumes 0 persistence. Standard errors are clustered at the school level.

Table 13: First Differenced Regressions of Standardized Student Test Score Gains on Attrition Competition Measures Interacted with Relative Achievement for Years 1997-2016: No School Trends, High Persistence, Private School and Distance Controls

VARIABLES	(1) Math	(2) Math	(3) Math	(4) Read	(5) Read	(6) Read
Attrition 0-1%	-0.007***	-0.007**	-0.008**	-0.002	-0.002	-0.003
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
Attrition >1%	-0.016**	-0.016**	-0.017**	-0.001	-0.001	-0.002
	(0.007)	(0.007)	(0.007)	(0.006)	(0.006)	(0.006)
Attrition 0-1% * Higher-Achieve CH	0.027***	0.027***	0.027***	0.011***	0.012***	0.011***
	(0.004)	(0.004)	(0.004)	(0.003)	(0.003)	(0.003)
Attrition >1% * Higher-Achieve CH	0.043***	0.043***	0.043***	0.017**	0.017**	0.017**
	(0.009)	(0.009)	(0.009)	(0.007)	(0.007)	(0.007)
Within 5 Closed Private		-0.009***			-0.005*	
		(0.003)			(0.002)	
Within 5 New Private		-0.000			0.006***	
		(0.003)			(0.002)	
Attrition 0% Within 10 CH			-0.002			-0.002
			(0.004)			(0.003)
Observations	4,016,834	4,016,834	4,016,834	3,994,899	3,994,899	3,994,899

TPS refers to traditional public school, and CH refers to charter school. Dependent variables are standardized traditional public school student test score gains in math or reading. All regressions include grade-year dummy variables, controls for student switching, grade repetition, and school level covariates. Attrition 0-1% indicates if a TPS has strictly greater than 0% but less than or equal to 1% of prior year enrollment non-structurally switch to any CH in the current year. Attrition >1% indicates if a TPS has >1% of prior year enrollment non-structurally switch to any charter in the current year. Attrition equal to zero is the omitted category. Non-structural switchers are students that switch schools when they could have stayed an additional year at their prior school. Higher-Achieve CH indicators are one if the average lagged test scores of students in a TPS are lower than the average lagged test scores of students in charter schools from which the TPS is facing attrition. Dependent and independent variables are first differenced with respect to student-school spells to remove student and school heterogeneity, and the resulting equation is estimated using OLS. High persistence assumes that persistence in test scores is 1, and low assumes 0 persistence. Standard errors are clustered at the school level. Columns 2 and 5 include indicators for whether a TPS is within 5 miles of a closing or opening private school. Columns 3 and 6 include a separate indicator for TPSs facing 0% attrition but still within 10 miles of a charter school. The addition of this dummy variable changes the base (omitted) category to 0% attrition not within 10 miles of any charter, and the competitive effects can be interpreted relative to this category.

Table 14: First Differenced Instrumental Variable Regressions of Standardized Student Test Score Gains on Attrition Competition Measures Interacted with Relative Achievement for Years 1997-2016: No School Trends, High Persistence

VARIABLES	(1) Math	(2) Read
Attrition 0-1%	-0.012*	-0.003
	(0.006)	(0.005)
Attrition >1%	-0.055***	-0.017
	(0.020)	(0.017)
Attrition 0-1% * Higher-Achieve CH	0.041***	0.016*
	(0.016)	(0.008)
Attrition >1% * Higher-Achieve CH	0.11***	0.045*
	(0.032)	(0.021)
First Stage F (0-1%)	171	169
First Stage F (>1%)	77	72
Hansen J P-Value	0.10	0.53
Observations	3,545,591	3,525,152

TPS refers to traditional public school, and CH refers to charter school. Dependent variables are standardized traditional public school student test score gains in math or reading. All regressions include grade-year dummy variables, controls for student switching, grade repetition, and school level covariates. Attrition 0-1% indicates if a TPS has strictly greater than 0% but less than or equal to 1% of prior year enrollment non-structurally switch to any CH in the current year. Attrition >1% indicates if a TPS has >1% of prior year enrollment non-structurally switch to any charter in the current year. Attrition equal to zero is the omitted category. Non-structural switchers are students that switch schools when they could have stayed an additional year at their prior school. Higher-Achieve CH indicators are one if the average lagged test scores of students in a TPS are lower than the average lagged test scores of students in charter schools from which the TPS is facing attrition. Dependent and independent variables are first differenced with respect to student-school spells to remove student and school heterogeneity, and the resulting equation is estimated using instrumental variables. High persistence assumes that persistence in test scores is 1, and low assumes 0 persistence. Standard errors are clustered at the school level. Terms interacted with Higher-Achieve CH are endogenous. There are four instrumental variables including relative achievement constructed from thrice lagged math scores interacted with 0-1% and >1% attrition, and relative achievement measures constructed from thrice lagged reading scores interacted with 0-1% and >1% attrition. The inclusion of instruments based on both math and reading overidentifies the model and allows for a test of overidentifying restrictions which is reported as Hansen J p-value. The null is that the instruments are valid. F-tests of the four excluded instruments are also reported for the two first stages (one for each endogenous regressor).

Table 15: First Differenced Regressions of Standardized Student Test Score Gains on Attrition Competition Measures Interacted with Relative Achievement and Demographic Measures for Years 1997-2016: No School Trends, High Persistence, Treatment Heterogeneity

VARIABLES	(1) Math	(2) Math	(3) Math	(4) Math	(5) Math	(6) Math	(7) Read	(8) Read	(9) Read	(10) Read	(11) Read	(12) Read
Attrition 0-1%	-0.002	-0.002	-0.001	-0.000	0.001	0.003	0.004	0.001	0.003	0.004*	0.004*	0.004*
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.002)	(0.002)	(0.002)	(0.003)	(0.003)	(0.002)	(0.002)
Attrition >1%	-0.002	0.005	0.004	0.012	0.005	0.004	0.011**	0.011**	0.011**	0.009*	0.008*	0.008**
	(0.008)	(0.006)	(0.007)	(0.008)	(0.006)	(0.005)	(0.005)	(0.005)	(0.005)	(0.006)	(0.005)	(0.004)
Attrition 0-1% * Higher-Achieve CH 2Lag	0.013***						0.001					
	(0.004)						(0.003)					
Attrition >1% * Higher-Achieve CH 2Lag	0.017*						0.001					
	(0.009)						(0.007)					
Attrition 0-1% * Higher-Achieve CH District		0.012***						0.007**				
		(0.004)						(0.003)				
Attrition >1% * Higher-Achieve CH District		0.002						-0.003				
		(0.009)						(0.007)				
Attrition 0-1% * Higher-Achieve CH-CH			0.008**						0.003			
			(0.004)						(0.003)			
Attrition >1% * Higher-Achieve CH-CH			0.003						-0.004			
			(0.009)						(0.007)			
Attrition 0-1% * Higher-White CH				0.006						-0.001		
				(0.004)						(0.003)		
Attrition >1% * Higher-White CH				-0.009						-0.001		
				(0.009)						(0.007)		
Attrition 0-1% * Higher-Disabled CH					0.003						-0.000	
					(0.004)						(0.003)	
Attrition >1% * Higher-Disabled CH					0.001						0.002	
					(0.009)						(0.006)	
Attrition 0-1% * Higher-LEP CH						0.001						0.000
						(0.005)						(0.004)
Attrition >1% * Higher-LEP CH						0.013						0.006
						(0.014)						(0.010)
Observations	3,876,324	4,016,929	4,016,929	4,016,929	4,016,929	4,016,929	3,854,874	3,994,994	3,994,994	3,994,994	3,994,994	3,994,994

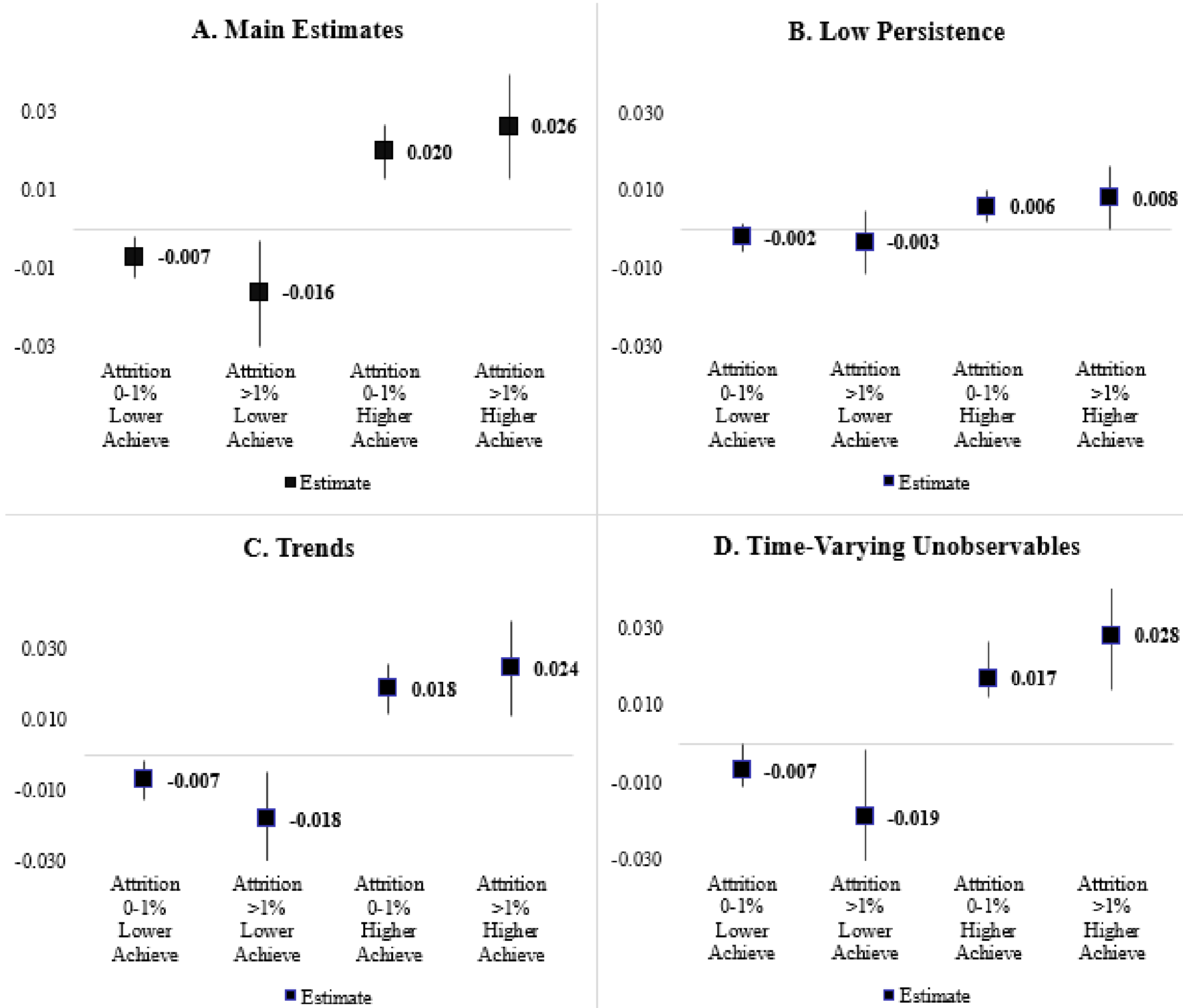
TPS refers to traditional public school, and CH refers to charter school. Dependent variables are standardized TPS student test score gains in math or reading. All regressions include grade-year dummy variables, controls for student switching, grade repetition, and school level covariates. Attrition 0-1% indicates if a TPS has 0-1% of prior year enrollment non-structurally switch to any CH in the current year. Non-structural switchers are students that switch schools when they could have stayed an additional year at their prior school. Higher-Achieve CH 2Lag indicates if the second lag of average lagged scores of students in a TPS are lower than the average lagged scores of students in competing CHs. Higher-Achieve CH District indicates if the lagged scores of students in competing CHs are greater than the average lagged scores of the district in which the TPS is located. Higher-Achieve CH-CH indicates if the CHs competing with a TPS have higher average lagged scores than that of the average of all CHs. Higher-White CH indicates if the TPS has a lower proportion of white students compared to competing CHs. Higher-Disabled CH and Higher-LEP CH (Limited English Proficient) are defined similarly. Dependent and independent variables are first differenced with respect to student-school spells to remove student and school heterogeneity, and the resulting equation is estimated using OLS. High persistence assumes that persistence in test scores is 1. Standard errors are clustered at the school level.

Table 16: First Differenced Regressions of Standardized Student Test Score Gains on Attrition Relative Achievement Competition Measures Interacted with Student Demographics for Years 1997-2016: No School Trends, High Persistence, Student Heterogeneity

	Black		Hispanic		Lim Eng Proficient		Disabled		Gifted		Econ Disadv	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
VARIABLES	Math	Read	Math	Read	Math	Read	Math	Read	Math	Read	Math	Read
Attrition 0-1% Lower-Achieve CH	-0.006**	-0.002	-0.007**	-0.002	-0.007***	-0.002	-0.008***	-0.001	-0.009***	-0.004	-0.007*	0.003
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.004)	(0.004)
Attrition 0-1% Higher-Achieve CH	0.014***	0.009***	0.014***	0.009***	0.019***	0.010***	0.019***	0.009***	0.021***	0.010***	0.012***	0.011***
	(0.004)	(0.003)	(0.004)	(0.003)	(0.004)	(0.002)	(0.004)	(0.003)	(0.004)	(0.003)	(0.005)	(0.003)
Attrition >1% Lower-Achieve CH	-0.021***	0.001	-0.022***	-0.000	-0.016**	-0.000	-0.016**	-0.002	-0.017**	-0.003	-0.034***	0.017*
	(0.008)	(0.007)	(0.008)	(0.007)	(0.007)	(0.006)	(0.007)	(0.006)	(0.007)	(0.006)	(0.011)	(0.010)
Attrition >1% Higher-Achieve CH	0.021***	0.011**	0.021***	0.013**	0.026***	0.016***	0.025***	0.014***	0.027***	0.016***	0.025***	0.017***
	(0.008)	(0.005)	(0.008)	(0.005)	(0.007)	(0.004)	(0.007)	(0.005)	(0.007)	(0.005)	(0.009)	(0.006)
Attrition 0-1 Lower-Achieve CH * Demo	-0.006	-0.002	-0.008	0.004	-0.012	-0.005	0.003	-0.011**	0.005	0.007*	-0.002	-0.004
	(0.004)	(0.004)	(0.006)	(0.006)	(0.008)	(0.009)	(0.004)	(0.005)	(0.004)	(0.004)	(0.004)	(0.004)
Attrition 0-1% Higher-Achieve CH * Demo	0.007	0.003	0.017**	-0.006	0.003	-0.010	0.000	0.002	-0.007	-0.001	0.010**	-0.001
	(0.005)	(0.004)	(0.007)	(0.005)	(0.008)	(0.007)	(0.005)	(0.005)	(0.005)	(0.004)	(0.004)	(0.004)
Attrition >1% Lower-Achieve CH * Demo	0.000	-0.003	0.006	-0.028*	-0.007	-0.046*	-0.007	0.004	0.004	0.008	0.014	-0.033***
	(0.010)	(0.009)	(0.015)	(0.015)	(0.018)	(0.024)	(0.011)	(0.014)	(0.010)	(0.010)	(0.010)	(0.012)
Attrition >1% Higher-Achieve CH * Demo	0.009	0.010	0.002	-0.011	-0.016	-0.019	0.004	0.008	-0.012	-0.010	-0.001	-0.006
	(0.009)	(0.007)	(0.011)	(0.009)	(0.013)	(0.012)	(0.009)	(0.009)	(0.010)	(0.008)	(0.008)	(0.007)
Observations	3,405,467	3,389,246	2,722,869	2,708,509	4,013,095	3,990,724	4,013,095	3,990,724	4,013,095	3,990,724	2,486,153	2,471,538

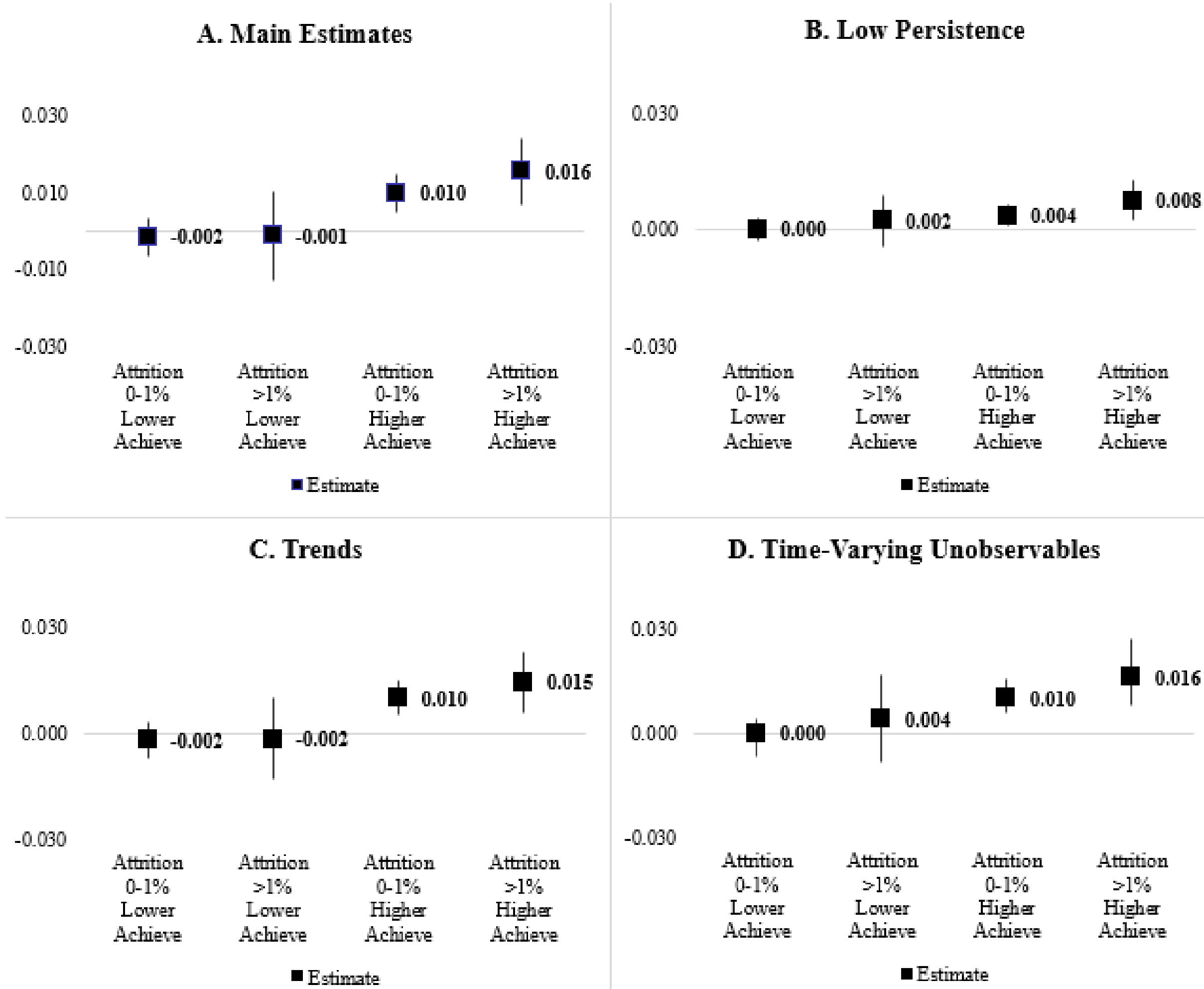
TPS refers to traditional public school, and CH refers to charter school. Dependent variables are standardized traditional public school student test score gains in math or reading. All regressions include grade-year dummy variables, controls for student switching, grade repetition, and school level covariates. Attrition 0-1% indicates if a TPS has strictly greater than 0% but less than or equal to 1% of prior year enrollment non-structurally switch to any CH in the current year. Attrition >1% indicates if a TPS has >1% of prior year enrollment non-structurally switch to any charter in the current year. Attrition equal to zero is the omitted category. Non-structural switchers are students that switch schools when they could have stayed an additional year at their prior school. Higher-Achieve CH indicators are one if the average lagged test scores of students in a TPS are lower than the average lagged test scores of students in charter schools from which the TPS is facing attrition. Instead of interacting Higher-Achieve CH with attrition dummies, I create separate group indicators for each combination of attrition (0-1% or >1%) and achievement (higher or lower). I interact these group indicators with indicators for whether a student is black, Hispanic, limited English proficient, disabled, gifted, or economically disadvantaged. The interaction terms change based on the specific demographic characteristic based on the column heading. Economically disadvantaged information at the student level is only available in period 2. Dependent and independent variables are first differenced with respect to student-school spells to remove student and school heterogeneity, and the resulting equation is estimated using OLS. High persistence assumes that persistence in test scores is 1, and low assumes 0 persistence. Standard errors are clustered at the school level.

Figure 1: Math Test Score Relative Achievement Estimates by Specification with 95% Confidence Intervals, 1997-2016



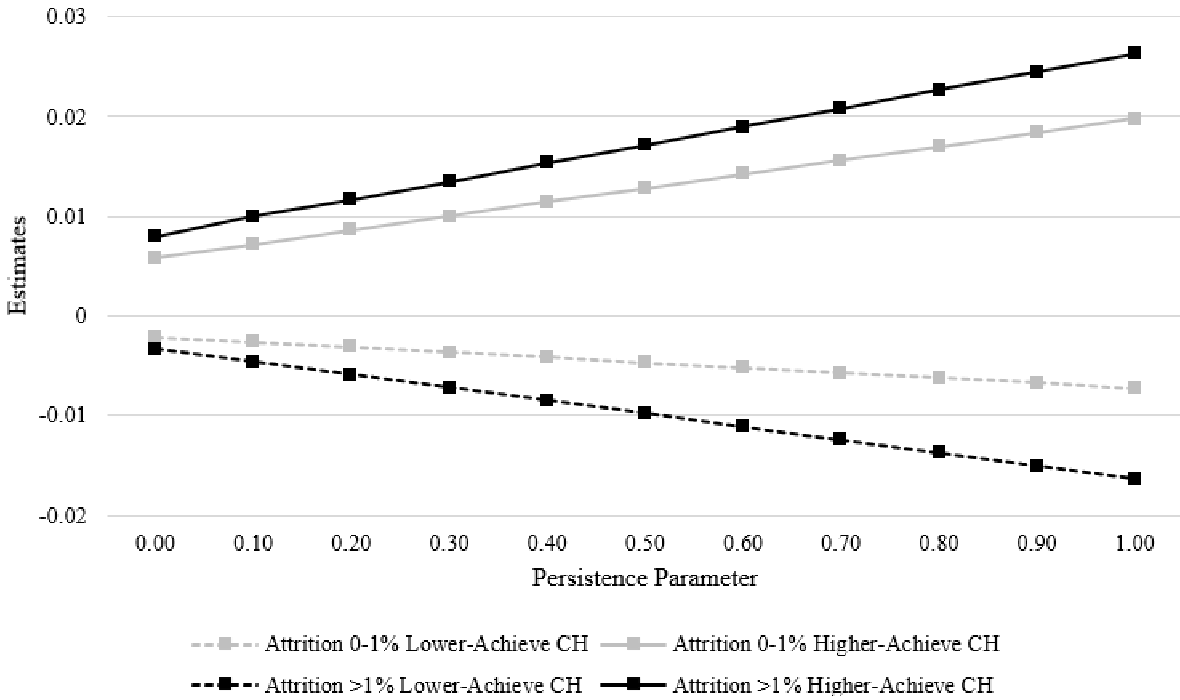
Notes: Main estimates are relative to schools facing no attrition and use high persistence of one. Panels B-D alter the main specification and are meant to be compared to Panel A. Panel B switches to low persistence of zero. Panel C adds controls for linear school trends. Panel D includes thrice lagged school characteristics. Panel A corresponds to Table 7, Panel B to Table 8, Panel C to Table 9, and Panel D to Table 10.

Figure 2: Reading Test Score Relative Achievement Estimates by Specification with 95% Confidence Intervals, 1997-2016



Notes: Main estimates are relative to schools facing no attrition and use high persistence of one. Panels B-D alter the main specification and are meant to be compared to Panel A. Panel B switches to low persistence of zero. Panel C adds controls for linear school trends. Panel D includes thrice lagged school characteristics. Panel A corresponds to Table 7, Panel B to Table 8, Panel C to Table 9, and Panel D to Table 10.

Figure 3: Relative Achievement Regression Coefficients by Persistence Parameter Values for Math, 1997-2016



TPS refers to traditional public school, and CH refers to charter school. This table reports the marginal effects of charter competition on traditional public school students for the groups: attrition 0-1% lower-achieving charter competition, attrition 0-1% higher-achieving charter competition, attrition >1% lower-achieving charter competition, and attrition >1% higher-achieving charter competition. Different estimates are reported for different persistent parameters ranging from 0 to 1 in increments of 0.10. The dependent variable is standardized math test score gains $(q_t - \lambda q_{t-1})$ where the gain varies based on the persistence parameter λ. All regressions include grade-year dummy variables, controls for student switching, grade repetition, and school level covariates. Attrition 0-1% indicates if a TPS has strictly greater than 0% but less than or equal to 1% of prior year enrollment non-structurally switch to any CH in the current year. Attrition >1% indicates if a TPS has >1% of prior year enrollment non-structurally switch to any charter in the current year. Non-structural switchers are students that switch schools when they could have stayed an additional year at their prior school. Higher-Achieve CH indicators are one if the average lagged test scores of students in a TPS are lower than the average lagged test scores of students in charter schools from which the TPS is facing attrition. Dependent and independent variables are first differenced with respect to student-school spells to remove student and school heterogeneity, and the resulting equation is estimated using OLS.

Appendices

A Geocoding

School level data files from NCDPI contain latitudes and longitudes for charter and traditional public schools in North Carolina. School latitudes are available starting in 2001 and addresses in 1999. Charter schools start entering in 1998 so I impute addresses from 1999 to 1998. This means that any schools open in 1998 that close in 1999 will not have location information. School universe files are not available for 2016 at the time of this study, so I obtain 2016 address information from the Educational Directory and Demographical Information Exchange (EDDIE) which is maintained by the North Carolina Department of Public Instruction. I then geocode all school addresses that do not have a corresponding latitude and longitude using http://www.gpsvisualizer.com/geocoder/. This website accesses Bing Maps for the actual conversion of addresses to latitude and longitude.

I link each traditional public school to every charter school and calculate distances between each pair to create distance based measures of competition. The STATA command I use is geodist which computes geodetic distances between two pairs of latitudes and longitudes. The geodetic distance is the length of the shortest curve between two points along the surface of a mathematical model of the Earth. There is concern that some school addresses in 1999 and 2000 may be mailing and not physical addresses. If an address contains any post office box information, I assume it is a mailing address and impute 2001 location information to 1999 and 2000. In general, school mailing addresses and physical location are likely to coincide and even if mailing addresses are used, they are likely close in proximity to the actual school.

Because some school-year location information is geocoded by the author and some is already available in the school universe files, there is slight variation in latitudes and longitudes across time for some schools without an address change. Even within the school universe files there is slight variation in latitudes and longitudes, and there are instances when a latitude and longitude for a school will drastically change for one year without an address change. To partially account for this, if a school address does not change over time, I impute the most recent latitude and longitude. I use the most recent assuming that accuracy in geocoding methods has improved over time. Finally, I impute surrounding school-year location information for any large jumps in latitude and longitude within a school. After these revisions, 6.2% of public schools moved more than 0.5 miles sometime between 1998 and 2016; among charter schools the proportion is 15.8%.

B Split Competition Measures

For each measure of competition (such as the number of charters within 10 miles of a traditional public school) two sets of variables are defined based on whether or not period 1 charter schools are taken into account in period 2. The main set of results are reported using *full* measures of competition that include charter schools that opened in period 1 when defining competition in period 2. Specifications are also run using *split* measures where competition is defined separately in each period so effects in period 1 can be interpreted as the effects of charter schools that entered sometime in period 1, and effects in period 2 can be interpreted as the effects of charter schools that entered sometime in period 2 ignoring charter schools that entered in period 1.

The main set of results presented in Table 7 use full competition while Table 17 presents results using split competition measures. This may provide a more direct comparison because then the effects of opening, closing, and expanding charter schools within each period are being compared. By construction any estimates for period 1 are left unchanged when compared to Table 7, but any coefficients on variables interacted with period 2 will likely change. Overall, results do not change very much compared to Table 7 in terms of sign and significance.

Table 17: First Differenced Regressions of Standardized Student Test Score Gains on Attrition Competition Measures Interacted with Relative Achievement for Years 1997-2016: No School Trends, High Persistence, Split Competition Measures

VARIABLES	(1) Math	(2) Math	(3) Read	(4) Read
Attrition 0-1%	0.005*	-0.006	0.003	-0.002
	(0.003)	(0.004)	(0.003)	(0.003)
Attrition >1%	0.003	-0.013	0.010**	-0.004
	(0.006)	(0.008)	(0.005)	(0.007)
Attrition 0-1% * Higher-Achieve CH		0.028***		0.011**
		(0.006)		(0.004)
Attrition >1% * Higher-Achieve CH		0.031***		0.024***
		(0.011)		(0.008)
Observations	4,016,929	4,016,929	3,994,994	3,994,994

TPS refers to traditional public school, and CH refers to charter school. Dependent variables are standardized traditional public school student test score gains in math or reading. All regressions include grade-year dummy variables, controls for student switching, grade repetition, and school level covariates. Attrition 0-1% indicates if a TPS has strictly greater than 0% but less than or equal to 1% of prior year enrollment non-structurally switch to any CH in the current year. Attrition >1% indicates if a TPS has >1% of prior year enrollment non-structurally switch to any charter in the current year. Attrition equal to zero is the omitted category. Non-structural switchers are students that switch schools when they could have stayed an additional year at their prior school. Higher-Achieve CH indicators are one if the average lagged test scores of students in a TPS are lower than the average lagged test scores of students in charter schools from which the TPS is facing attrition. Dependent and independent variables are first differenced with respect to student-school spells to remove student and school heterogeneity, and the resulting equation is estimated using OLS. High persistence assumes that persistence in test scores is 1, and low assumes 0 persistence. Standard errors are clustered at the school level.

C Relative Achievement Defined by School Achievement Lags

The primary definition of relative charter and traditional public school achievement used in this paper relies of the lagged test scores of students attending a school at time t. Using lagged test scores allows charter schools that are new to have a measure of achievement in their first year. The average lagged achievement of a new charter school does not exist, so if I were to use lagged school achievement, identifying variation from the opening of new charter schools would be lost. The test scores of students at the end of period t can not be used to construct relative achievement measures because these test scores are outcomes of the competitive process.

The concern with using lagged student test scores is that, in their first year of operation, new charter school achievement will be defined solely based on student test scores while in a different school. Additionally, students and families may not be accurate in assessing the expected quality of a new charter school which may result in noisy measures of relative achievement for the first year charters open. On the other hand, using lagged school level achievement would remove a significant amount of variation in competition measures due to the opening of new charter schools. This may be especially important for distance based measures of competition.

Table 18 presents results using school lags of achievement rather than the lagged test scores of students in a school at time t to construct relative achievement. Differences between these two measures may suggest that student's expectations of charter school quality before a charter opens is noisy or that the variation from the opening of new charter schools is important to the estimates. Results for both attrition and distance measures of competition reflect those found using student lags which suggest these are not a concern.

Table 18: First Differenced Regressions of Standardized Student Test Score Gains on Attrition and Distance Competition Measures Interacted with Relative Achievement (Defined by Lagged School Achievement) for Years 1997-2016: No School Trends, High Persistence

VARIABLES	(1) Math	(2) Read	(3) Math	(4) Read
Attrition 0-1%	-0.005*	0.000		
	(0.003)	(0.003)		
Attrition >1%	-0.011	0.011		
	(0.007)	(0.007)		
Attrition 0-1% * Higher-Achieve CH	0.024***	0.010***		
	(0.004)	(0.003)		
Attrition >1% * Higher-Achieve CH	0.034***	0.004		
	(0.010)	(0.008)		
Within 10 1 CH			-0.013	-0.001
			(0.010)	(0.008)
Within 10 2 or More CH			-0.002	0.011
			(0.014)	(0.010)
Within 10 1 CH * Higher-Achieve CH			0.032***	0.019***
			(0.008)	(0.005)
Within 10 2 or More CH * Higher-Achieve CH			0.048***	0.021***
			(0.010)	(0.007)
Observations	3,785,903	3,765,061	3,794,057	3,773,207

TPS refers to traditional public school, and CH refers to charter school. Dependent variables are standardized traditional public school student test score gains in math or reading. All regressions include grade-year dummy variables, controls for student switching, grade repetition, and school level covariates. Attrition 0-1% indicates if a TPS has strictly greater than 0% but less than or equal to 1% of prior year enrollment non-structurally switch to any CH in the current year. Attrition >1% indicates if a TPS has >1% of prior year enrollment non-structurally switch to any charter in the current year. Attrition equal to zero is the omitted category. Non-structural switchers are students that switch schools when they could have stayed an additional year at their prior school. Higher-Achieve CH indicators are one if average lagged TPS achievement is lower than the average lagged achievement of charter schools from which the TPS is facing attrition. Within 10 1 CH indicates if a TPS is within 10 miles of one charter school and one of the closest 10 TPSs to that charter. Within 10 2 or More CH indicates if a TPS is within 10 miles of more than one charter school and one of the closest 10 TPSs to those charter schools. Within 10 miles of no charter is the omitted category. Higher-Achieve CH indicators are one if average lagged TPS achievement is lower than the average lagged achievement of charter schools within 10 miles. Dependent and independent variables are first differenced with respect to student-school spells to remove student and school heterogeneity, and the resulting equation is estimated using OLS. High persistence assumes that persistence in test scores is 1, and low assumes 0 persistence. Standard errors are clustered at the school level.