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Jacob Vigdor and Thomas J. Nechyba

CESifo
Poschingerstr. 5, 81679 Munich, Germany
Phone: +49 (89) 9224 1410 - Fax: +49 (89) 9224 1409
E-mail: office@CESifo.de
Internet: http://www.cesifo.de

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Jacob Vigdor and Thomas Nechyba*

Duke University and NBER

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Abstract

We use administrative data covering all public school students in the state of North Carolina to estimate the relationship between peer characteristics and student achievement. In models defining peer groups at the classroom level and employing school fixed effects, we find a significant positive relationship between peer ability, as measured by 3rd grade standardized test scores, and 5th grade achievement. We also find that greater dispersion in peer ability predicts higher math test scores. We estimate a significant positive impact of 5th grade peer characteristics carrying forward to the 6th, 7th and 8th grades. Concerns of endogenous selection into peer groups are very important in this study. While the use of school fixed effects does not substantially affect our peer characteristic coefficients, alternative specifications that exploit changes in school composition associated with the redrawing of attendance zone boundaries show no significant impact of changes in peer group composition on changes in achievement.

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* Vigdor: Sanford Institute of Public Policy, Box 90245, Durham NC 27708, jacob.vigdor@duke.edu.
Nechyba: Department of Economics, Box 90097, Durham NC 27708, nechyba@econ.duke.edu
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1. Introduction

The economics of education literature has long struggled to identify the inputs that matter most in the production of school quality. Such inputs may include per-pupil spending in schools, measurable qualifications of teachers and administrators, the background and involvement of parents or the governance structure of the school. Increasingly, however, *peer effects* have emerged as a potential input that may play an important independent role in determining student outcomes. Peer effects are now widely discussed in policy circles and are routinely included as crucial components in theoretical and computational models of school choice (as, for example, in Epple and Romano 1998, Nechyba 2000, Ferreyra 2002). At the same time, they remain rather poorly understood, with empirical investigations often limited by both methodological constraints as well as severe data limitations.

In this paper, we utilize a comprehensive administrative dataset tracking North Carolina public school students to explore the relationship between peer characteristics and student achievement in elementary school. Several features of the North Carolina dataset enable us to pay careful attention to empirical issues that have plagued existing literature. We are able to match students with their classmates. This provides us with an opportunity to use a very basic tool to address the endogenous selection of individuals into peer groups: school fixed effects. Existing evidence suggests that the degree of sorting by ability across schools significantly exceeds the amount of sorting that takes place within schools in North Carolina (Clotfelter, Ladd and Vigdor 2004).

The ability to define peer groups at multiple administrative levels also permits us to evaluate some very basic hypotheses about why correlations between peer and individual characteristics exist. If peer characteristics are a signal for unobserved components of individual ability, then noisier measures of peer characteristics, such as statistics derived from classroom level data, should yield smaller estimates of peer influence than identical statistics derived from school level data. Indeed, existing evidence suggests that this pattern holds (Betts and Zau 2002). Our evidence suggests precisely the opposite pattern: that estimates of peer influence are stronger using classroom-level peer group definitions.

The longitudinal nature of our data, which track students so long as they remain enrolled in a public school somewhere in the state, permit an investigation into the persistence of peer influence. We measure significant, though dampened, correlations between a student's 5th grade peer characteristics and standardized test performance through the 8th grade.

Finally, we present analysis of a subsample of students who witnessed substantial turnover in their elementary schools between the 4th and 5th grades. Although these students did not switch schools themselves, changes in school attendance zones resulting from policy shifts or the opening of new schools imply that their peer groups were subject to potentially large changes. Our analysis of this subsample suggests that a significant portion of the effects we measure elsewhere in the paper are not truly causal in nature. This analysis underscores the importance of taking careful steps to address the endogenous formation of peer groups in public schools.

2. The peer effects literature

A growing literature in economics, sociology, and psychology documents the importance of peer group characteristics in determining individual outcomes. Within this literature, there exists great variation both in terms of the outcomes considered and the definition of an individual's peer group. Bertrand, Luttmer and Mullainathan (2000), for example, define peer groups by language spoken and metropolitan area, and find that welfare participation within the peer group predicts significantly higher individual participation. Peer effects in educational settings have been widely and intensively studied. Studies including Arcidiacono and Nicholson (2001), Bryk and Driscoll (1988), Caldas and Bankston (1997), Gaviria and Raphael (2001), Jencks and Mayer (1990), Link and Mulligan (1991), Mayer (1991), Robertson and Symons (1996), and Zimmer and Toma (1999) investigate peer effects in educational settings, where peer group characteristics are defined as characteristics of a school's student body. Some additional studies, summarized by Slavin (1987, 1990) have examined within-classroom peer effects, with a special emphasis on the effect of ability-grouping within schools. Betts and Zau (2002) estimate significant peer effects at both the grade and classroom levels.

A second strand of the literature has considered the implications of neighborhood characteristics for individual outcomes, particularly the developmental consequences of growing up in a poor neighborhood (Brooks-Gunn et al., 1993; Case and Katz, 1991; Chase-Lansdale et al., 1997; Duncan, 1994; Duncan et al., 1997; Ensminger et al., 1996; Halpern-Felsher et al., 1997; Hanratty et al. 2001; Katz et al. 2001; Leventhal and Brooks-Gunn, 2001; Ludwig, Duncan and Hirschfeld, 2001; Ludwig, Duncan and Pinkston, 2000; Ludwig, Ladd and Duncan, 2001; Rosenbaum 1991; Rosenbaum and Harris, 2000; Solon, Page and Duncan, 2000; see Jencks and Mayer, 1990; Ellen and Turner, 1997 and Gephardt, 1997 for literature reviews).

In all, the existing literature on both peer effects in educational settings and neighborhood effects has been inconclusive. The failure of previous studies to arrive at a consensus on the existence and magnitude of these effects reflects two essential challenges in estimating the importance of peer or neighborhood characteristics on student achievement. The first challenge arises from the difficulty in econometrically separating a group's influence on an individual's outcome from the individual's influence on the group (Manski, 1993; Moffitt, 1998; Nechyba et al. 1999). Many studies avoid this challenge by examining the relationship between "exogenous" characteristics of a peer group, such as race or gender, and the "endogenous" outcomes of an individual, rather than focus on the relation of endogenous outcomes between individual and peer. Other studies, such as Hanushek et al (2001), use lagged peer outcome measures to circumvent these issues. The second challenge stems from the endogenous choice of peer groups and neighbors in most situations. Individuals who choose to associate with a "good" peer group, for example, may be "good" persons themselves, in ways that are difficult to quantify or observe. A positive correlation between peer and individual might reflect these unobserved factors rather than any causal relationship.

To circumvent this latter challenge, studies have pursued several strategies. One is to exploit situations or policy experiments where individuals are randomly assigned to peer groups (Boozer and Cacciola 2001; Sacerdote 2001) or neighborhoods (Hanratty et al. 1998; Katz et al. 2001; Ludwig, Duncan and Hirschfeld, 2001; Ludwig, Duncan and Pinkston, 2000; Ludwig, Ladd and Duncan, 2001; Leventhal and Brooks-Gunn, 2001; Rosenbaum 1991). A variation of this strategy is to use idiosyncratic variation in the composition of peer groups – such as the differences between successive cohorts within a school, or across classrooms in an elementary school (Hoxby 2000; and Hanushek et al. 2001).

A second strategy employed by researchers seeking to understand the relationship between peer groups or neighborhoods and outcomes is to explicitly model the assignment process; that is, to analyze neighborhood and schooling choices. One relatively straightforward implementation of this strategy is to conduct an instrumental variable analysis that models peer group characteristics as a function of exogenous variables (Evans, Oates and Schwab, 1992). A number of studies have used discrete choice models and other econometric methods to analyze neighborhood and schooling consumption decisions (Bayer, 2000; Bayer, McMillan and Rueben 2002; Epple and Sieg 1999; McFadden 1978). Others have examined the relationship between local school characteristics or other policy variables and property values (Oates 1969; Black 1999) or the equilibrium demographic composition of communities (Cutler et al. 1993; Vigdor 2002). Finally, a growing simulation-based literature is seeking ways to simultaneously analyze school and neighborhood choice (Nechyba 1999, 2000, 2003, forthcoming(a),(b), Ferreyra 2002).

In this paper, we present an analysis using a form of the first strategy, focusing on changes in school attendance zone boundaries caused by the opening of new schools or broader changes in school integration strategies.[1] Our future efforts on this project, described in more detail in the concluding section, will attempt to integrate aspects of the first strategy with the more sophisticated modeling techniques of the second.

3. Data

Our estimation employs a dataset recording information on every public school student in the state of North Carolina between the 1994/95 and 2000/01 school years. Standardized end-of-grade tests are administered annually to students in North Carolina beginning in 3rd grade and

[1] The most drastic recent change in desegregation plans in North Carolina occurred this year in the state's largest district, the Charlotte/Mecklenburg County school system. Following a Federal court ruling, this district dropped its desegregation plan and adopted a modified neighborhood school assignment plan in the 2002/03 school year. Consequently, the average black elementary student witnessed an increase in black share of classmates from 52% to 57%: this increase would be equivalent to one extra black classmate in a class of twenty. The Charlotte-Mecklenburg system is about 40% black overall, implying that this increase in the proportion of black classmates for black students must be matched by a relatively equal decrease in the proportion for students of other races. Since race correlates very highly with socioeconomic status and standardized test performance, this change in the racial makeup of classrooms suggests changes in other peer characteristics measures as well. See Section D for more on recent school district changes in North Carolina.

continuing until 8th grade. Each student test score record contains information on the school attended and the identity of the teacher administering the test. It is this teacher information that permits us to match students who share a classroom within a school. This method of sorting students into classrooms is only effective in elementary school, where students spend nearly all their time with the same group of peers and receive most of their instruction from a single teacher. In secondary school, where one math or English teacher serves multiple classes' worth of students, this method is ineffective. For this reason, we focus our peer group analysis on the characteristics of a student's classmates and schoolmates in the 5th grade. Virtually all North Carolina school districts assign 5th grade students to elementary schools.

As Table 1 indicates, the North Carolina administrative data provide us with more than 900,000 observations of fifth grade students spread across 4 individual cohorts. For ease of interpretation, we normalize student test scores to have mean zero and variance 1.[2] In addition to standardized test score information, we observe basic demographic information on each student, including race, sex, and participation in the Federal free or reduced price lunch program. Beyond these widely available measures, we have teacher-reported information on parental education for each student.

We form a set of basic peer characteristic variables for each student in the dataset, including racial composition and measures of peer ability. Our peer ability variables use data on 3rd grade standardized test performance for those classmates that can be tracked two years. Across the entire sample, we are able to link about 80% of fifth grade students to their third grade test scores. As in existing literature, we use the mean of this lagged achievement variable

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[2] Mean math and reading test scores in our estimation sample exceed zero, and the standard deviation is less than one, primarily because the estimation sample omits students tested in exceptionally small classroom groups, which are likely to be special education classes.

as a basic ability measure.[3] In addition, we control for the standard deviation of peer lagged test scores. Controlling for both the mean and standard deviation of our ability measure allow us to test for the presence of nonlinearities in the relationship between peer ability and student achievement. This parameterization provides a very clear picture of the aggregate implications of choosing to stratify classrooms by ability or to randomly assign students to classrooms. If individual test scores increase in the standard deviation of peer ability, then mixing students of various ability levels in the same classroom will lead to the highest levels of aggregate achievement.[4]

Table 1 shows that the mean peer achievement level within classrooms is slightly higher than the population mean, indicating that lower-performing students tend to be assigned to smaller classrooms, consistent with Lazear's (2001) model of administrative efforts to maximize school output. Mean peer achievement within schools also exceeds the population average, indicating that high ability students attend larger schools on average. Widespread rural poverty in North Carolina most likely explains this pattern. The distribution of mean peer ability is considerably more dispersed than one would expect if schools and classrooms represented random samples of the overall student population.[5] This is evidence of the stratification of students by ability across classrooms and schools.

The peer standard deviation measures, at both the school and classroom levels, are slightly lower than the population standard deviation, providing additional evidence that students

[3] We omit a student's own lagged test score from the computation of mean classroom or grade level peer ability.
[4] Of course, the allocation of students to classrooms may influence the distribution of achievement levels even in situations where mean student achievement is constant. If individual school enrollment decisions are sensitive to the level of peer quality offered to a student of any particular type, the enrollment or achievement-maximizing allocation of students to classrooms may well deviate from the allocation identified in our analysis as aggregate achievement maximizing. For a theoretical analysis of the decision to employ tracking in public schools, see Epple, Newlon and Romano (2002).
[5] For example, if classrooms were random draws from the population, with sample sizes between 16 and 25, we would expect the standard deviation of mean peer ability to be between 0.20 and 0.25. School standard deviations would be even smaller.

in North Carolina public school classrooms are stratified by ability. The classroom level standard deviation measure is lower than the grade level measure, indicating that a portion of the observed ability stratification occurs within schools rather than between them. The peer standard deviation measure varies considerably; some schools and classrooms are almost entirely homogeneous, while others are considerably more heterogeneous than the state itself.

4. Basic Results

Table 2 presents coefficients from basic regression specifications examining the relationship between peer characteristics and student math and reading test scores. The first two columns examine the correlates of math scores, using basic least squares regression with grade- and classroom-level definitions of peer groups, respectively. At the grade level, there is a significant partial correlation between peer lagged test scores and individual achievement. A one standard deviation increase in peer achievement (0.30) predicts an increase in individual test scores equivalent to 2% of a standard deviation. The table also reveals a significant partial correlation between black share within the grade and the achievement of black students. A similar pattern appears for Hispanic students. For both groups of minority students, the results suggest that racial or ethnic achievement gaps are most pronounced in schools serving small minority populations. The estimated partial correlation between variation in peer ability and individual achievement is very small and not statistically distinguishable from zero.

For reasons discussed below, we are not eager to attach a causal interpretation to these results. Nonetheless, it is instructive to note the magnitude and significance of certain other coefficients in this introductory regression. A student's fourth grade test score is, not surprisingly, an incredibly strong predictor of fifth grade performance. The lagged test score coefficients in this and each other specification in the table are significantly less than one, suggesting that there is at least some mean reversion in test scores. Male students score slightly, though significantly, lower than their female counterparts. Finally, categorical controls for parental education reveal a strong relationship between that characteristic and student achievement. The predicted impact of having a college educated parent, rather than a high school dropout parent, is equivalent to the predicted impact of raising peers' mean achievement by four standard deviations.

Switching the definition of peer group from the grade to classroom level changes the magnitude of many estimated coefficients. The estimated effect of peer test scores on math achievement increases, and the standard deviation of peer test scores has a significant positive effect. The relationship between classroom racial composition on the test scores of White and Asian students continues to be negligible, though the interacted effects noted in the grade-level specification persist here.

Students are not allocated randomly to classrooms in North Carolina. It can be argued however, that most of this nonrandom allocation occurs at the school level (Clotfelter, Ladd and Vigdor 2004). Estimates presented in the third column of Table 3, which represent regression models that incorporate school fixed effects, should be purged of a great deal of any bias associated with nonrandom sorting into classrooms.

In the fixed effects specification, mean peer test scores continue to be a significant predictor of individual math achievement. The point estimate is somewhat smaller than in the previous specification, but still larger than the estimate derived from grade-level peer groups. A one standard deviation (0.40) increase in peer ability predicts a test score increase equivalent to 3% of a standard deviation. The impact of dispersion in peer test scores also retains significance, actually increasing in magnitude relative to the specification without school fixed effects. The relationship between classroom racial composition and student achievement changes notably. Students of all races now appear to receive lower test scores when the share black or Hispanic in their classroom is high relative to other classrooms in the same school.

The fourth, fifth and sixth regressions in Table 2 replicate the first three specifications, replacing both the dependent variable and peer test score variables with reading rather than math test scores. In general, the results in these specifications bear significant resemblance to the math results, though there are several noteworthy contrasts. The mean peer achievement coefficients derived from grade- and classroom-level peer groups are nearly identical in specifications without fixed effects. In the preferred school fixed effect model the coefficient on mean peer achievement, though still significantly greater than zero, is roughly one-third lower than either prior estimate. There is only limited evidence – a marginally significant coefficient in the fixed effects specification -- to suggest that dispersion in peer reading scores is advantageous to individual students. The link between classroom racial composition and individual achievement is also more tenuous here. In the fixed effects specification, non-Hispanic students in classrooms with a higher share of Hispanics tend to score lower; Hispanic students themselves, if anything, are positively affected by Hispanic share.

The finding that classroom-level peer achievement is an equal or greater predictor of individual test scores contrasts with Betts and Zau (2003), who find the opposite relationship in their study of data from the San Diego Unified School District. To further examine this pattern, Table 3 presents the results of specifications that simultaneously control for grade and classroom level peer characteristics. The two specifications in this table, which present results using math and reading scores as the dependent variable, support the conclusion that the characteristics of classroom peers are much more significant correlates of achievement than the characteristics of other students in the same grade at the same school. Mean lagged test scores among classmates continue to be significant positive predictors of achievement, while the coefficients on mean achievement for grade level peers are either insignificant or wrong-signed.

From a causal perspective, this pattern of results is quite sensible. If peer quality matters because of classroom interaction between peers, because the distribution of peer quality influences teachers' resource allocation, or because teachers' own pedagogical style or effort level responds to baseline student ability, then the ability of classroom peers should matter more than the ability of peers in the same school but not in the same classroom. If correlations between peer and individual achievement arise primarily through endogenous sorting into peer groups, then the relative greater importance of between-school sorting should lead to a situation where grade level characteristics are more significant predictors of achievement.[6]

There are several other interesting results in Table 3. Dispersion of peer ability within classrooms continues to be a significant predictor of increased math and reading achievement. School racial composition does not appear to be a significant predictor of achievement: simultaneously increasing black share or Hispanic share in all classrooms in a school predicts very little impact on individual achievement. There is some evidence to suggest, however, that nonblack students attain lower math test scores in classrooms serving a disproportionate share of black students, and that non-Hispanic students score lower on both math and reading tests in classrooms serving a disproportionate share of Hispanic students. There is at least some evidence to suggest that black and Hispanic students are partly immune from these own-race effects. Within-school sorting remains a plausible explanation for these results.

[6] The result pattern displayed here could result from extensive sorting within schools accompanied by insubstantial sorting across schools. While we cannot completely rule out this possibility, existing evidence suggests that sorting between schools is much more empirically relevant in North Carolina (Clotfelter, Ladd and Vigdor 2004).

There are several conceivable causal mechanisms linking classroom ability levels with individual achievement. When a given student is assigned to a classroom with higher ability peers, the teacher may be more willing or able to provide individual instruction, or spend a higher fraction of time on educational tasks rather than discipline. Students may also learn directly from peers or deepen their own understanding by instructing fellow students. Exposure to peers of higher quality may also ingrain more favorable long-term study habits or other relatively permanent traits. Different hypothesized causal mechanisms carry different implications for the persistence of peer influence on achievement. Peer quality may impart a largely transitory benefit on individuals, or may have lasting effects. The relative permanence of peer influence is a critical parameter for the design of achievement-maximizing schools or school districts. Tables 4 and 5 examine the persistence of peer characteristic effects by tracing the impact of fifth grade peer quality through 8^{th} grade.

Each of the specifications in these tables controls for a standard set of student-level covariates as well as fixed effects grouping students into the schools they attended in fifth grade. Peer characteristic variables are consistently defined on the basis of a student's classmates in fifth grade, including race and moments in the 3^{rd} grade test score distribution.

For both reading and math achievement, the results support the hypothesis of a significant persistent effect of fifth grade peer quality on student achievement. In the math score regressions, the effect of mean fifth grade peer ability in 6^{th}, 7^{th} and 8^{th} grade is consistently estimated at about one-half the magnitude of the effect measured in 5^{th} grade. Persistent effects are larger in both absolute and relative terms in the reading score regressions: there is little evidence of decay in the impact of fifth grade peer ability on student achievement. This persistence occurs even though students presumably have limited contact with their fifth grade classmates once they enter a middle school environment, partly because schools are larger at higher grade levels and partly because the structure of middle school implies less exposure to any particular set of classmates.

Other peer characteristics show mixed evidence of persistence. The benefits of being in a class with diverse math ability levels shows no consistent signs of persistence after 5^{th} grade. The benefits of diverse reading ability levels, though smaller in initial magnitude, show greater persistence, with significant coefficients estimated in 5^{th}, 6^{th} and 7^{th} grade. Classroom racial composition has a significant instantaneous effect on achievement, but in most cases this effect decays rapidly over time, to the extent that it appears irrelevant for most students by the end of their 8^{th} grade year. The possible exceptions to this generalization are the estimated negative impact of percent black in a student's 5^{th} grade classroom on 6^{th} and 8^{th} grade reading scores, and the large, though imprecisely estimated, math and reading gains to attending a class with a large Hispanic share for Hispanic students. The first of these effects appears too large to be credible, while the second is consistent with a view that initial concentration of Hispanic students is beneficial for those students' later performance.

5. Further efforts to address endogenous sorting

To this point, our most sophisticated efforts to address the nonrandom sorting of students into classrooms consist of presenting estimates of classroom-level peer effects controlling for school fixed effects. This strategy is a valid means of assessing the impact of classroom-level peer characteristics on achievement in situations where schools assign students to classrooms randomly. There is considerable evidence, however, that random assignment is not the universal norm in North Carolina. In Table 1, for example, the standard deviation of peer test scores within classrooms is smaller than the standard deviation of peer test scores within grades, suggesting at least some degree of ability stratification occurs within elementary schools.

A more convincing strategy for identifying the true causal impact of peer characteristics on student achievement would exploit some source of variation exogenous to the individual student and uncorrelated with his or her own ability conditional on observables. In this section we take advantage of two characteristics of North Carolina public schools that create situations where students are exposed to significantly different peer groups from one year to the next. First, certain parts of North Carolina have experienced rapid population growth in recent years. This growth has led to the construction and opening of many new schools. Wake County, the state's second largest school system, which serves Raleigh, has opened 50 new schools over the 15-year span beginning in 1988. Second, rulings from Federal courts have led some large districts across the state to change their practices regarding student assignment to schools, moving away from busing plans designed to achieve racial balance and towards other schemes.

Students re-assigned to a new school may experience a change in outcomes for several reasons. The composition of their peer group changes, but there may be other factors, including the social strain of adjusting to a new environment, or changes in the transportation time to the new school, which have the potential to influence achievement. For this reason, our exploitation of changes in school assignment will focus not on the students who switch, but rather on students who are consistently assigned to a school that experiences a significant change in enrollment. These "feeder" schools are those who lose at least 10% but less than 50% of their student body between one year and the next. We chose the lower threshold because small changes in peer group composition may be imperceptible to students, and the upper threshold because a situation where the majority of students in a school are replaced may be as traumatic to remaining students as a transfer to a new school.

Table 6 provides some summary statistics for these feeder schools. While feeder schools are quite representative of the state in terms of racial composition, average student test scores are almost one-tenth of a standard deviation higher, and average parental education levels are also disproportionately high. This stems from the tendency for such schools to be located in rapidly growing, more affluent areas of the state. Since it is conceivable that different peer influence mechanisms operate in schools serving disproportionately advantaged students, the results below should be interpreted with some degree of caution.

Table 7 reports regression results where the sample is restricted to students consistently assigned to feeder schools. These specifications use classroom-level peer group definitions, but omit school fixed-effects since the variation in peer group composition we seek to exploit is school- rather than classroom-level variation. The first two regressions are comparable to earlier tables, and illustrate that the patterns found in our entire sample also tend to hold in this restricted subsample. Higher mean peer achievement in 3rd grade continues to predict higher individual test scores in 5th grade, and greater dispersion in peer ability levels continues to predict significantly higher math test scores. Classroom racial composition is a significant predictor of achievement only for Hispanic students, who appear to perform better in classrooms with a higher share of their own group. Individual characteristics such as race, gender, and parent education continue to explain a significant amount of variation in achievement.

Even in the feeder school sample, cross-sectional variation in peer characteristics is most likely contaminated by endogenous sorting. Feeder schools, by definition, have maintained a significant portion of their student body intact from year to year. In a feeder school, the student body composition at any one point in time is likely to reflect endogenous sorting into the school. It is the change in student body composition that can be considered exogenous from the perspective of a student permanently assigned to the school. To more directly exploit this source of variation, the final specifications in Table 7 take first differences of both the dependent variable and the peer characteristic variables. Effectively, these regressions seek to determine whether changes in a student's performance between 4th and 5th grade can be linked to changes in classroom composition between 4th and 5th grade.

In these specifications, very few independent variables have any explanatory power. The regressions explain less than one percent of all variation in year-over-year changes in student test scores. The peer characteristic coefficients are generally smaller than in the level specifications and insignificant. The sole exception to this pattern is the coefficient on percent Hispanic in the classroom: student reading scores tend to decline in schools that experience an increase in the share of Hispanic students.

A basic reading of these results thus suggests that most, if not all, of the observed correlation in peer and individual achievement can be attributed to sorting and not any causal impact. The final regressions reported in Table 7 provide some additional information valuable in interpreting these final results. These models replicate the first-difference specification using the full sample of North Carolina 5th grade students. In the whole sample, there is a statistically significant, though empirically small, association between changes in lagged peer test scores and changes in individual test scores.

Perhaps the most interesting comparison between the full sample and the feeder school sample is between the average peer test score coefficients in the math specifications. The point estimate in the feeder school sample, where it is easier to argue that changes in peer characteristics is exogenous to the student, is actually larger than the statistically significant point estimate in the full sample. The feeder school coefficient fails to attain significance largely because the sample size is considerably smaller. Thus, one consistent reading of the evidence is that peer ability exerts a positive, though empirically small, effect on math achievement.

6. Conclusions and Future Directions

This paper has both provided evidence of significant correlations between peer characteristics and student achievement in North Carolina elementary schools and raised serious doubts regarding whether a causal interpretation can be assigned to such correlations. On the one hand, using classroom-level peer group definitions, the magnitude of the estimated impact of peer ability on individual achievement is relatively insensitive to the introduction of school fixed effects. This suggests that estimates are not greatly contaminated by sorting across schools, which is empirically a more recognizable phenomenon than sorting within schools. On the other hand, our analysis of students attending "feeder schools" where significant year-to-year variation in peer group composition arose from changes in school assignment policy or the opening of new schools found little evidence that changes in peer group composition lead to changes in achievement levels.

In the face of this inconclusive and somewhat contradictory evidence, it is clear that more research will be required to state the importance of peer influence on achievement with any degree of confidence. Our preliminary findings are intriguing from a policy perspective: they suggest that there are real gains, in terms of mean achievement test scores, from integrating classrooms by ability level. It is premature at this point to derive true policy prescriptions from these results.

Our future research agenda incorporates several strategies for disentangling the impact of peer characteristics from family background and other variables that presumably contaminate cross-sectional relationships. The feeder school analysis represents one such strategy. A similar strategy will be to use the sample of North Carolina elementary schools that appear to randomly assign students to classrooms, at least on the basis of observable characteristics (Clotfelter, Ladd and Vigdor 2004). Coupled with school fixed effects, this strategy promises to identify variation in peer characteristics that is truly uncorrelated with individual background variables.

A more ambitious strategy will incorporate further information on student background characteristics and family residential choices, by linking student test score records to student address data, and via address data to family characteristics derived from consumer credit databases. A link to an external source of data will be advantageous from many perspectives: it will allow us at least some ability to track those students who exit North Carolina public schools, for either a non-public alternative or for a public school in another state. In the long run, we expect this enhanced dataset to be rich enough to allow us to estimate a general equilibrium location model incorporating education production with peer effects (Bayer, 2000; Bayer et al. 2002). Until the data are in place to perform this estimation, we will continue to explore additional avenues in our quest to identify the true magnitude of causal peer effects in public schools.

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Table 1: Summary Statistics (N=939,453)

	Mean	Std. Dev.	Min.	Max.
Math score	0.039	0.987	-3.605	3.652
Reading Score	0.035	0.982	-4.021	2.968
Classroom peer groups:				
Average math score of peers (twice lagged)	0.052	0.432	-3.522	2.344
Average reading score of peers (twice lagged)	0.048	0.413	-7.328	2.012
Std. dev. in math score of peers (twice lagged)	0.856	0.247	0.000	8.406
Std. dev. In reading score of peers (twice lagged)	0.864	0.265	0.000	7.797
% Black in class	0.286	0.245	0.000	1.000
% Hispanic in class	0.027	0.048	0.000	1.000
Number of students in class	26.63	24.06	1.000	611.0
Grade peer groups:				
Average math score of peers (twice lagged)	0.045	0.335	-3.079	1.701
Average reading score of peers (twice lagged)	0.042	0.312	-2.152	1.828
Std. dev. in math score of peers (twice lagged)	0.902	0.178	0.000	3.302
Std. dev. In reading score of peers (twice lagged)	0.908	0.195	0.000	3.680
% Black in grade	0.290	0.235	0.000	1.000
% Hispanic in grade	0.027	0.038	0.000	0.486
Parent completed high school	0.443	0.497	0.000	1.000
Parent completed trade/business school	0.044	0.205	0.000	1.000
Parent completed community/tech. College	0.138	0.345	0.000	1.000
Parent completed 4-year college	0.229	0.420	0.000	1.000
Parent completed graduate school	0.057	0.233	0.000	1.000

Table 2: The Effect of Peer Characteristics on Test Scores

	Dependent variable: 5th Grade test score					
	Math Achievement			Reading Achievement		
	Grade	Classroom		Grade	Classroom	
Independent variable	OLS	OLS	Fixed Effects	OLS	OLS	Fixed Effects
Lagged test score	0.7841***	0.7803***	0.7788***	0.7677***	0.7654***	0.7627***
	[0.0073]	[0.0070]	[0.0071]	[0.0090]	[0.0091]	[0.0090]
Average score of peers (twice lagged)	0.0550***	0.0861***	0.0741***	0.0904***	0.0908***	0.0630***
	[0.0129]	[0.0082]	[0.0075]	[0.0095]	[0.0067]	[0.0065]
Std. dev. in scores of peers (twice lagged)	-0.001	0.0228**	0.0336***	-0.0096	0.0099	0.0102*
	[0.0185]	[0.0106]	[0.0092]	[0.0105]	[0.0064]	[0.0061]
% Black in peer group	-0.0024	-0.0151	-0.1327***	0.0360***	0.0252**	-0.0493**
	[0.0196]	[0.0172]	[0.0262]	[0.0126]	[0.0111]	[0.0200]
% Hispanic in peer group	-0.0586	-0.0656	-0.1225**	0.0545	-0.0121	-0.1227***
	[0.0885]	[0.0578]	[0.0519]	[0.0560]	[0.0383]	[0.0386]
%Black*black	0.1076***	0.1149***	0.0323*	0.0346*	0.0271	-0.001
	[0.0261]	[0.0237]	[0.0168]	[0.0193]	[0.0175]	[0.0153]
%Hispanic*hispanic	0.4471**	0.2718*	0.1577	0.5292***	0.3492***	0.3139***
	[0.2010]	[0.1488]	[0.1334]	[0.1483]	[0.1256]	[0.1180]
Grade/Class size	0.0029***	-0.0020***	-0.0009	0.0019***	0.0000	0.0007
	[0.0009]	[0.0007]	[0.0006]	[0.0006]	[0.0005]	[0.0005]
Male	-0.0093***	-0.0077***	-0.0069***	-0.0299***	-0.0287***	-0.0295***
	[0.0023]	[0.0024]	[0.0023]	[0.0026]	[0.0026]	[0.0026]
Black	-0.1508***	-0.1475***	-0.1195***	-0.1469***	-0.1399***	-0.1305***
	[0.0109]	[0.0098]	[0.0076]	[0.0092]	[0.0085]	[0.0076]
Hispanic	-0.0344**	-0.0226*	-0.0100	0.0029	0.0141	0.0126
	[0.0137]	[0.0120]	[0.0112]	[0.0127]	[0.0118]	[0.0115]
Parent completed high school	0.0719***	0.0718***	0.0887***	0.1132***	0.1123***	0.1212***
	[0.0055]	[0.0054]	[0.0048]	[0.0053]	[0.0053]	[0.0052]
Parent completed trade/business school	0.1144***	0.1139***	0.1375***	0.1668***	0.1663***	0.1778***
	[0.0080]	[0.0079]	[0.0072]	[0.0077]	[0.0077]	[0.0078]
Parent completed community/tech. college	0.1414***	0.1395***	0.1633***	0.1918***	0.1893***	0.2023***
	[0.0072]	[0.0070]	[0.0066]	[0.0076]	[0.0076]	[0.0078]
Parent completed 4-year college	0.2293***	0.2232***	0.2555***	0.2683***	0.2640***	0.2824***
	[0.0084]	[0.0080]	[0.0080]	[0.0094]	[0.0092]	[0.0097]
Parent completed graduate school	0.3288***	0.3198***	0.3437***	0.3353***	0.3298***	0.3428***
	[0.0108]	[0.0103]	[0.0103]	[0.0124]	[0.0121]	[0.0127]
R2	0.7109	0.7111	0.734	0.7001	0.7004	0.7086
N	233285	232742	232742	232523	232000	232000

*** denotes a coefficient significant at the 1% level. ** denotes a coefficient significant at the 5% level. * denotes a coefficient significant at the 10% level.

Note: Standard errors reported in parentheses. Peer variables are defined by 5th grade peer group at either the grade level or classroom level. Fixed effects regression controls for 5th grade school. Also control for year and include intercept, not shown. Data obtained from the North Carolina Education Research Data Center's End of Grade Tests data set.

Table 3: Defining Peer Groups at the Grade and Classroom Level

Independent variable	Dependent Variable: 5th grade test score Math	Reading
Lagged test score	0.7797***	0.7651***
	[0.0070]	[0.0091]
Classroom peers:		
Average score of peers (twice lagged)	0.1017***	0.0794***
	[0.0082]	[0.0070]
Std. dev. in scores of peers (twice lagged)	0.0335***	0.0117*
	[0.0103]	[0.0066]
% Black in peer group	-0.1630***	-0.0298
	[0.0321]	[0.0263]
% Hispanic in peer group	-0.1357**	-0.1256***
	[0.0582]	[0.0429]
%Black*black	0.1081**	-0.0462
	[0.0439]	[0.0410]
%Hispanic*hispanic	-0.0302	-0.0082
	[0.2185]	[0.2019]
No. of students in class	-0.0024***	-0.0002
	[0.0007]	[0.0005]
Grade peers:		
Average score of peers (twice lagged)	-0.0390***	0.0186*
	[0.0146]	[0.0098]
Std. dev. in scores of peers (twice lagged)	-0.0249	-0.0154
	[0.0199]	[0.0127]
% Black in peer group	0.1565***	0.0704**
	[0.0368]	[0.0292]
% Hispanic in peer group	0.0895	0.1889***
	[0.1060]	[0.0691]
%Black*black	0.0021	0.0830*
	[0.0497]	[0.0464]
%Hispanic*hispanic	0.4718	0.5140**
	[0.2885]	[0.2427]
No. of students in grade	0.0030***	0.0019***
	[0.0008]	[0.0006]
R2	0.7115	0.7005
N	232743	232003

*** denotes a coefficient significant at the 1% level. ** denotes a coefficient significant at the 5% level. * denotes a coefficient significant at the 10% level.
Note: Standard errors reported in parentheses. Peer variables are defined by 5th grade peer group at either the grade level or classroom level. Controls for parent's education, race, sex, year and the constant are also included but not shown. Data obtained from the North Carolina Education Research Data Center's End of Grade Tests data set.

Table 4: The Lasting Effects of Peer Characteristics on Math Scores

	Dependent variable: End of grade math score			
Independent variable	5th grade	6th grade	7th grade	8th grade
Lagged math score	0.7788***	0.8035***	0.8149***	0.8290***
	[0.0071]	[0.0019]	[0.0021]	[0.0022]
Average score of classmates	0.0741***	0.0346***	0.0322***	0.0350***
(twice lagged)	[0.0075]	[0.0057]	[0.0051]	[0.0049]
Std. dev. in scores of	0.0336***	0.0077	-0.0049	0.0185***
classmates (twice lagged)	[0.0092]	[0.0064]	[0.0056]	[0.0053]
% Black in class	-0.1327***	-0.0768***	-0.0549***	-0.0181
	[0.0262]	[0.0216]	[0.0188]	[0.0178]
% Hispanic in class	-0.1225**	-0.0541	-0.0876**	0.0407
	[0.0519]	[0.0403]	[0.0358]	[0.0355]
%Black*black	0.0323*	0.0343**	-0.0001	0.0037
	[0.0168]	[0.0153]	[0.0150]	[0.0148]
%Hispanic*hispanic	0.1577	0.1433	0.1480	0.2477**
	[0.1334]	[0.1077]	[0.1025]	[0.1098]
No. of students in class	-0.0009	0.0007**	0.0003	-0.0001
	[0.0006]	[0.0003]	[0.0002]	[0.0001]
Male	-0.0069***	-0.0449***	0.0107***	-0.0133***
	[0.0023]	[0.0022]	[0.0022]	[0.0023]
Black	-0.1195***	-0.1146***	-0.1226***	-0.0665***
	[0.0076]	[0.0065]	[0.0062]	[0.0064]
Hispanic	-0.0100	0.0120	-0.0153	0.0101
	[0.0112]	[0.0107]	[0.0110]	[0.0115]
Parent completed	0.0887***	0.0848***	0.0737***	0.0781***
high school	[0.0048]	[0.0045]	[0.0048]	[0.0050]
Parent completed	0.1375***	0.1294***	0.1089***	0.1130***
trade/business school	[0.0072]	[0.0069]	[0.0072]	[0.0076]
Parent completed	0.1633***	0.1559***	0.1299***	0.1358***
community/tech. college	[0.0066]	[0.0052]	[0.0057]	[0.0056]
Parent completed	0.2555***	0.2119***	0.1981***	0.1843***
4-year college	[0.0080]	[0.0054]	[0.0054]	[0.0057]
Parent completed	0.3437***	0.2685***	0.2556***	0.2385***
graduate school	[0.0103]	[0.0071]	[0.0069]	[0.0070]
R2	0.7340	0.7533	0.7651	0.7692
N	232742	240255	224911	211458

*** denotes a coefficient significant at the 1% level. ** denotes a coefficient significant at the 5% level. * denotes a coefficient significant at the 10% level.
Note: Standard errors reported in parentheses. Peer variables are defined by 5th grade classroom peers. Also control for year, an intercept, and 5th grade school fixed effects. Data obtained from the North Carolina Education Research Data Center's End of Grade Tests data set.

Table 5: The Lasting Effects of Peer Characteristics on Reading Scores

Independent variable	Dependent variable: End of grade reading score 5th grade	6th grade	7th grade	8th grade
Lagged reading score	0.7627***	0.7778***	0.7766***	0.7569***
	[0.0090]	[0.0018]	[0.0023]	[0.0021]
Average score of classmates (twice lagged)	0.0630***	0.0453***	0.0489***	0.0577***
	[0.0065]	[0.0054]	[0.0052]	[0.0050]
Std. dev. in scores of classmates (twice lagged)	0.0102*	0.0117**	0.0130**	0.0049
	[0.0061]	[0.0054]	[0.0055]	[0.0055]
% Black in class	-0.0493**	-0.0942***	-0.0178	-0.0776***
	[0.0200]	[0.0175]	[0.0180]	[0.0183]
% Hispanic in class	-0.1227***	-0.0630*	-0.0809**	-0.0133
	[0.0386]	[0.0349]	[0.0348]	[0.0351]
%Black*black	-0.0010	-0.0173	-0.0170	-0.0055
	[0.0153]	[0.0149]	[0.0152]	[0.0155]
%Hispanic*hispanic	0.3139***	0.1697	0.2000*	0.2039
	[0.1180]	[0.1161]	[0.1147]	[0.1259]
No. of students in class	0.0007	0.0008**	0.0005	0.0000
	[0.0005]	[0.0003]	[0.0003]	[0.0001]
Male	-0.0295***	-0.0662***	-0.0354***	-0.0580***
	[0.0026]	[0.0022]	[0.0023]	[0.0025]
Black	-0.1305***	-0.1025***	-0.1201***	-0.1626***
	[0.0076]	[0.0063]	[0.0064]	[0.0065]
Hispanic	0.0126	-0.0030	0.0132	-0.0211*
	[0.0115]	[0.0110]	[0.0116]	[0.0123]
Parent completed high school	0.1212***	0.1041***	0.1137***	0.1245***
	[0.0052]	[0.0046]	[0.0054]	[0.0058]
Parent completed trade/business school	0.1778***	0.1461***	0.1618***	0.1734***
	[0.0078]	[0.0069]	[0.0078]	[0.0082]
Parent completed community/tech. college	0.2023***	0.1877***	0.1843***	0.2067***
	[0.0078]	[0.0054]	[0.0061]	[0.0064]
Parent completed 4-year college	0.2824***	0.2447***	0.2250***	0.2690***
	[0.0097]	[0.0054]	[0.0060]	[0.0063]
Parent completed graduate school	0.3428***	0.2958***	0.2461***	0.3293***
	[0.0127]	[0.0070]	[0.0073]	[0.0075]
R2	0.7086	0.7255	0.7121	0.7047
N	232000	239544	224515	211036

*** denotes a coefficient significant at the 1% level. ** denotes a coefficient significant at the 5% level. * denotes a coefficient significant at the 10% level.
Note: Standard errors reported in parentheses. Peer variables are defined by 5th grade classroom peers. Also control for year, an intercept and 5th grade school fixed effects. Data obtained from the North Carolina Education Research Data Center's End of Grade Tests data set.

Table 6: Summary Statistics by Feeder School

	Feeder=0		Feeder=1	
	Mean	Std. Dev.	Mean	Std. Dev.
Math score	0.036	0.987	0.119	0.982
Reading Score	0.032	0.983	0.125	0.964
Classroom peer groups:				
Average math score of peers (twice lagged)	0.048	0.433	0.141	0.395
Average reading score of peers (twice lagged)	0.044	0.414	0.139	0.395
Std. dev. in math score of peers (twice lagged)	0.857	0.249	0.851	0.188
Std. dev. In reading score of peers (twice lagged)	0.863	0.266	0.871	0.242
% Black in class	0.287	0.247	0.262	0.192
% Hispanic in class	0.027	0.048	0.030	0.045
Number of students in class	26.58	23.86	27.75	28.99
Grade peer groups:				
Average math score of peers (twice lagged)	0.042	0.336	0.134	0.303
Average reading score of peers (twice lagged)	0.039	0.312	0.135	0.289
Std. dev. in math score of peers (twice lagged)	0.902	0.180	0.884	0.113
Std. dev. In reading score of peers (twice lagged)	0.909	0.197	0.904	0.152
% Black in grade	0.291	0.237	0.266	0.180
% Hispanic in grade	0.027	0.038	0.030	0.033
Parent completed high school	0.445	0.497	0.402	0.490
Parent completed trade/business school	0.044	0.204	0.049	0.217
Parent completed community/tech. College	0.138	0.345	0.131	0.337
Parent completed 4-year college	0.227	0.419	0.288	0.453
Parent completed graduate school	0.057	0.232	0.067	0.249
N	906239		33214	

Table 7

	Feeder Schools				Whole Sample	
	Level		First Difference		First Difference	
	Math	Reading	Math	Reading	Math	Reading
Lagged test score	0.8000***	0.7570***				
	[0.0084]	[0.0118]				
Average score of peers (twice lagged)	0.0472***	0.0660***	0.0169	0.0005	0.0110***	0.0037*
	[0.0166]	[0.0130]	[0.0107]	[0.0101]	[0.0023]	[0.0022]
Std. dev. in scores of peers (twice lagged)	0.0456*	0.0075	0.0104	0.0042	0.0028	0.0004
	[0.0261]	[0.0143]	[0.0172]	[0.0121]	[0.0029]	[0.0024]
% Black in peer group	-0.0719	-0.0252	-0.0289	-0.015	-0.0220***	-0.007
	[0.0479]	[0.0320]	[0.0367]	[0.0319]	[0.0084]	[0.0076]
% Hispanic in peer group	0.0936	-0.1001	0.0151	-0.1555**	0.0202	-0.0039
	[0.1164]	[0.0886]	[0.0858]	[0.0769]	[0.0170]	[0.0150]
%Black*black	0.0402	0.023	0.0231	0.0453	0.0193*	0.0096
	[0.0611]	[0.0437]	[0.0566]	[0.0459]	[0.0113]	[0.0108]
%Hispanic*hispanic	0.8885**	0.8902***	-0.2920	-0.1384	-0.0258	-0.0310
	[0.3571]	[0.3110]	[0.3525]	[0.3676]	[0.0746]	[0.0773]
Grade/Class size	-0.0001	0.0002	-0.0003***	0.0000	-0.0001**	-0.0001
	[0.0001]	[0.0002]	[0.0001]	[0.0001]	[0.0001]	[0.0001]
Male	-0.0103*	-0.0445***	-0.0078	-0.0115*	-0.0076***	-0.0082***
	[0.0059]	[0.0060]	[0.0064]	[0.0068]	[0.0013]	[0.0013]
Black	-0.1274***	-0.1450***	0.0135	0.0011	0.0021	-0.0116***
	[0.0216]	[0.0168]	[0.0104]	[0.0090]	[0.0028]	[0.0024]
Hispanic	-0.0751**	-0.0552**	0.0017	0.0369	0.007	0.0166***
	[0.0315]	[0.0273]	[0.0265]	[0.0268]	[0.0057]	[0.0059]
Parent completed high school	0.0589***	0.1109***	-0.0215	0.0072	-0.0056*	0.0115***
	[0.0146]	[0.0152]	[0.0159]	[0.0189]	[0.0031]	[0.0031]
Parent completed trade/business school	0.1125***	0.1419***	0.0089	-0.0199	0.0021	0.0183***
	[0.0211]	[0.0188]	[0.0225]	[0.0232]	[0.0045]	[0.0043]
Parent completed community/tech. college	0.1350***	0.1910***	-0.0065	0.0070	0.0000	0.0177***
	[0.0171]	[0.0168]	[0.0181]	[0.0196]	[0.0036]	[0.0035]
Parent completed 4-year college	0.1974***	0.2531***	0.0043	0.019	0.0086**	0.0164***
	[0.0173]	[0.0171]	[0.0174]	[0.0188]	[0.0037]	[0.0035]
Parent completed graduate school	0.2453***	0.2909***	0.0129	0.0004	0.0280***	0.0175***
	[0.0204]	[0.0209]	[0.0202]	[0.0212]	[0.0045]	[0.0041]
R2	0.7403	0.6978	0.0029	0.0014	0.0007	0.0004
N	31776	31698	28806	28743	849945	847815

*** denotes a coefficient significant at the 1% level. ** denotes a coefficient significant at the 5% level. * denotes a coefficient significant at the 10% level. Note: Standard errors reported in parentheses. Peer variables are defined by 5th grade classroom peers for students attending feeder schools in 5th grade. Also control for year and an intercept. Data obtained from the North Carolina Education Research Data Center's End of Grade Tests. First differences indicate that the independent peer variables are defined by 5th grade peer group characteristic minus 4th grade peer group characteristic. The dependent variable in this case is the difference between achievement score in 5th grade minus achievement score in 4th.