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EdWorkingPaper No. 19-63

The Hidden Costs of Teacher Turnover

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VERSION: May 2019

Suggested citation: Sorensen, L.C. & Ladd, H.F. (2019). The Hidden Costs of Teacher Turnover (EdWorkingPaper No.19-63). Retrieved from Annenberg Institute at Brown University: http://edworkingpapers.com/ai19-63

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This work was supported by the National Center for Analysis of Longitudinal Data in Education Research (CALDER). We are extremely grateful to Alisa Chapman at UNC-Chapel Hill for numerous conversations and insights that guided the early development of this paper. We also appreciate comments received from participants at the Association of Education Finance and Policy (AEFP) session on Teacher Working Conditions and the Annual CALDER Conference.

Abstract

High teacher turnover imposes numerous costs on the schools and districts from which teachers depart. This study asks how schools respond to spells of high teacher turnover, and assesses organizational and human capital losses in terms of the changing composition of the teacher pool. Our analysis uses more than two decades of linked administrative data on math and ELA teachers at middle schools in North Carolina to determine school responses to turnover across different policy environments and macroeconomic climates. We find that, even after accounting for school contexts and trends, turnover has marked, and lasting, negative consequences for teacher quality and student achievement. Our results highlight the need for heightened policy attention to issues of teacher retention and working conditions.

Keywords: Teacher turnover, teacher attrition, teacher effectiveness, middle school

Introduction

Much has been written about high rates of teacher turnover in K-12 schools (Carver-Thomas & Darling-Hammond, 2017). Turnover refers to the change in teachers from one year to the next in a particular school setting. Although some turnover of staff is natural, desirable, and occurs in all occupations, high rates of turnover are often of particular concern in the field of K-12 education. High turnover can contribute, for example, to teacher shortages if it reflects the departure of teachers from the profession or from schools in specific locations or subject areas as teachers move among schools or districts. In addition, a high turnover of teachers in a particular school may have adverse impacts on outcomes for the school's students (Ronfeldt, Loeb, & Wyckoff, 2013; Hanushek, Rivkin, & Schieman, 2016). Student outcomes will be adversely affected, for example, if turnover leads to a lower quality mix of teachers, loss of coherence within the school's educational program, or the inability of the school to replace all the teachers who leave (Ingersoll, 2001). Finally, teacher turnover inevitably imposes financial human resource costs on schools or local school districts because of the need to hire replacement teachers.

In this paper, we do not directly examine the relationship of teacher turnover to the broader issue of teacher shortages (Sutcher, Darling-Hammond, & Carver-Thomas, 2016). That topic would require attention to the movement of teachers out of the profession and not just out of particular schools, and would require careful analyses of the pipeline of new teachers to the profession. Nor do we specifically examine the underlying causes and types of teacher departure from schools (Ladd, 2011).

Instead, we are interested in how schools respond to the loss of teachers, especially teachers of core subjects. Such responses are potentially relevant not only for student outcomes and the smooth operation of the school in the immediate period (including for student achievement about which we provide some information at the end of the paper), but also potentially for subsequent periods. A better understanding of the strategies that schools use in response to sustained periods of teacher turnover is directly relevant for policy.

Specifically, we provide new empirical evidence on how individual schools respond to teacher turnover, and on how that response differs across school contexts. We use school-level data from North Carolina on math and English language arts (ELA) teachers at the middle school level. A school may respond to the loss of teachers in a particular year or subject by increasing class sizes, either as a chosen strategy or because of its inability to hire replacement teachers. Alternatively, a school may respond by replacing the teachers who leave with other teachers, either from within the school or from outside the school. If the replacement teachers are more qualified than the ones they replace either in terms of their instructional effectiveness or their ability to work with others toward the institutional mission of the school or both, the change could be beneficial for students. In contrast, if the replacement teachers are less qualified than the ones they replace along either or both dimensions, the change will be detrimental to student outcomes and to the smooth operation of the school.

This study is grounded in the ongoing debate among researchers about the extent to which teacher turnover is likely to strengthen or weaken the mix of teachers within individual schools. As we discuss below in section 2, much of the existing research on this topic focuses on the quality of the teachers who leave, with at most limited attention to the quality of the replacement teachers. Our strategy is to explore the net effect of departures and new arrivals by estimating how the turnover of core teachers at the middle school level affects the number and mix of teachers in the school the following year.

We find little evidence that schools respond to turnover of middle school math and ELA teachers by increasing class sizes, a finding that may reflect in part North Carolina's system of funding teaching slots. At the same time, we consistently find that the loss of math or ELA teachers at the school level leads to larger shares of teachers with limited experience or who are lateral entrants or have provisional licenses. We find suggestive evidence that turnover also leads to higher shares of teachers that are not certified in the specified subject, and of teachers with lower average licensure test scores. All four of these characteristics typically signify less effectiveness in the classroom, and may signify a lower ability to contribute to the coherence of the school's mission. Greater shares of the teachers with these characteristics may also contribute to higher future turnover rates, given that departure rates for members of these categories of teachers tend to be high. Moreover, we find that the adverse effects of turnover rise linearly with the rate of turnover and are higher in high poverty schools and higher during periods of student enrollment growth. The bottom line is that high rates of teacher turnover are costly in terms of their impacts on the mix of teachers in a school, in addition to the direct financial burdens turnover imposes on the system (Barnes, Crowe, & Schaefer, 2007).

The next section provides the context for this study by summarizing some of the relevant literature. The following section describes the data and our methodology. In the final two sections, we present the results and discuss their policy implications.

Context and Literature Review

How teacher turnover will affect the composition of the teachers in a school depends in part on the quality of the teachers who leave a school relative to those who remain. In addition, though, it also depends on the quality of the replacement teachers. With a few exceptions, most of the existing empirical research on teacher attrition at the school level examines the first issue alone, with little or no attention to the second.

A growing consensus among many empirical researchers who rely on value added models of teacher quality is that the teachers who leave a school are less able than those who remain (Boyd et al, 2011; Goldhaber et al, 2007; Hanushek & Rivkin, 2010). In addition, some studies show that the relative effectiveness of stayers as compared to leavers may be highest in schools with large proportions of low achieving students (Clotfelter, Ladd, Glennie, & Vigdor, 2008; Hanushek et al, 2007).

There are reasons, however, to question value-added measures of teacher effectiveness (Hendricks, 2016). A value-added measure refers to how effective a teacher is in raising the test scores of her students in core areas, such as math and reading, for which students take standardized tests on an annual basis. Although many researchers argue that such measures of teacher quality are preferred to measures based on proxies for teacher ability, such as teacher licensure test score, or the selectivity of the colleges that teachers attended, the value-added approach is subject to a number of econometric limitations that lessen its usefulness for our purpose.

In addition to restricting the analysis to teachers of tested subjects (which is not a problem for the present study), it works best for teachers who have been teaching long enough to generate sufficient student test scores. In addition, many value-added models fail to control fully for unobserved aspects of school contexts that may confound the patterns because of the correlation between positive school contexts and the willingness of teachers to remain in a school. As demonstrated by Feng and Sass (2012) and Krief (2007), when school or student fixed effects are included in the estimated models, the pattern of higher attrition among the less effective teachers is less evident. A further limitation is the frequent failure of many such models to adjust fully for the relationship between teacher effectiveness and years of teacher experience (Ladd & Sorensen, 2017; Clotfelter, Ladd, & Vigdor, 2007; Wiswall, 2013; Papay & Kraft, 2016).

An alternative approach would be to use teacher licensure scores as a proxy for teacher quality. One advantage of this approach is that such scores represent teacher ability at the time of entry to the profession, and, hence are not contaminated by any gains in effectiveness that occur with experience. Based on this measure, Hendricks (2016) documents for a longitudinal sample from Texas that among teachers with only one year of experience, low quality teachers leave at higher rates than their higher ability counterparts. In contrast to much of the other literature, however, he finds that once teachers have a few years of experience, those with higher licensure scores are more likely to leave a district or the profession than are their peers with lower licensure scores.

This pattern of attrition among non-novice teachers would support the case for policies specifically designed to retain high ability teachers (that is, those with high licensure test scores). The goal would be to give them an opportunity to become more effective as they continue to gain experience and to make productive use of the training and experience they already have. In contrast, the attrition pattern that Hendricks finds for the first-year teachers, as well the comparable patterns that emerge from many of the value-added based attrition studies, suggests a different approach. Namely, it suggests that policy makers would do well to encourage low performing teachers to depart – provided, however, that they can be replaced with higher quality teachers (Hanushek et al, 2016). Yet, surprisingly few studies have been able to shed much light on the quality of replacements. Indeed, within the context of value-added models of teacher effectiveness, it is often difficult to calculate the effectiveness of replacement teachers given that many of them are likely to be new to the profession or to the district, and therefore have too few student test score results to analyze.

One of the most interesting, albeit non-generalizable, pieces of evidence for the potential for teacher turnover to improve the quality of the teacher work force comes from Washington DC. As part of its performance-assessment and incentive system, called IMPACT, the district introduced a formal evaluation system which then led to the firing of the lowest performing teachers and the sanctioning of other teachers, some of whom then voluntarily left. A careful study of the first year of the program showed that the district was able to replace the teachers who left as part of the program with more effective teachers (Adnot et al, 2017), implying that the teacher turnover induced by the program generated positive outcomes. The positive results are not directly generalizable to other districts, however, because as part of its reform strategy, the district offered a substantial increase in teacher salaries and also benefitted from a large supply of potential teachers in the area. Without that context, the results might not have been so positive.

The main contribution of the present study is its analysis of the net effect of turnover, defined as how the composition of teachers changes within schools in response to the departure of existing teachers. A second contribution is the analysis of how the effects of turnover vary across time periods characterized by different rates of student enrollment growth or decline, and strong and weak macroeconomic climates. A third contribution is that it confirms the findings of earlier studies (Ronfeldt et al 2013 and Hanushek et al, 2016) that show that teacher turnover reduces student test scores.

Data and Methods

We use longitudinal administrative data from the North Carolina Department of Public Instruction, accessed through the North Carolina Education Research Data Center. With this information, we can track individual teachers matched to specific classrooms and schools for a time period of twenty-two years – from the 1994-1995 school year to the 2015-2016 school year. This dataset contains a number of files at the student, teacher, classroom, and school levels from which we extract relevant measures to create a final merged dataset.

We restrict the sample to teachers of math and English/Language Arts in the middle school grades of six through eight. Within a school, the teachers of math (or ELA) in these grades are likely to teach similar types of material, may work together to offer a coherent curriculum, and, to some extent, may be interchangeable. Importantly, the departure of one of them is likely to affect the others. Turnover of teachers within these clearly-defined subject groups, which conveniently also correspond to student tested subjects, should allow clear interpretation of the effects of turnover. We further restrict the sample to teachers of only year-long courses that do not combine multiple subjects, and to cohorts with at least three teachers teaching that subject in the school that year.

The dataset begins with a single observation for every math or ELA classroom for each year, which generates approximately 600,000 total observations, or around 300,000 per subject. Each classroom is matched to its primary instructor. We merge in instructor-specific information on their licensure area code, type of teaching certification, teacher licensure exam scores (Praxis), and years of experience. We also merge in information on students, including total number of students in the classroom, and counts by race and gender. We collect information specific to each school, including the geographic location and proportion of students eligible for free lunch.

We specify five outcome measures, corresponding to types of school responses to teacher turnover. We test for three categories of potential responses: (1) changing the average qualifications of teachers through hiring or replacement; (2) shifting teachers within the school to subject areas that are not their primary area; and/or (3) combining class sections and increasing class size. Corresponding to hypothesis 1, we observe the proportion of teachers with three or fewer years of experience; the proportion of teachers with lateral or provisional licenses; and the average teacher licensure exam score measured in standard deviations. Corresponding to hypothesis 2, we also observe the proportion of teachers that are not certified in the subject they are teaching. And finally, corresponding to hypothesis 3, we observe average class size. All outcome measures are calculated at the subject, school, and year level. This means that, in contrast to earlier studies on the topic, we are not examining characteristics of teachers leaving, or of teachers coming in, but rather the aggregate net effects of turnover on the full group of math and ELA teachers at the school.

These measured teacher outcomes represent important facets of school quality. Teachers with less experience in the classroom are on average much less effective at improving student outcomes (Ladd & Sorensen, 2017; Papay & Kraft, 2015; Wiswall, 2013). Teachers who enter the profession through lateral entry or a provisional license also exhibit weaker teaching performance (Clotfelter, Ladd, & Vigdor, 2010; Henry et al., 2013), and are more likely to subsequently leave teaching (Redding & Henry, 2018; Redding & Smith, 2016). Although the merit of using teacher credentials to proxy for teacher quality is debated (Goldhaber, 2008; Kane, Rockoff, & Staiger, 2008), licensure exam scores and certification in the taught subject are also generally correlated with enhanced student learning (Clotfelter, Ladd, & Vigdor, 2010; Goldhaber, 2007). Finally, smaller class sizes can yield lasting benefits for students (e.g. Angrist

& Lavy, 1999; Krueger, 1999). If high teacher turnover were either to negatively shift the proportion of highly-qualified teachers working in the school or to increase average class size, it would likely be to the detriment of education quality. With our supplemental analysis of student test scores, we directly test whether student learning suffers as a consequence of periods of sustained teacher turnover.

The teacher turnover rate is our primary independent variable of interest. Because we are exploring the impacts of teacher departure on the teachers of related subjects at that same school, we calculate teacher turnover at the school, subject, and year level. This contrasts with Ronfeldt, Loeb, and Wyckoff (2013) who define both teacher attrition and teacher entry at the grade level. The use of school (and subject) level measures makes sense in the context of middle school math and ELA because teachers will regularly teach across multiple grade levels and/or switch back and forth across grades. At school j in subject s, turnover is calculated as the number of teachers who left between school year $t-1$ and school year t divided by the total number of teachers in that subject and school at year $t-1$:

$$Turnover_{jst} = \frac{Teachers\ Leaving_{js,t-1}}{Teachers_{js,t-1}}$$

This variable incorporates no information on why a teacher leaves the school, and makes no distinction between a teacher leaving the profession or just moving to a different school. As noted by Papay, Bacher-Hicks, Page, and Marinell (2017), counting teachers who leave a school temporarily and return in a later year in the turnover measure leads to misleadingly high turnover rates. This type of departure could represent personal leave or lapses in administrative records, and is likely to be less disruptive to schools than teachers leaving for good. Therefore, we exclude such temporary leavers from the turnover count.

Holme, Jabbar, Germain, and Dinning (2017) emphasize the importance of measuring long-term instability of schools with longitudinal turnover data for understanding the cumulative effects of turnover on schools. Accordingly, we calculate a three-year running average of teacher turnover for each subject within each school:

$$Average\ Turnover_{jst} = \frac{1}{3}\sum_{k=t-2}^{t} \frac{Teachers\ Leaving_{js,k-1}}{Teachers_{js,k-1}}$$

We anticipate that single year shocks of increased turnover may operate differently than sustained periods of high turnover, and so generally prefer this three-year average measure. Nonetheless, we also examine alternative dynamic specifications of turnover, by incorporating multiple lagged annual turnover rates. (See Appendix Figure A2). All of our turnover measures would include both mid-year and end-of-year departure events (Redding & Henry, 2018). Based on the conclusions of Henry and Redding's study of turnover in North Carolina schools, we would expect particularly detrimental effects of mid-year teacher departure for student learning, but not necessarily for average teacher qualifications (Henry & Redding, 2018).

Since both the independent and dependent variables of interest vary at the school-subject rather than classroom level, we collapse the student- and classroom-level dataset to one observation for all math classrooms and one observation for all ELA classrooms for each year within each school. For most analyses, we also exclude the 1995, 1996, and 1997 school years since average turnover from the prior three years can only be calculated from the 1998 school year to the 2016 school year. This exclusion still allows a nineteen-year panel of data and results in a new collapsed sample size of 15,616 observations, or 7,808 for each subject.[1]

Table 1 provides summary statistics for this resulting analytical dataset. One can note that, on average across math and ELA middle school classrooms, 21.3 percent of teachers have three or fewer years of experience, 12.2 percent have lateral or provisional licenses, and 29.3

percent are teaching out of their subject of certification. Licensure exam scores of middle school math and ELA teachers are on average 0.13 standard deviations below the mean of all teachers.[2] The average class size for this sample is 19.9 students.

Listed student characteristics for our sample match the North Carolina middle school population during this time period.[3] In recent years, the Hispanic student population and the number of students eligible for free lunch have increased, suggesting that we need to control for demographic changes in the student population in our estimating models. Certain measures, including student special education placement, and limited English proficiency status, are only available for select years in the dataset, and so we cannot include them in the final analysis. Of particular interest to this study, the average three-year teacher turnover rate across math and ELA is 25.7 percent, with a standard deviation of 12.9 percent. For the average middle school, this translates into approximately 2.4 math teachers and 2.9 ELA teachers departing each year.

Trends and Patterns of Turnover in North Carolina Schools

We begin by describing trends in teacher attrition and mobility in North Carolina over the course of the past two decades. As shown in Figure 1, the average three-year turnover rate of middle school math and ELA teachers of around 26 percent masks significant variation over our analysis period. The figure shows that the average school teacher turnover rate fluctuated between 20 and 30 percent, with a clear drop in teacher turnover during the economic recession (years 2008 to 2012). Since the recession, turnover rates have steadily climbed again, reaching their peak in the 2016 school year. Although this graph represents only middle school teachers of math and ELA subjects, the trends roughly approximate those across the entire teacher sample of North Carolina.

Prior research documents that teacher turnover is not distributed evenly across school settings (Carver-Thomas & Darling Hammond, 2017). This is certainly the case in our sample. Figure 2 shows how average turnover rates vary by school poverty level and school geographic location. We classify schools into four quartile categories of student poverty based on a school's median proportion of students eligible for free lunch across the full time period. We classify schools into an urbanicity index of (1) rural; (2) town; (3) suburban; and (4) city based on the school's district urban-centric locale code from the Common Core of Data (CCD).[4] Across all geographic regions, schools with more concentrated student poverty have higher yearly teacher turnover. Likewise, schools located in urban regions experience higher teacher turnover than those in rural regions, confirming that urban areas experience more within-district churning of teachers (Atteberry, Loeb, & Wyckoff, 2017; Lankford, Loeb, & Wyckoff, 2002). This pattern makes sense given that teachers are more likely to leave schools when there are many neighboring school options or more employment opportunities outside of teaching. To compare the extremes, an urban school with high levels of student poverty faces an average turnover rate of over 34 percent versus just above 20 percent in low-poverty rural schools.

To the degree that teacher departure negatively affects school environments and instructional quality, such costs will accrue disproportionately to schools serving economically disadvantaged students, with detrimental effects recurring continuously over time.

Empirical Strategy

To estimate the causal effects of subject-specific teacher turnover on the composition of teachers and average classroom characteristics at the school level, we must be alert to four primary empirical concerns. First, school observable and unobservable characteristics may contribute both to higher teacher turnover and to the composition of the teacher workforce, creating potential omitted variable bias. We anticipate that such mechanisms would lead the estimated effects of turnover to be upward biased in a naïve OLS model. That is likely to be the case whenever a school characteristic that is associated with poor working conditions generates high rates of teacher departure and also makes it difficult for the school to attract high quality replacements. Second, even if we account for the relevant school characteristics, internal or external "shocks" to schools during the observed time period may generate other biases. For example, the arrival of a new principal at a school may induce many teachers to leave and also have other consequences for the school environment and instructional effectiveness. The third and fourth concerns arise in the context of choosing the appropriate parametric form and lag structure for estimating effects of teacher turnover. Failure to capture nonlinearities in how the turnover rate shapes school outcomes, or failure to consider the dynamic impacts of periods of high turnover over time, could limit the usefulness of our findings.

In this section, we detail the empirical approach, with attention to these four empirical challenges. Our first model (Model 1) estimates the effect of the three-year rate of teacher turnover on school-subject-level outcomes using within-school variation in turnover levels over time. In this way, we can account for any observable or unobservable time-invariant school differences that could affect both turnover levels and dependent variables:

$$Y_{jst} = \beta_1 \overline{Turnover}_{jst} + \beta_2 X_{jst} + \sigma_s + \gamma_j + \delta_t + \varepsilon_{jst} \quad (1)$$

In this equation, Y_{jst} is the outcome measured at school j in subject s during academic year t. $\overline{Turnover}_{jst}$ is the three-year running average of the school-subject specific proportion of teachers who left from the prior year (as defined earlier in the data section); X_{jst} is a vector of time-varying characteristics of the students enrolled in subject s classes; σ_s is a subject indicator equaling one for math, zero for ELA; and γ_j and δ_t are school and year fixed effects.

By including school and year fixed effects, we account for any time-invariant characteristics of schools and any statewide time-specific shocks that would affect all schools. The effect of turnover is therefore identified using the within-school variation in the levels of recent teacher turnover from year to year. The estimated β_1 coefficient has a specific interpretation – the net effect of increasing teacher turnover from 0 percent to 100 percent on the composition of teachers (or classrooms) in that subject in the following year. For example, a coefficient estimate of 0.2 on the turnover measure for the "proportion of teachers with zero to three years of experience" outcome implies that increasing teacher turnover by 100 percentage points would increase the percent of novice teachers for that school and subject by 20 percentage points. One can interpolate from such estimates to predict how smaller (and more realistic) magnitude changes in teacher turnover would affect the school. All standard errors are clustered at the school level.

We develop an alternative model (Model 2) to address the second empirical concern, namely that school-specific time trends or shocks could bias estimated effects of teacher turnover. This second approach exploits the fact that each school-year observation in our sample contains two separate teacher turnover measures: one for math teachers at that school, and one for ELA teachers. Because of this, we can add school-by-year interaction term fixed effects and still have variation in turnover from differential turnover rates across subjects within a single year in the same school. For example, if a school loses several math teachers in year t but none of its r ELA teachers, this model compares the difference in changes in teacher/classroom characteristics for the subject with relatively higher turnover to those for the subject with relatively lower turnover. In this alternative model, the outcome of interest is once again a function of turnover as follows:

$$Y_{jst} = \beta_1 Turnover_{jst} + \beta_2 X_{jst} + \sigma_s + \gamma_j + \delta_t + (\gamma_j \times \delta_t) + \varepsilon_{jst} \quad (2)$$

This equation is identical to Model 1 with the addition of school-by-year fixed effects $(\gamma_j \times \delta_t)$ $which$ account for any contemporaneous trends or events at the school level. Once again, we cluster standard errors by school.

The identifying assumptions for the overall empirical approach are reasonable. Model 1 requires changes in teacher turnover across years to be exogenous to unobservable school-specific time-varying factors. Model 2 requires teacher turnover shocks in one subject to not affect teachers in a different subject. To the extent that there were spillovers in turnover effects across subjects, our overall estimates would be attenuated. Together these estimation strategies are capable of constructing a causal narrative of how schools respond to sustained periods of teacher departure.

Findings

Table 2 shows our main findings about how the departure of teachers affects the schools they leave behind. Each set of two columns represents an outcome of interest, and within that outcome the first column provides estimates from Model 1 (with school and year fixed effects), and the second column estimates from Model 2 (with school-by-year fixed effects). The predictor variable of interest is specified as the average turnover rate from the prior three school years, which ranges from zero to one. Therefore, each coefficient represents the estimated effect of increasing teacher turnover from zero percent to one hundred percent, which is outside the normal range of year to year changes in average turnover rates. In the text, we translate them as appropriate to reflect more reasonable changes.

As shown in columns 1 and 2, we find, not surprisingly, that teacher turnover increases the proportion of teachers with three or fewer years of experience in the school, and that the estimate is statistically significant. The estimated coefficient on the turnover rate of 0.390 ($p<0.01$) in Model 1, represents a 39.0 percentage point increase in the proportion of novice teachers. By calculation, a more moderate increase in average teacher turnover of 10 percentage points would increase the proportion of novice teachers at that school by 3.9 percentage points, from a baseline average of 21.3 percent. Model 2 confirms the findings from Model 1 with a coefficient of 0.346 ($p<0.01$). In addition, as shown in columns 3 and 4, higher teacher turnover rates also significantly increase the proportions of teachers with lateral or provisional licenses (coefficients = 0.146 and 0.154). A 10-percentage point increase in teacher turnover would raise the proportion of teachers with either lateral or provisional licenses by 1.5 percentage points, from a baseline average of 12.2 percent. These effects on the shares of novice teachers and teachers with lateral or provisional licenses represent substantive – and educationally undesirable – changes in the overall composition of teachers working at a school.

The patterns in Columns 5 through 8, which indicate how teacher turnover affects average teacher licensure exam scores, measured in standard deviation units, and the proportion of teachers teaching outside their subject of certification, are somewhat less consistent. The turnover rate has a significant effect on average teacher licensure exam scores in model 1, with a coefficient of -0.071 ($p<0.1$). The point estimate is still negative in model 2, although statistically insignificant. The model 1 estimate suggests that a 10-percentage point increase in turnover would generate a loss of 0.01 standard deviations of teacher licensure exam scores. The estimated effect on the proportions of teachers teaching outside their areas of certification are 0.019 (not significant) in model 1 (column 7) and 0.083 ($p<0.01$) in model 2 (column 8). The latter coefficient implies that a 10-percentage point rise in teacher turnover increases the proportion of teachers teaching out of subject by about 0.8 percentage points. Relative to the average of 29.3 percent of teachers teaching out-of-subject, this is a modest effect size, but still relevant as partial evidence of disruption to the instructional environment within a school.

The final regression models estimate the effects of teacher turnover on average class size within a particular school and subject, presented in Table 3 columns 9 and 10. We uncover a small and only marginally significant effect of teacher turnover on average class size in model 1 (coefficient = 0.573; $p<0.1$), but not in model 2 (coefficient = -0.022). These results suggest that when middle schools in North Carolina lose math or ELA teachers, they are likely able to replace those teachers, albeit with teachers with weaker qualifications as indicated in the prior columns, and do not often combine class sections or operate without teachers in certain subjects for extended periods of time. This weak or null finding with respect to class size is not surprising given that math and ELA are core subjects with state end of grade tests, and the state has maximum course size requirements.

The following sections report estimated impacts of heightened teacher turnover within particular school contexts or time periods. These comparisons provide information regarding when and where one should expect turnover to cause the greatest harm to schools. From this point forward, we present only estimates from the preferred model 1 specification since the two models produce consistent results.

Diffferential Effects by School Characteristics

As described in the descriptive trends and patterns of turnover section, and documented in Figure 2, schools with high concentrations of student poverty are more likely to experience high teacher attrition on a regular basis than lower poverty schools. Here, we examine whether any given rate of teacher turnover has differential effects for schools with more concentrated student poverty. Table 3 shows the effects of three-year average teacher turnover on the five outcomes of interest, adding an interaction term of (Turnover x High Poverty). School poverty levels, as before, are classified into quartiles using the proportion of students eligible for free lunch. A high poverty school is then defined as a school in the top quartile of student poverty.

Row 1 of Table 3 indicates that in schools in the bottom three quartiles of student poverty, increases in the three-year average teacher turnover increase the proportion of novice teachers (coef = 0.389, $p<0.01$); increase the proportion of teachers with lateral entry or provisional licenses (coef = 0.130, $p<0.01$); decrease average teacher licensure exam scores (coef = -0.079, $p<0.1$), and may slightly raise average class size (coef = 0.656; $p<0.1$). Only for the proportion of teachers with lateral entry or provisional licenses, however, do we find larger effects in the highest poverty schools. In those schools, the effects are larger by 6.3 percentage points ($p<0.01$), for a total effect size of 19.2 percentage points. Since schools serving high poverty student populations already experience above average turnover rates, these differential impacts are of particular concern.

Tests for several other possible sources of heterogeneity in effects showed similar, or non-significant differences (Results are available in Appendix Tables A1, A2, and A3). Dividing schools by levels of their baseline student performance we find, analogously to the by-school-poverty results, that increased teacher turnover led to higher increases in lateral entry teachers and teachers with provisional licenses in low-performing schools than it did in high- or mid-performing schools. We also hypothesized that school geography may be an important source of heterogeneity, either by urban/rural status, or by distance to nearest teacher preparation program (TPP) – which could serve as a proxy for the strength of supply of new teachers to the profession. Surprisingly, we find no differences in effects of turnover between urban and rural schools, or between schools that are geographically close to TPPs and those that are further away. Overall, these models confirm that turnover has adverse impacts on the composition of teachers across many different school contexts.

Effects of Turnover by Time Period

We have already documented that teacher turnover rates of math and ELA teachers varied over time, with a big drop during the recession and subsequent rise since 2012 (see Figure 1). Here we explore the extent to which turnover rates differentially affected the mix of a school's math and ELA teachers over time. One might expect, for example, that teacher turnover might have had smaller adverse effects on a school's mix of teachers during the recession when turnover rates were low and declining than when they were higher and rising. To that end, we divide the sample period into a pre-recession period of 1996 to 2008, a recession period of 2009-2012, and a post-recession period of 2013-2016.

We begin by describing the trends that might have a bearing on the estimated effects of turnover. Figure 3 indicates that the number of middle school students increased quite steadily from 1996 to 2003, declined between 2005 and 2009, and then increased through the present. The rapid student enrollment growth from 1996 to 2003 certainly affected the overall demand for teachers, and so we may expect the harmful impacts of teacher departure to be more pronounced during this earliest period. The number of associated math and ELA teachers grew in parallel with student enrollment growth in this period, but did not keep pace during more recent years (see Figure 3). One result was an increase in class size from an average of 19.0 in the pre-recession period, to 20.6 in 2009-2012, to 21.2 from 2013-2016 (See Table 5).[5]

Table 5 also documents trends in the qualifications of teachers teaching middle school math and ELA over the designated time periods, showing a striking decline in the proportion of novice teachers and a slight increase in the proportion of teachers who are lateral entry or who have provisional licenses. A more detailed analysis of year-to-year differences shows that the period from about 2005 to 2012 featured the most significant decline in the average qualifications of middle school math and ELA teachers. This decline in average qualifications corresponds to a decline in teacher salaries during this period. In 1999, the average teacher salary was close to the national average, and higher than the averages in the neighboring states of South Carolina, Tennessee and Virginia. By 2009, however, teacher salaries in North Carolina had fallen to about 15 percent below the national average and even farther by 2011, when, for the first time in 50 years, North Carolina's average salary was below that of all three border states. This decline in salaries may well account, at least in part, for the difficulties that districts had in hiring teachers with strong qualifications during this period.

By themselves, however, these trends do not answer the question of whether a specified rate of teacher turnover had larger adverse effects on teacher qualifications at some points during the study period than others. To explore that question, we estimate models in which we interact the turnover rate with indicator variables for the time periods and test for statistically significant different effects by period. The results shown in Table 5 are based on equations that are comparable to our basic models for each of the separate dependent variables, but also include indicator variables for the specific periods (coefficients not reported) and the turnover rate interacted with the 2009-2012 period and the 2013-2016 period. The first row of coefficients are the estimated effects of turnover during the period 1996-2008. During this pre-recession period, turnover led to higher proportions of teachers with 0-3 years of experience or who were lateral entrants, and led to drops in average licensure exam scores (but again no effect on class size). The large magnitude of turnover effects during this base time period may in part reflect the contemporaneous rapid student enrollment growth (see Figure 3), which would put pressure on schools to not only replace existing teachers but hire new ones. We hypothesize this heightened state-wide demand for teachers could make finding ones with sufficient qualifications more challenging.

The second row of Table 5 indicates that the effects on two of these measures were smaller during the recessionary period of 2009-2012. In particular, during that period, schools responded to teacher turnover by relying less on lateral entry or provisional teachers than during the prior years and less on teachers teaching out of subject. The drop in overall turnover rates brought on by the recession (see Figure 1) likely contribute to these dampened effects. Even during this period however, the net effect (calculated by adding the coefficients in the first two rows) of turnover during the recession was to increase the proportions of novice teachers and lateral entry/provisional teachers. During the 2013-2016 period, turnover had somewhat smaller average effects than during the initial period on the proportions of novice teachers – a finding that is consistent with the reduced overall reliance on inexperience math and ELA middle school teachers between 2013 and 2016, as shown in Table 5.

In sum, during the economic recession, teacher turnover dropped by nearly six percentage points and resulted in somewhat smaller adverse effects on the mix of middle school math and ELA teachers relative to the other two periods. However, the recession clearly does not account for the overall adverse effects reported in earlier sections of this paper.[6]

Robustness Tests

We perform several robustness tests to better understand the validity and/or limitations of our empirical models. First, we note that teachers with lateral and provisional licenses represent a diverse group of teachers. A portion of these teachers without formal licenses in North Carolina enter teaching through the Teach for America (TFA) program. Whereas lateral entry and provisionally-licensed teachers are typically less effective than fully-licensed teachers, Teach for America teachers may be more effective in the classroom compared to other teachers with their same levels of experience (e.g. Xu, Hannaway, & Taylor, 2011). For this reason, it is important to tease out whether our estimated turnover effects are driven by increased TFA teacher placement, or by an increase in other supply sources of teachers. Appendix Table A4 presents results replicated from all primary models in Table 2, but with the sample restricted to only districts for which less than 1 percent of teachers are TFA.[7] For each outcome, the coefficients on turnover are nearly identical to those in the results from the full sample of school districts, and in some cases larger in magnitude.

Second, our primary estimates of the effects of teacher turnover rely on three-year moving averages of turnover. This approach reflects an assumption that three-year average turnover will better reflect how cumulative teacher departures affect school environments than one year turnover rates. We test directly through a distributed lag model how the one-year turnover rates from the year prior, from two years prior, and from three years prior, affect teacher characteristics in the current year. Across the two outcome measures with largest overall effects – proportion of novice teachers and proportion of teachers with lateral/provisional licenses – turnover from the preceding year has the largest effect on these indicators, with effect sizes shrinking each additional year prior (but not to zero). Results from this analysis are presented graphically in Appendix Figure A2.

Finally, one may wonder whether there may be a threshold of the turnover rate under which turnover is not particularly harmful, or perhaps may even be beneficial to schools. We estimate alternative models for the proportion of novice teachers and proportion of laterally/provisionally-licensed teachers outcome as a function of quintiles of teacher turnover to investigate the potential for nonlinearities. The graphical results in Appendix Figure A3 illustrate that in fact the relation between turnover and the composition of teachers is fairly linear across the distribution.

Effects of Turnover on Student Achievement

We have claimed that changes in the average qualifications of teachers in a school resulting from high turnover could be detrimental to student learning. Given our data linking student records to specific teachers and schools, we can test this claim directly. As with the teacher qualification outcome measures, we calculate averages of student achievement for each school-year-subject unit. Table 4 presents model 1 estimates from a regression of average student achievement on the three-year turnover rate (again with school fixed effects and time-varying controls). In column 1 we show that a 100 percentage-point increase in subject-specific teacher turnover decreases test scores in that subject by 0.154 standard deviations ($p<0.01$). A more moderate 10 percentage-point increase in turnover would decrease test scores by 0.015 standard deviations. When we separate out results by average reading test scores regressed on ELA teacher turnover, and average math test scores regressed on math teacher turnover, a similar pattern emerges – though more pronounced in math. A 100 percentage-point increase in turnover leads to reductions of 0.129 standard deviations in reading performance and 0.167 standard deviations in math performance, both statistically significant at the 0.01 level.

In short, we confirm that periods of high turnover have an adverse effect on student academic outcomes. It is tricky to compare directly the magnitude of these effect sizes with prior studies given our use of a three-year average subject-specific turnover measure instead of a one-year grade-specific turnover measure. To the extent that the two turnover measures are comparable, however, it appears that our estimated test score effects are nearly double those found in Ronfeldt, Loeb, and Wyckoff (2013). The changing composition of teachers following turnover events stands out as a likely mechanism of such effects, although others are certainly possible.

Concluding Discussion

This study confirms that a high rate of teacher turnover at the school level raises significant policy concerns. Our analysis differs from that of other researchers by drawing attention to how the departure of teachers from a school adversely affects the composition of the school's teachers in subsequent years. Specifically, we focus neither on those who leave a school nor on those who arrive, but rather on the net effect of the two types of flows. In particular, we document that the turnover of teachers in math and ELA classes in North Carolina middle schools from the late 1990s to 2016 increased a school's share of math and ELA teachers with low levels of experience and without full licensure in subsequent years, with the largest effects in high poverty schools. We find some evidence that turnover also moderately increases the share of those teaching out of their subject area of certification and those who score less well on teacher licensure tests. All else held constant, these four teacher characteristics are widely believed to signal lower quality of education for students. And indeed, our findings confirm significant drops in student math and reading scores as a consequence of the turnover of math and ELA middle school teachers.

A careful analysis of how rates of teacher turnover and characteristics of the teaching workforce shifted before, during, and after the economic recession further illuminates how the impacts of turnover differ across contexts. Under student enrollment growth pressures between 1996 and 2005, teacher turnover led to some of the largest negative consequences for schools. During the midst of the economic recession, however, turnover had more limited adverse effects as teachers were significantly less likely to leave their positions. Since 2012, the rapidly increasing turnover rate, growth in class sizes, and expanded use of teachers with lateral entry or provisional licenses, should concern North Carolina policy-makers.

This study is not the first one to document that teacher turnover reduces student achievement as measured by student test scores (Hanushek et al, 2016; Henry & Redding, 2018; Ronfeldt et al, 2013). Our new findings help to explain such findings, and, in the process, generate somewhat broader implications for the immediate and ongoing capacities of schools experiencing high rates of turnover. In particular, the compositional effects of turnover that we report are likely to be detrimental in three ways. As a consequence of the greater proportion of teachers with weak qualifications and experience in the subjects they teach, turnover is likely to reduce the quality of teaching, and hence student learning, in individual classrooms. In addition, the influx of new and inexperienced teachers is likely to be disruptive and to interfere with the development of a coherent program of education within the school. Although some of that disruption would occur regardless of the characteristics of the replacement teachers relative to the departing teachers, it is likely to be magnified when the new teachers have weaker qualifications and experience than the departing teachers, as is the case in North Carolina middle schools. Finally, that compositional change may lead to greater turnover in subsequent years because of the greater proclivity of the identified groups of teachers than others to leave a school (Redding & Henry, 2018; Redding & Smith, 2016).

The potential for higher subsequent turnover strengthens the case for policymakers to address directly the challenges posed by high teacher turnover rather than focusing only on longer-term strategies designed to improve the quality of the overall teacher labor force. Neither firing the lowest performing teachers, nor providing performance-based incentives to raise teacher effectiveness are solutions to the problem of teacher turnover at the school level. General salary increases, in contrast, could potentially be somewhat beneficial in this case, but primarily to the extent that higher salaries reduce the incentives for some teachers to leave the profession or increase the flow of new teachers into the state's teacher workforce. Similarly, a general increase in educational resources at the district or school level could be useful, but their effects on teacher turnover would depend on how they were distributed and used within schools. Instead, what is needed are policy interventions that are targeted specifically at the causes and consequences of teacher turnover at the school level.

A full discussion of such policy options is beyond the scope of this paper. Here, though, are examples of the types of approaches that might be useful. One would be to improve the working conditions in schools with higher rates of turnover given that poor working conditions have emerged in several studies as a significant determinant of a teacher's decision to leave a school (Simon & Johnson, 2015; Loeb, Darling-Hammond &Luczak, 2005) Further, studies show that a key determinant of a school's working conditions is the quality of school leadership (Kraft, Marinell, & Yee, 2016; Ladd, 2011). Hence, one strategy to reduce teacher turnover in particular schools would be to promote policies designed to assure that schools subject to high teacher turnover have strong school leaders. Another strategy would be to offer differential pay for teachers to teach in and remain in schools that find it hard to attract teachers overall or in particular subject areas (Clotfelter et al., 2008; Fulbeck, 2014). To reduce turnover such programs would need to offer differentially high salaries for extended periods, and not just one year bonuses. In addition, the differential pay may need to be quite large to offset the challenges teachers experience in schools that are highly segregated by race or economic status (Clotfelter, Ladd, & Vigdor, 2011).

A complementary approach would be to adopt policies designed to make schools more resilient to the loss of teachers, such as providing high quality mentoring and induction programs designed to support inexperienced teachers in their early years. Such programs might help to keep teachers who have potential from leaving the school or the profession before they have a chance to master the art of teaching (Ingersoll & Strong, 2011). Similar efforts could be made to retain the more experienced teachers by giving them shared decision making roles and additional professional development as needed. Each of these approaches is likely to be more effective in some contexts than in others, no one of them is a panacea by itself, and their effects will depend on how well they are implemented. Nonetheless they illustrate the types of targeted programs needed to address the serious educational problem of teacher turnover.

Notes

1. We make several minor sample restrictions to remove extreme outliers from the data, which are likely to be the result of errors in record-keeping or data collection. We only keep school-subject-year observations if the number of teachers in that school in that subject is greater than 3 and less than 50. We keep average class sizes within the range of 5 and 50, and we keep teacher licensure exam scores that fall within 3 standard deviations from the mean. The full distribution of teacher counts by subject prior to sample restriction is shown in Appendix Figure A1.

2. For every teacher in the North Carolina dataset, we restrict to the test score from their most recent PRAXIS test date. We then standardize test scores by year of testing, such that every testing year has a mean of zero and standard deviation of one. Because the current study's sample of middle school math and ELA teachers are normalized to the full sample of teachers, their mean test score value is not equal to zero, and standard deviation not equal to one.

3. Readers may notice that average school test score achievement has a mean of -0.06 and standard deviation of 0.36. This is because reading and math z-scores were first standardized to have mean zero and standard deviation of one in each year and grade for the full sample of students, and then subsequently aggregated to the school-year level.

4. Rural schools contain the following locale categories: rural in a remote region, rural in a distant region, and rural on the fringe of a city; town schools contain the following locale categories: town in a remote region, town in a distant region, town in the fringe of a city; suburban schools contain the following locale categories: suburb of a small city, suburb of a midsize city, and suburb of a large city; and urban schools contain the following locale categories: small city, midsize city, and large city.

5. Session Law 2011-145 Senate Bill 200, 7.21(b) permitted LEAs to break the previous maximum class size requirements for all grades above 3rd grade to give them the flexibility needed to make budgetary cuts. This may in part explain the drift in average class sizes.

6. We also estimated the by-time-period model using one-year or two-year average turnover rates instead of the three-year turnover rates, and found similar results.

7. We cannot identify TFA teachers directly in our data, but do know the primary TFA regions and districts partnered with TFA, as well as how many TFA teachers districts have in total.

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Figures and Tables

Figure 1. Average Three-Year Teacher Turnover Rate by Year 1998-2016

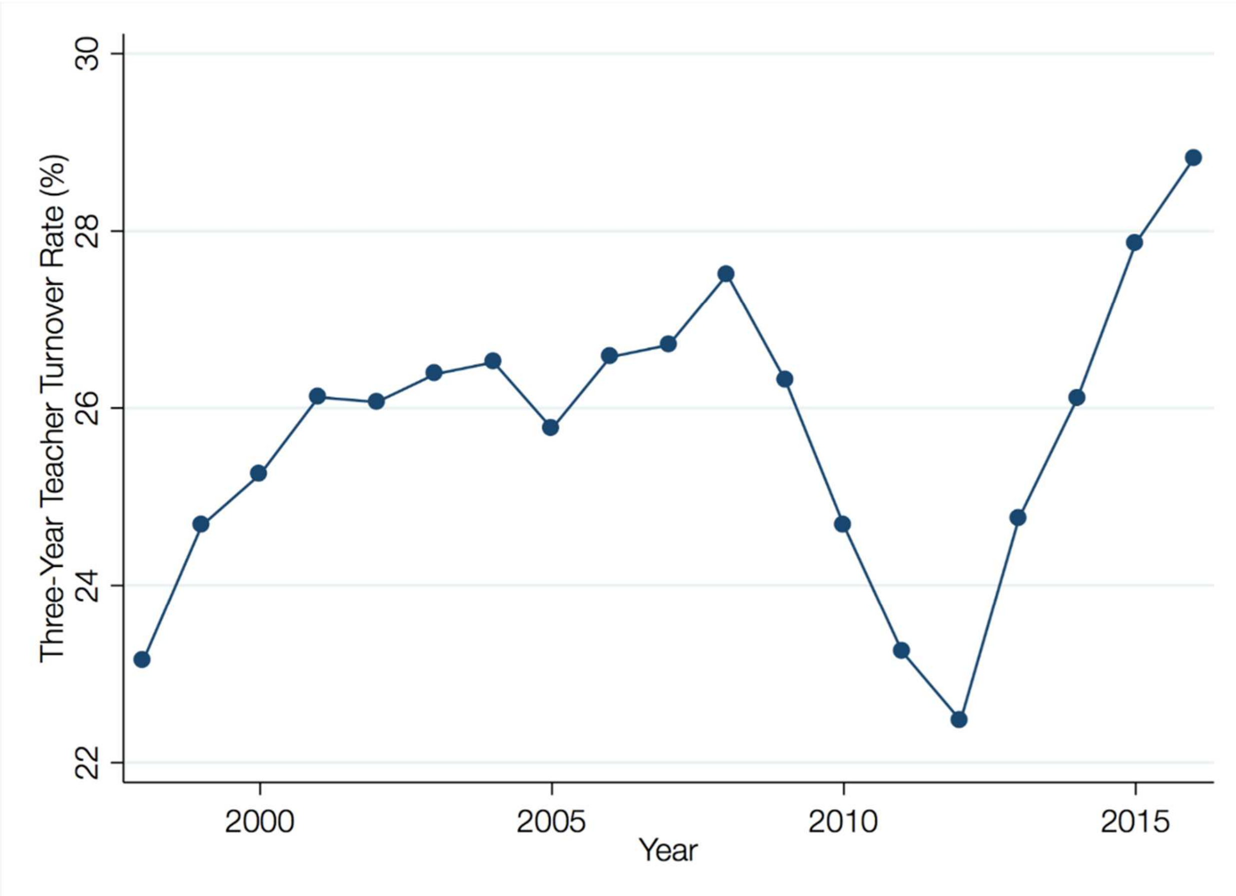
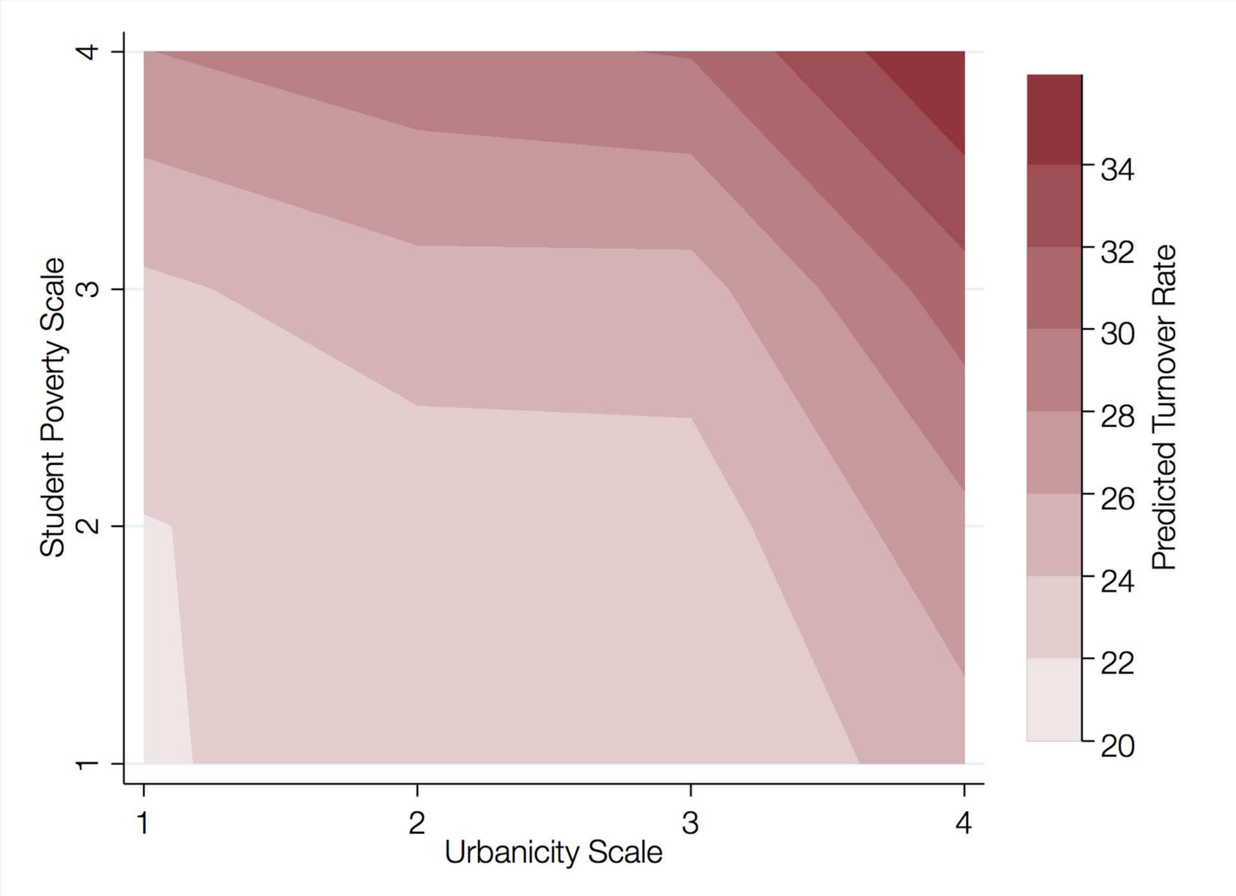
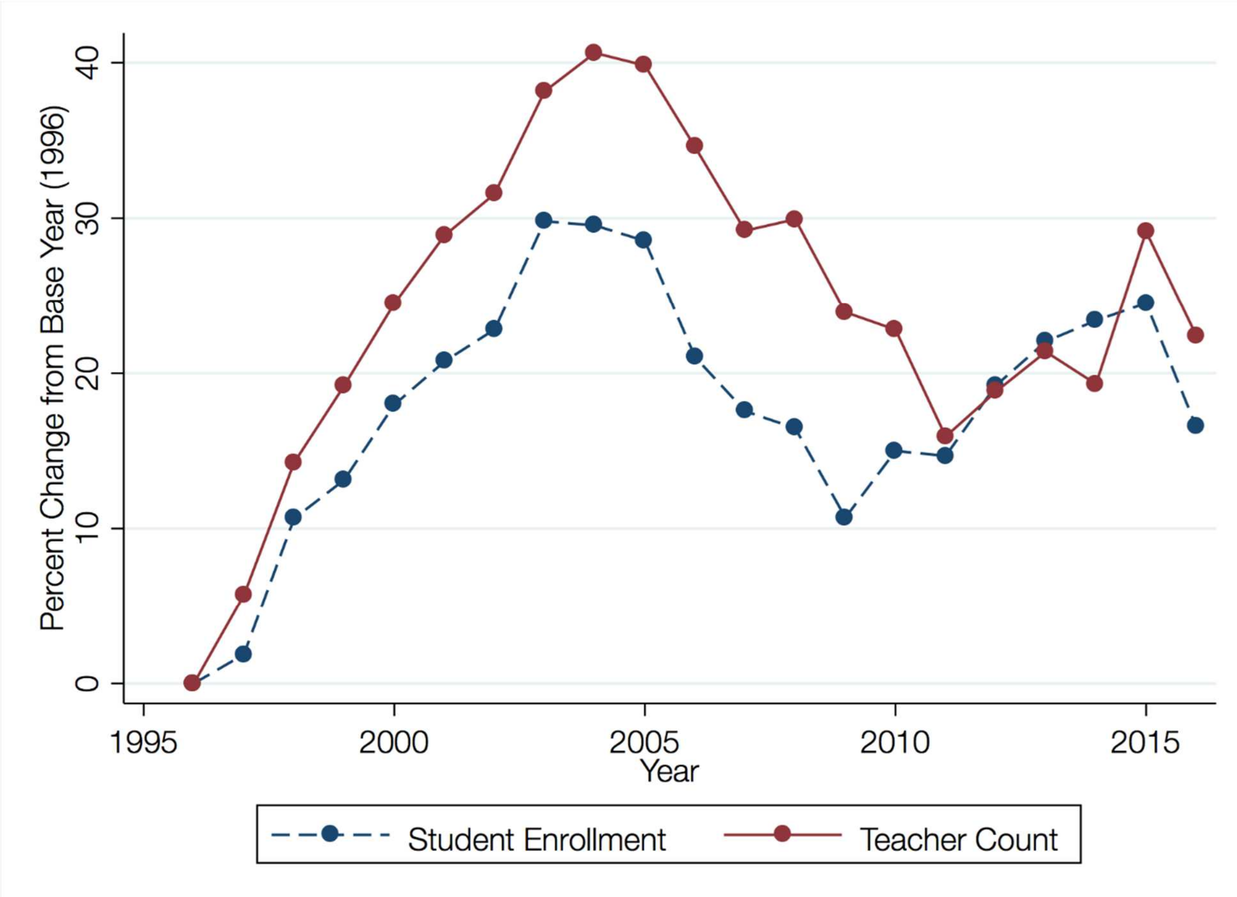


Figure 2. Average Turnover Rates by School Poverty Level and Urbanicity



Note. For the student poverty index, schools are categorized into quartiles based on the percent of students eligible for free or reduced price lunch. The urbanicity index of schools is generated using NCES locale codes as follows: 1 for rural remote, rural distant, and rural fringe; 2 for town remote, town distant, and town fringe; 3 for small suburb, midsize suburb, and large suburb; and 4 for small city, midsize city and large city.

Figure 3. Percent Cumulative Change in Student Enrollment and Teacher Counts 1996-2016



Note. This count of students and teachers only includes middle school classrooms of math and ELA, and has the same restrictions as the analytical sample. For example, school-year observations with fewer than three teachers in a subject are removed for both the student and teacher count. Student enrollment is taken as the maximum value at a school between students enrolled in math and students enrolled in ELA, since there is likely significant overlap between the two groups.

Table 1. Summary Statistics of Analytical Sample of Middle School Math and ELA Teachers

Variable	N	Mean	Std. Dev.	Min	Max
Teacher Composition					
Proportion Novice	15,616	0.2131	0.1723	0.0000	1.0000
Proportion Lateral/Prov	15,616	0.1216	0.1379	0.0000	1.0000
Licensure Exam Z-Score	15,616	-0.1311	0.3714	-2.3008	2.7954
Proportion Out-of-Subject	15,616	0.2929	0.1778	0.0000	1.0000
Other Outcomes					
Average Class Size	15,616	19.908	3.9291	5.0000	47.500
Test Score Achievement	15,612	-0.058	0.3615	-2.155	1.2099
Turnover Measures					
One Year Turnover Rate	15,614	0.2606	0.1794	0.0000	1.0000
Three Year Turnover Rate	15,616	0.2569	0.1295	0.0000	1.0000
Number of Math Teachers	15,616	9.3078	4.0567	3.0000	28.000
Number of ELA Teachers	15,616	11.276	5.8849	3.0000	50.000
Student Characteristics					
Proportion Black	15,616	0.3202	0.2396	0.0000	1.0000
Proportion Hispanic	15,616	0.0930	0.0954	0.0000	0.7776
Proportion Female	15,616	0.4621	0.0524	0.0502	1.0000
Proportion Free Lunch	15,064	0.4342	0.2156	0.0000	0.9975

Note. Observations are at the school-subject-year level averaged across math and ELA classrooms in grades six through eight; the sample is restricted to the analytic sample (years for which average three-year turnover can be calculated). Other minor sample restrictions to remove outliers are described in the main text.

Table 2. Cumulative Effects of Average Turnover from Prior Three Years on Teacher Characteristics

	Proportion Teachers with 0 to 3 Years Experience		Proportion Teachers with Lateral or Prov. License		Average Teacher License Exam Score (SD)		Proportion Teachers Teaching Out-of-Subject		Average Class Size (# Students)	
Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Turnover Rate	0.3895***	0.3459***	0.1457***	0.1544***	-0.0712*	-0.0337	0.0187	0.0825***	0.5726*	-0.0221
	(0.017)	(0.023)	(0.014)	(0.021)	(0.043)	(0.062)	(0.017)	(0.021)	(0.331)	(0.280)
Student Controls										
Percent Black	0.0279		0.0284		-0.0872		0.1674***		-6.4280***	
	(0.023)		(0.020)		(0.056)		(0.025)		(0.671)	
Percent Hispanic	0.0182		0.0333		0.0788		-0.0259		0.8488	
	(0.049)		(0.037)		(0.108)		(0.051)		(1.310)	
Percent Female	-0.0497		-0.0762**		0.0533		-0.4436***		16.5001***	
	(0.037)		(0.030)		(0.073)		(0.042)		(1.213)	
Math Subject	-0.0009	-0.0017	-0.0016	-0.0018	-0.0498***	-0.0496***	0.0162***	0.0166***	0.8947***	0.9079***
	(0.003)	(0.003)	(0.003)	(0.003)	(0.014)	(0.014)	(0.004)	(0.004)	(0.052)	(0.054)
Observations	15,613	15,602	15,613	15,602	15,613	15,602	15,613	15,602	15,613	15,602
R-squared	0.369	0.720	0.414	0.711	0.307	0.589	0.493	0.769	0.591	0.915
School FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
School-by-Year FE	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES

Robust standard errors in parentheses, clustered by school.
*** p<0.01, ** p<0.05, * p<0.1

Table 3. Cumulative Effects of Teacher Turnover by Student Poverty

Variables	Proportion Novice Teachers (1)	Proportion Teachers Lateral/Prov (2)	Average Licensure Score (3)	Proportion Teachers Out-of-Subject (4)	Average Class Size (5)
Turnover Rate	0.3891***	0.1295***	-0.0786*	0.0194	0.6558*
	(0.018)	(0.014)	(0.045)	(0.018)	(0.376)
Turnover * High Poverty	-0.0011	0.0626***	0.0081	0.0004	-0.3859
	(0.022)	(0.018)	(0.044)	(0.021)	(0.502)
Percent Students Black	0.0298	0.0260	-0.0795	0.1734***	-6.5550***
	(0.023)	(0.020)	(0.058)	(0.026)	(0.665)
Percent Students Hispanic	0.0251	0.0165	0.0940	-0.0254	0.9200
	(0.050)	(0.037)	(0.109)	(0.052)	(1.306)
Percent Students Female	-0.0570	-0.0772**	0.0507	-0.4463***	16.5815***
	(0.037)	(0.030)	(0.075)	(0.043)	(1.224)
Math Subject	-0.0006	-0.0020	-0.0516***	0.0162***	0.9077***
	(0.003)	(0.003)	(0.014)	(0.004)	(0.052)
Observations	15,083	15,083	15,083	15,083	15,083
R-squared	0.372	0.415	0.307	0.494	0.591
School FE	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES
School-by-Year FE	NO	NO	NO	NO	NO

Robust standard errors in parentheses, clustered by school.
*** p<0.01, ** p<0.05, * p<0.1

Table 4. Cumulative Effects of Teacher Turnover on Student Math and Reading Achievement

Variables	Test Scores (All Subjects)	Test Scores (Reading)	Test Scores (Math)
Average Three Year Turnover Rate	-0.1542***	-0.1292***	-0.1668***
	(0.019)	(0.023)	(0.028)
Percent Students Black	-0.3649***	-0.3652***	-0.3747***
	(0.058)	(0.058)	(0.065)
Percent Students Hispanic	-0.3227***	-0.3998***	-0.2328**
	(0.075)	(0.066)	(0.102)
Percent Students Female	0.4306***	0.3929***	0.4895***
	(0.083)	(0.085)	(0.092)
Math Subject	-0.0064*		
	(0.004)		
Observations	15,609	7,793	7,773
R-squared	0.872	0.898	0.874
School FE	YES	YES	YES
Year FE	YES	YES	YES
School-by-Year FE	NO	NO	NO

Robust standard errors in parentheses, clustered by school.
*** p<0.01, ** p<0.05, * p<0.1

Table 5. Trends in Teacher and Classroom Characteristics by Time Period

Time Period	Proportion Novice Teachers	Proportion Teachers Lateral / Prov	Average Licensure Score	Proportion Teachers Out-of-Subject	Average Class Size
Pre-Recession: 1998-2008	0.255	0.121	-0.103	0.354	19.0
Mid-Recession: 2009-2012	0.181	0.118	-0.179	0.228	20.6
Post-Recession: 2013-2016	0.153	0.126	-0.149	0.219	21.2

Note. Each cell represents the average value of the variable listed in the column during the specified time period. 1996 and 1997 are excluded since average three-year turnover cannot be calculated for those years.

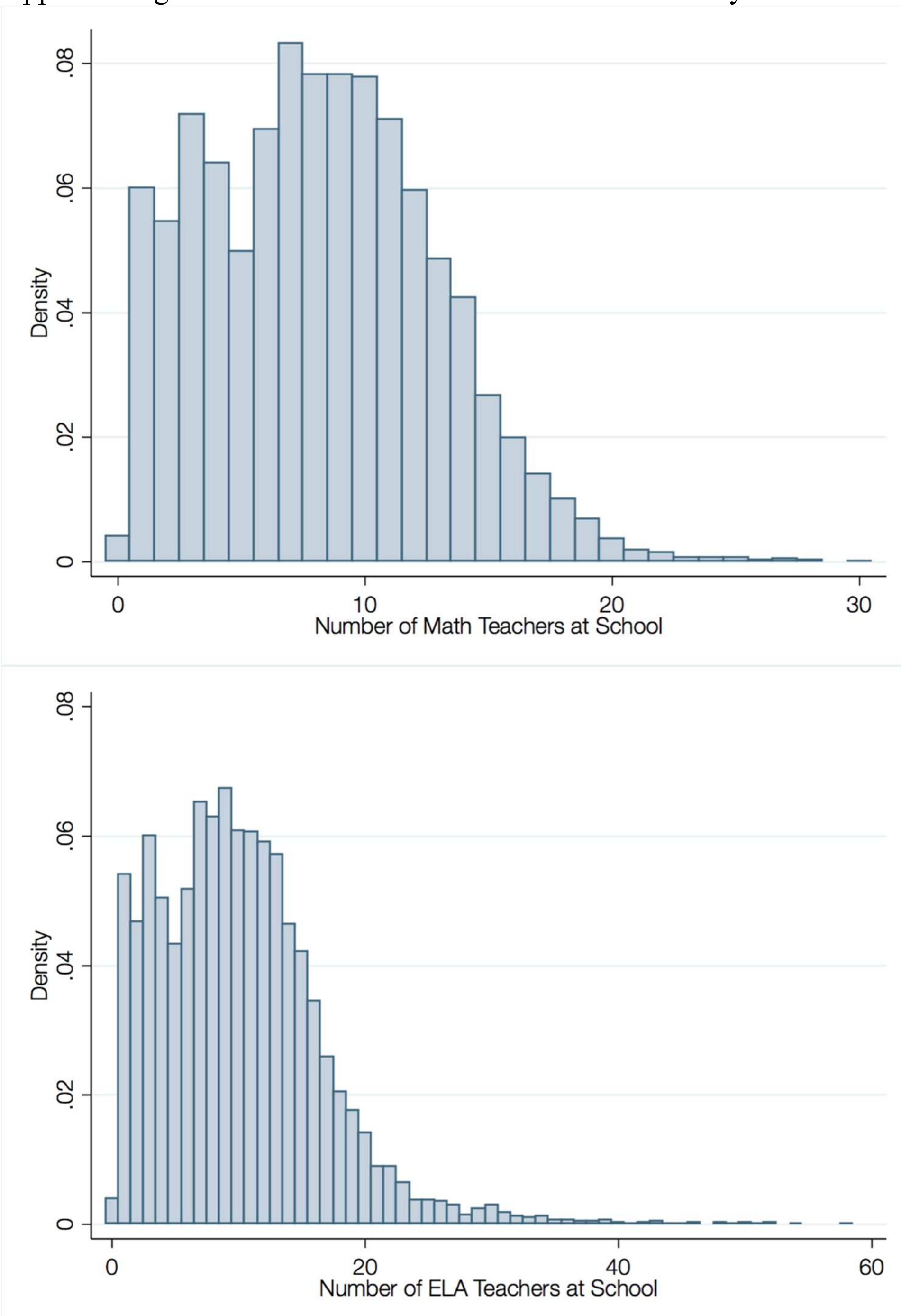
Table 6. Cumulative Effects of Teacher Turnover by Time Period

Variables	Proportion Novice Teachers (1)	Proportion Teachers Lateral/Prov (2)	Average Licensure Score (3)	Proportion Teachers Out-of-Subject (4)	Average Class Size (5)
Turnover Rate	0.4179***	0.1514***	-0.0930*	0.0319	0.2754
	(0.023)	(0.016)	(0.056)	(0.021)	(0.444)
Turnover * 2009-2012	-0.0129	-0.0663**	0.0122	-0.0644*	0.4400
	(0.039)	(0.028)	(0.077)	(0.037)	(0.677)
Turnover * 2013-2016	-0.1011***	0.0268	0.0669	-0.0028	0.8391
	(0.038)	(0.035)	(0.085)	(0.034)	(0.824)
Percent Students Black	0.0254	0.0263	-0.0854	0.1653***	-6.3962***
	(0.023)	(0.020)	(0.056)	(0.026)	(0.675)
Percent Students Hispanic	0.0299	0.0300	0.0724	-0.0282	0.7632
	(0.050)	(0.037)	(0.109)	(0.051)	(1.296)
Percent Students Female	-0.0454	-0.0804***	0.0500	-0.4445***	16.4612***
	(0.037)	(0.030)	(0.073)	(0.042)	(1.212)
Math Subject	-0.0009	-0.0017	-0.0501***	0.0161***	0.8949***
	(0.003)	(0.003)	(0.014)	(0.004)	(0.052)
Observations	15,636	15,636	15,636	15,636	15,636
R-squared	0.370	0.415	0.306	0.493	0.591
School FE	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES
School-by-Year FE	NO	NO	NO	NO	NO

Robust standard errors in parentheses, clustered by school.
*** p<0.01, ** p<0.05, * p<0.1

Appendix

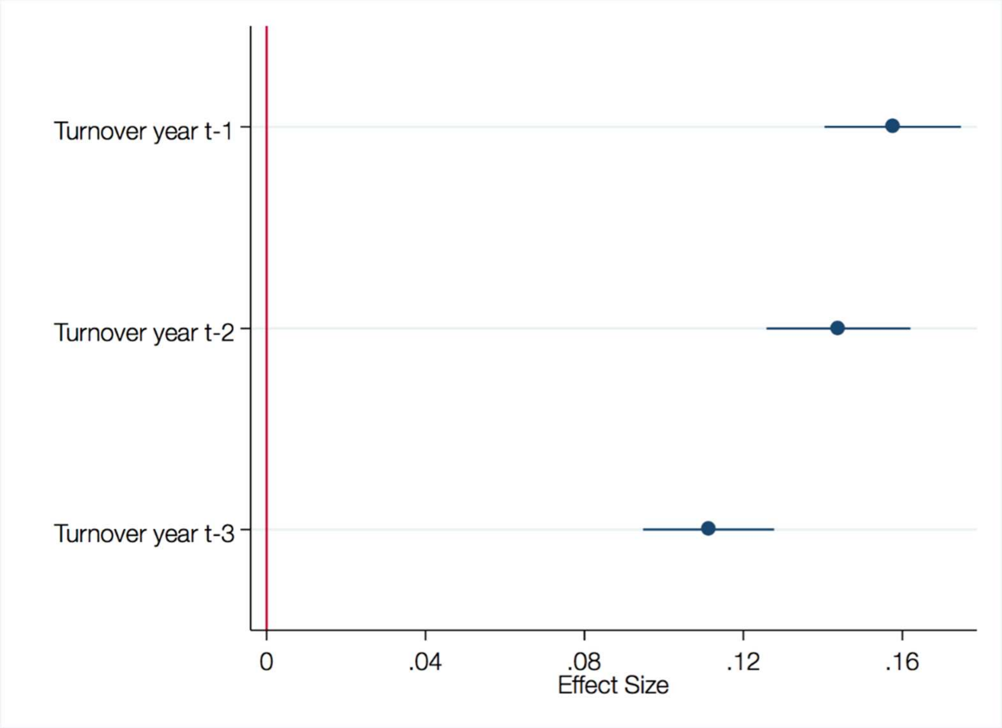
Appendix Figure A1. Number of Math and ELA Teachers by School-Year Observation



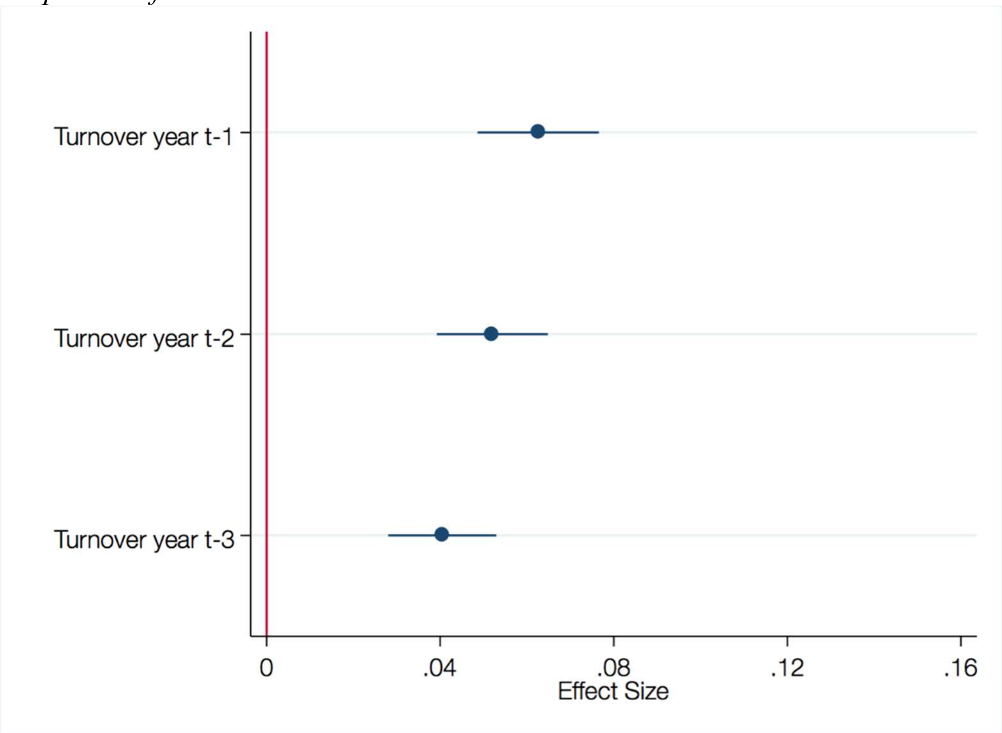
Note. These distributions were plotted prior to a sample restriction based on teacher count. In all subsequent analyses in the main document, we restrict the sample to school-subject-year observations in which at least 3 and fewer than 50 teachers were teaching in both math and ELA.

Appendix Figure A2. Dynamic Effects of Teacher Turnover Rate in Prior Three Years

Proportion of Teachers with 0-3 Years of Experience

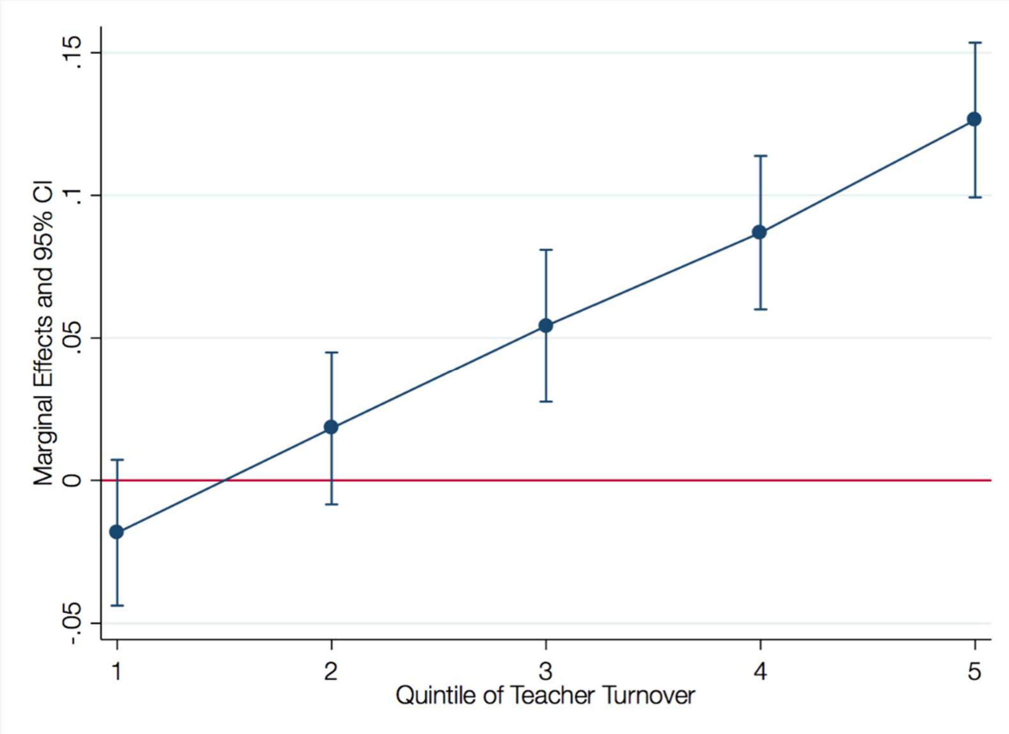


Proportion of Teachers with Lateral or Provisional License

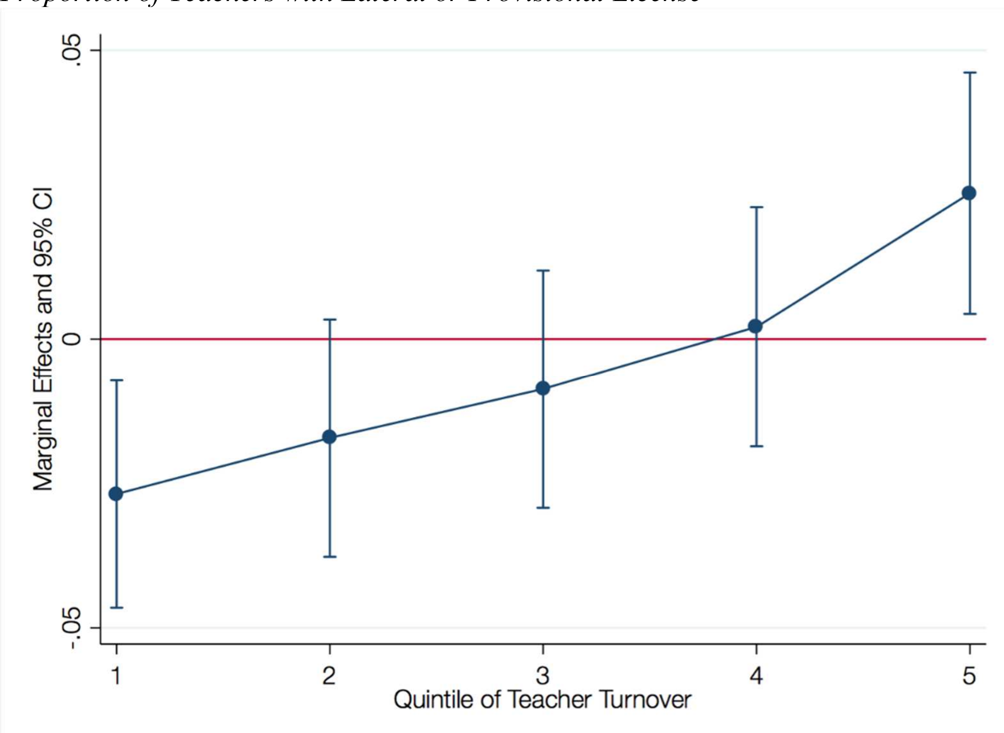


Appendix Figure A3. Nonlinear Effects of Teacher Turnover by Quintile of Turnover Rates

Proportion of Teachers with Three or Fewer Years Experience



Proportion of Teachers with Lateral or Provisional License



Appendix Table A1. Cumulative Effects of Teacher Turnover by School Baseline Performance

Variables	Proportion Novice Teachers (1)	Proportion Teachers Lateral/Prov (2)	Average Licensure Score (3)	Proportion Teachers Out-of-Subject (4)	Average Class Size (5)
Turnover Rate	0.3898***	0.0985***	-0.1253**	0.0226	0.6097
	(0.023)	(0.014)	(0.052)	(0.021)	(0.414)
Turnover * Low Performing	-0.0027	0.1217***	0.1388	-0.0116	-0.0736
	(0.035)	(0.029)	(0.086)	(0.035)	(0.674)
Observations	15,556	15,556	15,556	15,556	15,556
R-squared	0.368	0.412	0.306	0.492	0.590
Control Variables	YES	YES	YES	YES	YES
School FE	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES
School-by-Year FE	NO	NO	NO	NO	NO

Robust standard errors in parentheses, clustered by school. Schools are defined as low-performing if they were in the bottom decile of average math and reading performance in their first year observed in the data.
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Appendix Table A2. Cumulative Effects of Teacher Turnover by School Urbanicity

Variables	Proportion Novice Teachers (1)	Proportion Teachers Lateral/Prov (2)	Average Licensure Score (3)	Proportion Teachers Out-of-Subject (4)	Average Class Size (5)
Turnover Rate	0.4008***	0.1433***	-0.0800	0.0191	0.4388
	(0.021)	(0.016)	(0.052)	(0.019)	(0.366)
Turnover * Urban	-0.0455	0.0089	0.0269	-0.0013	0.5409
	(0.035)	(0.031)	(0.085)	(0.039)	(0.794)
Observations	15,636	15,636	15,636	15,636	15,636
R-squared	0.369	0.414	0.306	0.493	0.591
Control Variables	YES	YES	YES	YES	YES
School FE	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES
School-by-Year FE	NO	NO	NO	NO	NO

Robust standard errors in parentheses, clustered by school. Schools are classified as urban if they are located in a small, mid-sized, or large city.
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Appendix Table A3. Cumulative Effects of Teacher Turnover by School Distance to Major Teacher Preparation Program

Variables	Proportion Novice Teachers (1)	Proportion Teachers Lateral/Prov (2)	Average Licensure Score (3)	Proportion Teachers Out-of-Subject (4)	Average Class Size (5)
Turnover Rate	0.3958***	0.1376***	-0.0817*	0.0185	0.7011*
	(0.019)	(0.015)	(0.045)	(0.019)	(0.368)
Turnover * Far from TPP	-0.0362	0.0408	0.0446	0.0015	-0.5907
	(0.045)	(0.037)	(0.116)	(0.043)	(0.819)
Observations	15,636	15,636	15,636	15,636	15,636
R-squared	0.369	0.414	0.306	0.493	0.591
Control Variables	YES	YES	YES	YES	YES
School FE	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES
School-by-Year FE	NO	NO	NO	NO	NO

Robust standard errors in parentheses, clustered by school. `Far from TPP' is defined as over one hour travel time from a teacher preparation program that enrolls a substantive cohort of students regularly.
*** p<0.01, ** p<0.05, * p<0.1

Appendix Table A4. Teacher Turnover Effects Excluding Districts with Teacher for America (TFA) Placements

	Proportion Teachers with 0 to 3 Years Experience		Proportion Teachers with Lateral or Prov. License		Average Teacher Licensure Exam Score (SD)		Proportion Teachers Teaching Out-of-Subject		Average Class Size (# Students)	
Variables	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
Turnover Rate	0.3961***	0.3443***	0.1251***	0.1334***	-0.0996**	-0.0504	0.0250	0.0745***	0.7356**	-0.0660
	(0.020)	(0.025)	(0.014)	(0.020)	(0.046)	(0.066)	(0.019)	(0.024)	(0.354)	(0.321)
Student Controls										
Percent Black	-0.0096		0.0298		-0.2011**		0.1992***		-9.2656***	
	(0.033)		(0.032)		(0.091)		(0.043)		(1.176)	
Percent Hispanic	-0.0138		-0.0221		0.1315		0.0831		-3.0284**	
	(0.063)		(0.039)		(0.135)		(0.057)		(1.431)	
Percent Female	-0.1165**		-0.0852**		-0.0650		-0.4979***		17.7691***	
	(0.048)		(0.035)		(0.087)		(0.049)		(1.437)	
Math Subject	0.0024	0.0012	-0.0009	-0.0008	-0.0534***	-0.0540***	0.0202***	0.0198***	0.8942***	0.9125***
	(0.003)	(0.003)	(0.003)	(0.003)	(0.014)	(0.014)	(0.004)	(0.004)	(0.052)	(0.057)
Observations	12,839	12,808	12,839	12,808	12,839	12,808	12,839	12,808	12,839	12,808
R-squared	0.345	0.710	0.376	0.692	0.314	0.604	0.496	0.768	0.605	0.917
School FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
School-by-Year FE	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES

Robust standard errors in parentheses, clustered by school. Districts are excluded if more than one percent of their entire teaching workforce is from Teach for America. This includes the following districts: Bertie County, Charlotte-Mecklenburg County, Clinton City, Duplin County, Edgecombe County, Granville County, Halifax County, Lenoir County, Nash-Rocky Mount Schools, Northampton County, Sampson County, Vance County, Warren County, and Weldon City.

*** $p<0.01$, ** $p<0.05$, * $p<0.1$