Teacher Pension Systems, the Composition of the Teaching Workforce, and Teacher Quality

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Cory Koedel
Department of Economics
University of Missouri
118 Professional Building
Columbia, MO 65211
koedelc@missouri.edu

Michael Podgursky
Department of Economics
University of Missouri
118 Professional Building
Columbia, MO 65211
podgurskym@missouri.edu

Shishan Shi
Department of Economics
University of Missouri
118 Professional Building
Columbia, MO 65211
ss4x5@mail.missouri.edu

Teacher pension systems concentrate retirements within a narrow range of the career cycle by penalizing individuals who separate too soon or remain employed too long. The penalties result in the retention of some teachers who would otherwise choose to leave, and the premature exit of some teachers who would otherwise choose to stay. We examine the link between teachers' pension incentives and workforce quality and find no evidence to suggest that the incentives raise quality. Given the large and growing costs associated with maintaining teacher pension systems, and the lack of evidence regarding their efficacy, experimentation by traditional and charter schools with alternative retirement benefit structures would be useful.

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I. Introduction

Unlike most private-sector professionals, public educators are nearly universally enrolled in defined-benefit (DB) pension plans (Hansen, 2010). Considerable resources are devoted to fund these plans – for example, in Missouri, the location of our study, 29 percent of teachers' earnings are currently required to fund retirement benefits (Koedel et al., 2012). Funding requirements in other states are also substantial and have increased in recent years (Snell, 2012). The costs associated with maintaining teacher pension systems have become more apparent during the recent financial crisis. Some states have enacted changes in their teacher pension plans in order to reduce their long-term pension liabilities (e.g., Illinois, Rhode Island, Utah) and many others are considering such changes (Snell, 2012). As reform efforts around these systems continue to intensify, it is important to understand how various aspects of the pension structure influence workforce quality.[1]

Pension-wealth accrual for teachers is highly uneven over the course of the career cycle (Costrell and Podgursky, 2009). The uneven accrual creates an incentive structure that shapes the workforce. First, leading up to the system-targeted retirement date, educators are encouraged to remain in teaching because the pension formula is heavily backloaded. The backloading creates "pull" incentives that have been argued by some to improve workforce quality (Weller, 2011), but we are not aware of any direct evidence to support this hypothesis.[2] Drawing on Lazear (1986), a benefit of backloading wealth accrual in DB pension plans is that it can raise worker productivity by

[1] Teacher quality has been consistently shown to be one of the most important determinants of student success in schools (Hanushek and Rivkin, 2010). Recent research has focused on the potential for selective teacher retention policies to influence quality (Boyd et al., 2011; Chetty et al., 2011; Goldhaber and Hansen, 2010; Hanushek, 2009; Staiger and Rockoff, 2010), and teacher evaluation and performance-pay programs (Muralidharan and Sundararaman, 2011; Podgursky and Springer, 2007; Springer et al., 2010; Taylor and Tyler, 2012). The influence of teacher pension incentives on workforce quality has gone largely unstudied.

[2] Weller's argument is based on his conclusion that teacher pension systems reduce turnover – he comes to this conclusion through an indirect analysis, but several other studies disagree. We address the turnover issue below. Another issue is teacher experience. Goldhaber and Hansen (2010) find that there is considerable overlap in the distributions of teacher quality across experience levels. They show that there are many highly-experienced teachers who do not perform as well as novice teachers in the classroom, which implies that the simple fact that teachers improve with experience is insufficient to draw conclusions about whether it is desirable to retain teachers by backloading compensation. As noted by Friedberg and Turner (2010), the fundamental question linking the pension incentives to workforce quality centers on teachers at the margin – that is, those whose retirement behaviors are directly influenced by their pension incentives.

eliciting effort. The textbook context is one where performance monitoring is imperfect and workers risk losing their pensions by shirking. But this context is a poor fit for public school teachers because experienced teachers have tenure, which makes the threat of losing a pension not credible.[3]

After becoming eligible for retirement, teachers quickly move from the "pull" region to the "push" region of the incentive structure. The "push" incentives derive from the fact that pension benefits can only be collected upon retirement. Once an individual becomes collection eligible, there is an immediate spike in the opportunity cost of continued work in the system (the forgone pension payments). Put differently, collection-eligible individuals who continue working could earn a fraction of their salary – typically a substantial fraction – without working at all. Teachers clearly respond to the "push" incentives, as evidenced by the fact that they retire much earlier than private-sector professionals. For example, the median retirement age for Missouri teachers is 57, which is close to the national median of 59 (Ehlert et al., 2009).

This article examines whether teachers' pension incentives improve workforce quality. If teacher pension systems do not yield workforce-quality benefits, the funds currently devoted to their maintenance may be better-used in other ways. Alternatively, if some aspects of these systems positively affect workforce quality, then they should be identified and preserved to the extent possible during the legislative reform process.

We use administrative micro data from Missouri for the analysis. Our empirical strategy is facilitated by the rules of the Missouri system, where teachers experience up to two large, exogenous spikes in pension wealth generated by two different early-retirement provisions over the course of the teaching career. Teachers who exit the system before reaching the first spike in pension wealth

[3] Lazear (1986) analyzes the efficiency rationale for this type of incentive structure in the context of a competitive firm. A key factor in his model is the role of a pension as a performance bond to discourage shirking. The model also features the divergence of worker productivity and earnings beyond a certain level of experience, hence the need to push workers out of the workforce.

incur a substantial financial loss. Teachers who continue teaching beyond the second spike face large penalties associated with continued work.

We begin by comparing classroom effectiveness as measured by value-added for teachers who retire under different segments of the incentive structure. We identify three key groups of retirees: (1) retained teachers, (2) typical retirees and (3) pushed-out teachers. *Retained teachers* are those who, based on their observed retirement behaviors, are the most likely to have been held in the profession by the "pull" incentives in the pension system. *Typical retirees* are pension-wealth maximizers – they work as long as the pension system incentivizes them to do so but quit before the disincentives kick in. *Pushed-out teachers* are observed teaching for several years after the work disincentives take effect, well into the "push" region of the pension incentive structure.

A finding that retained teachers are more effective than other retirees would be consistent with the system incentives improving workforce quality. That is, if the teachers who are the most likely to have been held in the system by the "pull" incentives are more effective, the compositional effect of the system on quality will be positive. Similarly, a finding that pushed-out teachers are less effective than other retirees would also be consistent with the pension system improving workforce quality. Here, the idea is that if the system is incentivizing ineffective teachers to leave, then teacher quality on the whole should increase as a result.

We do not find any evidence of quality differences between teachers working on different segments of the incentive structure near retirement. This result suggests that it may be possible to increase the targeted retirement age set by the pension system without harming K-12 achievement, which would yield large cost savings. More broadly, our analysis calls into question the educational benefits of the retirement targeting in teacher pension systems. The substantial resources that are currently diverted to fund educator retirement benefits may be used more strategically to improve workforce quality, or for other instructional expenditures. In a concluding section we discuss ideas for policy experimentation and future research.

II. Pull and Push Incentives in Teacher Pension Systems

Educators in public schools in the United States are nearly universally enrolled in final-average-salary DB pension plans. Most plans are administered at the state level and share a common structure (Costrell and Podgursky, 2009). The following general formula is used to determine the annual benefit at retirement:

$$B = F * YOS * FAS \tag{1}$$

In (1), *B* represents the annual benefit, *F* is a formula factor, which is usually close to two percent (in Missouri, *F* = 0.025), *YOS* indicates years of service in the system, and *FAS* is the teacher's final average salary, commonly calculated as the average of the final few years of earnings. Future benefits may or may not be adjusted for inflation. In Missouri there is an annual inflation adjustment.

It typically takes 3-5 years for teachers to become vested in the system (in Missouri vesting is at five years). Once vested, teachers are eligible to collect a pension upon retirement. The official "normal retirement age" varies across plans and is usually between the ages of 60 and 65. However, an important aspect of all teacher pension plans, and one that is crucial for our work, is that they include generous provisions for early retirement. For example, in Missouri, where the "normal" retirement age is 65, teachers can take advantage of two different early-retirement provisions. The first provision is referred to as "25-and-out". The 25-and-out provision allows teachers to exit and begin collecting benefits immediately, regardless of age, as long as they have 25 years of system experience. There is a modest penalty associated with retirements via 25-and-out, but it is much less than what would be actuarially appropriate. The second provision is referred to as "the rule of 80". The rule of 80 states that whenever a teacher's combination of age and experience sums to 80, she can retire and begin collecting benefits immediately and without penalty. This means, for instance, that a teacher who begins work at age 22 and works continuously would be eligible for full retirement benefits at age 51 with 29 years of experience.

Figure 1 shows the evolution of pension-wealth accrual over time for a representative mid-career teacher in Missouri, currently 37 years old, who began her career at the age of 25.[4] The figure shows that pension wealth accrues very slowly moving into the teacher's 40s, with small single-year gains in pension wealth. However, the option-value of continued work during the 40s is high – if the teacher survives to the 25-and-out clause, the first spike in the figure, there is a substantial payoff in pension wealth. In fact, in the single year of the 25-and-out spike, the present discounted value of the teacher's pension-wealth earnings, discounted to her current age, is roughly $120,000 (in year-2009 dollars). The spike is so dramatic because with fewer than 25 years of experience the teacher cannot begin collecting her pension until her combination of age and experience sums to 80. For example, if she were to quit at the age of 48 with 24 years of experience, she could first collect a pension payment under the rule of 80 when she turned 56 years old – eight years later. But by working one additional year and earning her 25th year of experience, she can retire and begin collecting benefits immediately.

A second, smaller spike in pension wealth occurs when the teacher becomes eligible to retire under the rule-of-80 a few years later. Pension wealth increases continuously up to the rule-of-80 year, then jumps $24,000 in that single year because the teacher can collect her full regular pension without penalty. After the rule-of-80 spike, the pension system imposes costs on continued teaching that increase over time because pension payments cannot be collected while working.[5] Initially, the pension-wealth profile is nearly flat beyond the second pension-wealth spike because continued

[4] The calculations underlying the figure require several assumptions about the individual's life expectancy, discount rate, wage-growth profile, etc. – these assumptions and other details about the calculations are discussed in Appendix A. Additionally, Appendix Table B.1 shows a brief history of the pension rules in the Missouri system. Figure 1 shows pension-wealth calculations based on the current system rules, which have remained unchanged since 2002.
[5] There is a small third "spike" in the pension system on the downward sloping portion that corresponds to what is effectively a retroactive bonus to teachers who work their 31st year in the system. See Appendix Table B.1 for details.

work increases the size of future pension payments by enough to roughly offset the cost of not collecting. But over time, the cost of not collecting overwhelms the gains from continued work.[6]

The uneven pattern of pension-wealth accrual in Missouri, where the marginal pension-wealth returns to work are initially small, then rise very fast, and then flatten out and become negative over the course of the career cycle, is typical of teacher pension systems nationwide (Costrell and Podgursky, 2009). Less typical, although still not uncommon, is the two-spike structure of the Missouri system generated by the two different early-retirement provisions. We exploit the two spikes in the Missouri system to examine how teachers' pension incentives are related to workforce quality.

III. Empirical Strategy

The retirement compensation structure shown in Figure 1 can be rationalized if there are large changes in teaching effectiveness within a fairly narrow range of the career cycle. For example, based on the figure one would expect performance to decline rapidly as teachers age past their mid-50s. At the same time, the compensation structure also suggests that there are large benefits associated with retaining teachers up until shortly before the work disincentives take effect. To investigate how the incentive structure aligns with teacher performance in the classroom, we construct a model of student achievement designed to distinguish performance differences across teachers who we observe retiring on different segments of the incentive structure. Using classroom-linked data for students and teachers, we estimate the following model:

$$\begin{aligned} Y_{isgjt} &= Y_{isgj(t-1)}\gamma_1 + X_{it}\gamma_2 + S_{ist}\gamma_3 \\ &+ PE_{ijt}\delta_1 + RT_{ijt}\delta_2 + TR_{ijt}\delta_3 + PO_{ijt}\delta_4 + LPE_{ijt}\lambda_1 + LRT_{ijt}\lambda_2 + LTR_{ijt}\lambda_3 + LPO_{ijt}\lambda_4 + \\ &RE_{ijt}\pi + \xi_g + \xi_t + \xi_s + u_{isgjt} \end{aligned} \tag{2}$$

[6] An alternative way to think about the declining pension wealth for late-career teachers is to think about the pension-system replacement rate. Based on the parameters of the system in Missouri, if the representative teacher in Figure 1 worked through age-60, her annual pension benefit if she chose to retire would be equal to 90 percent of her final average salary (she would have 36 years of service, and the formula factor is 0.025). Factoring in that she would no longer contribute to the pension system, she would receive a larger income as a retiree than if she continued teaching.

Equation (2) is a typical, unrestricted value-added model of student achievement (Harris et al., 2011; Todd and Wolpin, 2003). Y_{isgjt} indicates a test score for student *i* at school *s* in grade *g* with teacher *j* during year *t;* X_{it} is a vector of observable characteristics for student *i*, including race, gender, free-lunch status, language status and mobility status; and S_{ist} is a vector of school-level characteristics analogous to the student-level information, but measured as building-level compositions for the school attended by student *i* in year *t*. ξ_g, ξ_t and ξ_s are grade, year and school fixed effects, respectively; we report estimates from models with and without school fixed effects.[7]

The variables of primary interest are the first four variables in the second row of the equation: PE_{ijt}, RT_{ijt}, TR_{ijt} and PO_{ijt}.[8] These variables denote teachers by type, where the types are determined based on teachers' observed exit behaviors over the course of our data panel. In order, the variables identify premature exiters (PE), retained teachers (RT), typical retirees (TR) and pushed-out teachers (PO). The latter three groups are retirees. The second set of controls in the second row of the equation shows an analogous set of variables, each preceded by the letter "*L*." These variables are last-year-of-work indicators (for the last year of work occurring in year-*t*). Our inclusion of these variables is motivated by Hansen (2008), who shows that productivity declines for teachers in the year prior to exiting the profession. The specification in (2) allows for heterogeneity in the performance decline across teacher types.[9] Finally, the variable RE_{ijt} is an indicator variable equal to one if the teacher is eligible for retention status based on his/her age-experience profile. As

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[7] We exclude school-level covariates from the school-fixed-effects models. The coefficients on the school-level covariates are mechanically identified in the school-fixed-effects models because the covariates vary over time within schools, but it is not clear that the identifying variation is useful in the school-fixed-effects models. For completeness we also estimated school-fixed-effects models that include the school covariates (results omitted for brevity), and our findings are nearly identical to what we report below.

[8] We also estimated models that explicitly account for school and grade changers. Whether we include controls for school and grade changers has no bearing on our findings.

[9] We also estimated models where we excluded the last year of work for each teacher entirely and obtained results nearly identical to those reported below. Further, we considered models that allow for a trend of declining productivity starting in the second-to-last-year of work, but we did not find evidence of a trend (although we note that our data panel is not well-suited to investigate the potential for a trend of declining productivity because it is too short – see Section IV).

will become clear below, some teachers in our sample are ineligible for the "retained teacher" designation. The purpose of this control is to capture any systematic performance differences associated with retention eligibility so that they will not confound the retiree-to-retiree comparisons.

Teacher Classification Details

The first subgroup of exiting teachers, denoted by PE_{ijt}, are premature exiters. Premature exiters leave teaching prior to reaching the first pension-wealth spike in the Missouri system. Because a large fraction of observed exits are premature by this definition (see Section IV), we further divide premature exiters into three subgroups based on teaching experience at the time of exit: those with 0-4 years of experience, 5-9 years of experience, and 10 or more years of experience.

The next group of exiting teachers are retained teachers, denoted by RT_{ijt}. We define retained teachers as those who retire within one year of reaching the first pension-wealth spike in the Missouri system, but prior to becoming eligible for full retirement under the rule-of-80.[10] We hypothesize that retained teachers are the most likely to have been held in the profession by the pension system up to the point of their observed exits, as evidenced by their quick retirements upon becoming collection eligible.[11]

The third group of exiting teachers, denoted by TR_{ijt}, are teachers who we identify as typical retirees. For the purposes of our analysis, a "typical" retirement occurs when the teacher does not exit until she is eligible to collect under the rule of 80, but does exit within three years of attaining eligibility. Typical retirees are likely influenced by both the pull and push incentives in the pension

[10] We include teachers with 25 or 26 year of experience in this group to increase our sample size. If we rigidly define retained teachers as those who exit with exactly 25 years of experience we get similar, noisier results. In a robustness test below we also include teachers who exit with 24 years of experience in the "retained" group, which would be reasonable if these teachers actually reached 25-and-out but there is measurement error in data.

[11] Per the above discussion, note that some teachers (e.g., late entrants) have age-experience profiles such that they will reach the rule-of-80 prior to attaining 25 years of service, making them ineligible for retained status based on our definition. We account for potential performance differences between teachers related to retention-eligibility directly in our models (see Equation (2)).

system. Prior research shows that a large fraction of teachers exit within the first few years of becoming eligible for full retirement (Podgursky and Ehlert, 2007).

Finally, the fourth group of exiting teachers consists of "pushed-out" teachers, denoted by PO_{ijt}. We define pushed-out teachers as those who work for more than three years after becoming eligible for benefit collection under the rule of 80, and are observed exiting at some point during the data panel. Returning to Figure 1, note that these teachers are working over the range of the career cycle where pension wealth meaningfully declines with continued work. To illustrate the power of the "push" incentives, note that a typical pushed-out teacher as defined in our main analysis could exit teaching with a pension that replaces approximately 80 percent of her income (based on her highest three years of earnings). Furthermore, she would no longer be required to contribute to the pension plan. Her effective replacement rate, then, would exceed 90 percent; or put differently, her real pecuniary compensation for continued work would amount to pennies on the dollar.

We assign a static "type" to each teacher based on her observed exit behavior. For example, if a teacher is observed exiting the profession as a pushed-out teacher in the second year of our data panel, she is coded as a pushed-out teacher in the first year as well. This is her "type." By virtue of the static definitions, our models are designed to capture fixed quality differences across teacher types. Table 1 summarizes the teacher classifications that correspond to the exit variables.

The structure of the model in equation (2) facilitates a number of comparisons. We are particularly interested in retiree-to-retiree comparisons. If the pension incentive structure is related to teacher quality, it suggests that there is a sharp change in teacher quality over a fairly narrow range of the career cycle around the time when retirements are targeted. Our models also facilitate comparisons between retirees and pre-retirement exiters, as well as various non-retiree subgroups.

Finally, note that we do not include controls for observable teacher characteristics in our main models. In addition to the fact that observable teacher characteristics typically do not have significant impacts on student achievement (with the exception of teacher experience), the larger issue for our work is that we wish to attribute any quality differences across teachers to the exit-type variables, even if the differences coincide with observable teacher characteristics. If the pension system leads teachers with particular characteristics to stay in the profession longer or leave earlier, our interest is in the net quality effect, regardless of whether the teachers differ in observable or unobservable ways.[12]

IV. Data

We use administrative panel data from the state of Missouri for our analysis. Student test scores in math and communication arts (reading), with links to classroom-teacher assignments, are available statewide for students during three school years: 2008-2009, 2009-2010 and 2010-2011. We also have several years of prior test-score data for students. We standardize all student test scores by subject, grade and year. Our evaluation focuses on elementary teachers in self-contained classrooms in grades four, five and six.[13] Basic descriptive statistics for the dataset are provided in Table 2.[14]

The data include information about student race, gender, free-lunch status, language status and mobility status. We aggregate the student-level information to the building level to construct measures of school compositions. As discussed above, and shown in Table 1, we use information about teachers' age-experience combinations to divide observed exits from teaching into the different exit categories. Our main regression model in (2) requires data from multiple time periods for each year-cohort of students – we use year *t* information about students, schools and teachers; year *(t-1)* information about student test scores; and information from at least one future year to

[12] We add controls for teacher experience in an extension of the model shown in equation (2). See Section V for details. As a practical matter, none of our comparative findings are qualitatively sensitive to whether we include observable teacher characteristics in our models or not.
[13] We cannot use data from earlier grades because no pre-test is available for students.
[14] We exclude students and teachers from Kansas City and St. Louis from our analysis because the two urban districts operate their own pension systems. Both of the urban-district pension systems have different parameters, with a key difference being that both are characterized by a single pension-wealth spike. Less than 10 percent of the teachers and students in Missouri are excluded from our analysis because they are in Kansas City or St. Louis.

categorize teachers based on their mobility and exit behaviors (we have access to personnel data through 2011-2012 to identify teacher types). The analytic sample includes data from over 200,000 unique students taught by 7,275 unique teachers (see Table 2).

V. Results

Tables 3 and 4 show the estimated effects for exiting and continuing teachers on student achievement in math and reading, respectively.[15] Each column in each table shows results from a different version of the model shown in equation (2). The first four columns in each table show results from models without school fixed effects; the last four columns show models where school fixed effects are included.

The estimates reported in the tables are relative to an omitted comparison group that is changing as we change the set of explicit controls moving across models. The most important comparisons do not involve the omitted comparison group at all (i.e., comparisons between the retiree types); however, we briefly describe how the omitted group changes across models for ease of interpretation. First, in columns (1) and (5) we compare all retirees (retained, typical, pushed-out) to all other teachers in the workforce. Columns (2) and (6) use the same omitted comparison group, but we separately estimate the effects of the different retiree types to facilitate retiree-to-retiree comparisons. In columns (3) and (7) we include explicit controls for the other types of exiters in the data, which changes the omitted comparison group to include all *non-exiting* teachers. However, note that the comparison-group change is substantively small when we move to columns (3) and (7) because most teachers are not observed exiting over the course of the data panel. Finally, in columns (4) and (8) we add controls to measure teacher performance by experience level. The experience-level controls, in combination with the exiter controls, have the net result of shrinking the omitted comparison group to include only *non-exiting novice* teachers (with five or fewer years of experience).

[15] Estimates for the other coefficients from the main models are reported in Appendix Table B.2.

In the discussion that follows we restrict our attention to the school-fixed-effects models in columns (5) through (8) in each table, although our results are substantively similar with and without school fixed effects.[16] The estimates of interest are for retirees (in the first four rows of the tables). The other estimates are provided for comparative purposes. Also, at the bottom of each table we report coefficients that measure productivity during the last-year-of-work for each exiter type. These heterogeneous last-year-of-work controls purge the main estimates of productivity declines in the terminal year for exiting teachers. Although the pattern of estimates for the last-year-of-work indicators offers some insights, from our perspective they are nuisance parameters. That is, we are interested in general productivity differences across worker types (retirees in particular), and for this reason we do not want to overweight differential performance declines during the final year of work.[17]

We begin by comparing retirees to non-retirees in column (5) of each table. Our estimates provide no indication that retirees, on average, differ from the typical non-retiring teacher. In column (6) we split retirees into the three groups: retained teachers, typical retirees and pushed out teachers. Based on the pattern of career-cycle wealth accrual shown in Figure 1, two natural hypotheses emerge. The first is that retained teachers are the most effective of the three retiree types. That is, if the structure of wealth accrual is designed to improve workforce quality, the teachers who are the most likely to have been retained by their pension incentives (as evidenced by their leaving the system quickly upon becoming collection eligible) should be the ones who are performing at the highest level in the classroom. However, none of the estimates in Tables 3 and 4

[16] The similarity is consistent with a minimal effect of sorting bias in the estimates from the models without school fixed effects, which is in line with recent findings by Chetty et al. (2011).

[17] The estimates in Tables 3 and 4 suggest that there are productivity declines in the terminal year across most teacher types, but there is heterogeneity across types in the magnitude of the decline. In an omitted analysis we also look for a trend in declining productivity leading up to exit by examining second-to-last-year-of-work effects. We do not find consistent evidence of a productivity decline in the second-to-last-year of work.

indicate that retained teachers are particularly effective, and to the contrary, in math their point estimates suggest that they perform *worse* than typical retirees and pushed-out teachers.[18]

A caveat to our findings for retained teachers is that our standard errors are large, and particularly in reading we cannot rule out that retained teachers are more effective than typical retirees and pushed-out teachers. However, the source of our large standard errors is noteworthy: there are very few retained teachers. Returning to Table 2, typical retirees outnumber retained teachers in our data by a ratio of nearly 7-to-1, and pushed-out-teachers outnumber retained teachers by a 6-to-1 ratio. In addition to our estimates giving no indication that retained teachers are more effective, the fact that there are so few retained teachers raises questions about the general value of the retention benefits of the pension structure.[19]

The next hypothesis suggested by Figure 1 is that pushed-out teachers are less productive than typical retirees. A finding along these lines would be consistent with the work disincentives that these teachers face enhancing workforce quality. However, we again find no evidence to support this hypothesis. Pushed out teachers are indistinguishable from typical retirees in both math and reading.

The retiree-to-retiree comparisons provide no indication that the powerful pull and push incentives that teachers face in close proximity to the targeted retirement date are related to teacher performance. The teachers who are the most likely to be held in the profession by their pension incentives do not perform any better than other teachers leading up to their ultimate retirements, and there appear to be very few of these individuals. Teachers working in the "push" region of the

[18] In math, the p-value from a test for equality between the effects of retained teachers and typical retirees is 0.04; for the same test comparing retained teachers to pushed-out teachers the p-value is 0.09 (both of these p-values are based on estimates from the model in column 8, although test results using the other models are similar). In reading the point estimates for retained teachers are marginally higher than for the other retirees, but the differences are not statistically significant.

[19] This is consistent with previous research by Harris and Adams (2007), who compare teachers to other professionals and find limited evidence of a retention effect. Note that one reason that we may observe relatively few retained teachers is that some teachers are ineligible for "retained" status (e.g., late entrants into teaching who reach the rule-of-80 before accruing 25 years of system service); however, roughly two-thirds of the teachers in our sample are eligible for "retained" status based on their age-experience combinations – enough that the lack of eligibility alone is insufficient to explain the small number of retained teachers.

incentive structure are no less effective than other retirees despite their being encouraged to retire by the pension structure.

Next we compare retirees to specific groups of non-retirees using the models in columns (7) and (8). In column (7) we include explicit controls for exiters who are retirement-ineligible. Overall, retirees perform similarly to other exiters, with the exception of exiters with fewer than five years of experience (who are particularly ineffective – also see Boyd et al., 2008).

In column (8) we add controls for differences in teacher performance by experience level. The coefficients for retirees in column (8) compare them directly to continuing teachers with 15-plus years of experience; correspondingly, the total retiree effect for each retiree-type is the summation of the retiree coefficient and the coefficient for teachers with 15 or more years of experience.[20] In math, typical retirees and pushed out teachers are statistically indistinguishable from other teachers with 15 or more years of experience, while retained teachers appear to be less effective. In reading, all retirees are statistically indistinguishable from other teachers with 15 or more years of experience. Note that the group of teachers with 15-plus years of experience includes retirement-eligible and ineligible teachers – in an omitted analysis we confirm that there are not statistically significant performance differences between teachers with 15 or more years of experience who differ in terms of retirement eligibility.[21,22]

Perhaps it is more interesting to compare retirees to less-experienced teachers. Tables 3 and 4 show that typical retirees and pushed-out teachers are no more effective, on average, than teachers

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[20] With the exception of a very small number of cases where rule-of-80 eligible retirees work with fewer than 15 years of experience during the data panel (i.e., particularly late entrants into teaching).

[21] Because retirement-eligible teachers typically retire quickly, the majority of the teachers in the data working with 15-or-more years of experience are not eligible for retirement. In our data, only 9.4 percent of observed teaching years by teachers with 15 or more years of experience are from teachers who are eligible for retirement.

[22] We also estimated models analogous to those shown in column (8) but where we replace the experience "bins" with experience indicators for every level of experience. The retiree-to-retiree comparisons are qualitatively unchanged, and in fact, the retiree coefficients relative to experienced non-retirees are similar as well. Our findings in this regard are consistent with previous research which shows that there are not significant quality differences between teachers who differ in experience late in their careers (e.g., see Clotfelter et al., 2006; Wiswall, 2011).

with five or more years of experience.[23] The comparisons by teacher experience are important because considerable resources are devoted to narrowly target teacher retirements through the pension system. The fact that teachers working near the targeted retirement date are no more effective than their much-younger peers raises questions about the value of this aspect of the pension structure. For example, it seems reasonable to ask why the retirement target is not set at a much younger or older age, or abandoned altogether. The data do not reveal anything particularly special about the currently-targeted retirement timing.

The key challenge in interpreting our findings is that we do no observe a true counterfactual environment where teachers are not enrolled in a DB pension system.[24] However, it is notable that across all of the observational comparisons that are afforded by the data, no evidence emerges that links the powerful pension incentives to workforce quality.

VI. Robustness and Other Issues

Sensitivity Analysis

We begin by considering the robustness of our findings to adjustments to the definitions of the retiree groups. First, we re-define retained teachers as having 24, 25 or 26 years of experience without reaching the rule of 80. This definition assumes that individuals who are observed exiting with 24 years of experience, and prior to reaching the rule of 80, represent measurement error in the data. A notable source of measurement error is that in some instances teachers can buy years of service toward retirement, which can be particularly lucrative near the pension-system spikes. Purchased service years are not recorded in the data.

[23] We performed statistical tests for coefficient equality to verify that the visual patterns in the output in Tables 3 and 4 are not misleading. The interpretation provided in the text – that typical retirees and pushed-out teachers perform similarly to other teachers with at least 5 years of experience – is supported by the statistical tests.
[24] This limitation reflects a general lack of data availability because educators are nearly universally enrolled in DB pension plans, or at the least, pension plans with a sizeable DB component (e.g., see Hansen, 2010).

We also adjust the definition of pushed out teachers by differentially categorizing teachers who are observed working well beyond their rule-of-80 year. Using our definition in Table 1, all teachers who work for more than three years after their rule-of-80 year are defined as pushed out (as long as they are observed exiting over the course of the data panel). However, one could argue that particularly late-exiting teachers are unresponsive to their pension incentives, in which case it would be inappropriate to attribute their behaviors to the pension system. With this in mind, we alternatively define pushed-out teachers as those who work for between 4 and 7 years after reaching the rule of 80. That is, we remove particularly late-exiting teachers from the "pushed-out" group.[25]

Table 5 reports results using the new teacher definitions.[26] For brevity we only report estimates from the models shown in columns (2) and (6) in Tables 3 and 4. The estimates in Table 5 are consistent with our main results. We conclude that our findings are robust to reasonable adjustments to the definitions of the retiree groups.

Next we consider an alternative group of potentially "retained" teachers by dividing typical retirees into two groups; one that includes teachers who are observed retiring immediately upon attaining eligibility for full retirement under the rule-of-80, and another that includes typical retirees who teach for at least one additional year after becoming eligible. Table 6 reports our findings in the same format as Table 5.

A limitation of dividing the typical-retiree group is that we lose precision in the process.[27] Noting this caveat, our findings do not indicate that "immediate" and "non-immediate" typical retirees are differentially effective. In reading even the nominal differences between the two

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[25] These late-exiting teachers are essentially working for free. They may view teaching as leisure, or alternatively, they may not understand their pension incentives (Chan and Stevens, 2008; Gustman and Steinmeier, 2004).

[26] Minor adjustments to the other exiting groups are made to facilitate the adjusted definitions for retained and pushed-out teachers where appropriate. For example, when we modify our definition of "retained" teachers to include individuals with 24 years of experience at the time of the observed exit, we adjust the "premature 3" group to exclude these individuals.

[27] Immediate exiters are marginally underrepresented among typical retirees, although the underrepresentation is not statistically significant (they account for 28 percent of all typical retirees– if they were evenly represented they would account for one-third of all typical retirees).

subgroups are very small. In math, the point estimates are suggestive of a difference, but they are sufficiently noisy that they cannot be statistically distinguished. Also note that the gap in the point estimates for immediate and non-immediate typical retirees in math partly offsets a larger gap in the point estimates during the terminal work year, which goes in the opposite direction.[28] Although statistical imprecision limits the inference from Table 6 to some degree, the evidence does not indicate that retained teachers by this alternative definition are substantively different than other typical retirees.

Sources of Bias

We have shown that our findings are robust to changing the way that students are linked to teachers, and to adjusting the definitions for retirees. But the general concern remains in all of the previous models that unobserved differences in the working conditions for teachers could contribute to the retirement behaviors that we observe, and to student achievement, which would make the retirement variables endogenous. As a specific example, it could be that teachers who stay in the profession longer than is typical, whom we categorize as "pushed-out," do so partly because of favorable working conditions that are positively related to student achievement and poorly proxied by the controls in our models. Similarly, retained teachers might exit immediately upon becoming benefit-eligible because their working conditions are unfavorable. If our models do a poor job of controlling for the relevant aspects of the schooling environments for teachers, then our estimates may not reflect true differences in teaching performance between retirees and non-retirees, and across retiree groups.

[28] Like with the other differences between immediate and non-immediate retirees, the last-year-of-work differences are also too noisy to be more than suggestive. The pattern of the nominal differences in point estimates, if taken literally, is consistent with either (a) immediately-retiring typical retirees supplying less effort than other typical retirees in the terminal year and/or (b) immediately-retiring typical retirees responding to a particularly bad year, which just happens to coincide with their becoming retirement eligible, by retiring. We cannot distinguish between these competing explanations with our data.

Two aspects of our analysis suggest that any bias from factors related to unobserved differences in working conditions is small. First, in unreported results we confirm that our findings are robust to using school-by-grade links in place of the classroom links, which limits concerns about systematic student-teacher sorting bias along the lines of those raised by Rothstein (2010).[29] Second, our richest models include thorough sets of student- and school-level covariates, including lagged test scores for students, and school fixed effects. In the models that include school fixed effects, any bias from differences in the favorability of schooling environments across retirees must come from within-school differences, which are plausibly small.

Although the potential for bias in our estimates seems limited, we nonetheless perform a secondary regression analysis to directly address the bias concern. The secondary model is adjusted to be time-inconsistent. Specifically, we estimate the same model as in equation (2), but lag the test-score variables for students by an additional year. That is, we regress year-(*t-1*) achievement on year-(*t-2*) achievement, and otherwise use year-*t* information to predict outcomes. If particular teacher-types are systematically assigned students with particular achievement-growth histories (which, per Rothstein (2010), would potentially introduce bias into our estimates) the time-inconsistent models will uncover these patterns. A limitation of the time-inconsistent models is that we can only evaluate students in grades 5 and 6; students in grade-4 do not have second-lagged test scores. This reduces the estimation sample substantially, although a large enough sample remains to perform the analysis.[30]

Table 7 reports our findings from the time-inconsistent models in math and reading, using model (6) from Tables 3 and 4. Because the analytic sample in Table 7 is fundamentally different (we drop all grade-4 students), we first re-estimate the main models from Tables 3 and 4 using the

[29] The results from our school-by-grade linked models are broadly similar to those reported in the text.
[30] Note that most of the students in our analytic sample are in grades 4 and 5 – most grade-6 students in Missouri attend middle schools where students are not in self-contained classrooms. Correspondingly, when we drop grade-4 students from the time-inconsistent models are sample sizes decline by nearly 50 percent.

restricted sample. The updated, real estimates are reported in the first and third columns of Table 7 for math and reading, respectively. The second and fourth columns of the table report our findings from the time-inconsistent models. In the absence of bias from systematic sorting, our estimates in columns (2) and (4) should be statistically indistinguishable from zero, which is what we find in both the math and reading models. Table 7 provides no indication that our primary findings are biased by unobserved student-teacher sorting.[31]

Misclassification Error

The way that we define exits and retirements is likely to result in some misclassification error. There are two misclassification issues that merit attention. First, some teacher exits are unplanned. As an example, consider an exit that occurs because of an unexpected medical event immediately after a teacher attains her 25^{th} year of service. We would interpret the exit as evidence that the teacher belongs to the "retained" group; but she may be very different from the typical teacher who *plans* to exit immediately after reaching her 25^{th} year of service. Similarly, happenstance teacher exits that coincide with any of the exit definitions will lead to teacher misclassifications. Misclassification errors along these lines will attenuate differences in teaching performance across the exiter subgroups, although we expect these types of errors to be uncommon.

Another source of misclassification error comes from how we identify exits using the data. Specifically, we identify exits based on whether teachers re-appear in the data panel in future year(s). So, for example, a "typical retiree" is defined as such if she is observed teaching up until she reaches the rule-of-80, and then is no longer observed in the data panel. To maximize the use of available data, a teacher can be classified into an exit category based on as little as a single year of information looking forward; extending the previous example, the typical retiree in question may have worked up

[31] We also test for coefficient equality between the regular and time-inconsistent models for each teacher type and in each subject (six tests in all). We bootstrap to obtain the covariance parameters that are required to construct the test statistics in each case (our procedure follows Bhatt et al., forthcoming). We cannot reject the null hypothesis of coefficient equality between the regular and time-inconsistent models in any of the tests.

through 2010-2011 and not shown up in the 2011-2012 data to earn her designation. But the possibility that she reappears in 2012-2013 – which is beyond our data panel – cannot be precluded. We examine the prevalence of misclassification errors along these lines in Appendix B. In brief, while misclassification errors do occur they are rare, particularly for teachers who are classified as exiting into retirement. Put differently, while some early-career exiters are misclassified because they leave and come back, late-career teachers rarely move in and out of the data panel. We conclude that attenuation bias from misclassification errors along these lines will be small.

VII. Additional Workforce Effects

Initial Selection into Teaching

A limitation of our study is that we condition on individuals who initially select into teaching (i.e., we do not have data from individuals who choose not to teach). If the structure of teacher pension systems affects the initial entry decision, which seems likely given the substantial fraction of compensation that pension benefits represent for teachers (Costrell, 2011; Koedel et al., 2012), this should also be incorporated into a broader evaluation of the compositional effects of pension systems. Current data prevent a formal analysis of initial selection because teachers are nearly universally enrolled in DB pension plans. Policy experimentation in this area would open up the possibility for direct research on this issue.[32]

In the absence of formal evidence, we note that economic theory suggests that heavily backloaded teacher pension plans will not be an effective recruiting tool for high-quality young teachers, particularly as the workforce becomes more mobile. For example, the pension structure penalizes mobility, and Groes et. al. (2010) show that across the top 80 percent of the ability spectrum, job mobility is positively related to general ability and productivity. If higher ability

[32] One interesting potential source of policy variation is charter schools. In sixteen states charter schools can opt out of state teacher pension plans and set up their own plans, and many have chosen to do so. There has been almost no research on the charter school experience in this area (Olberg and Podgursky, 2011).

individuals place higher *ex ante* probabilities on exits from teaching, as evidence suggests they do (e.g., Murnane and Olsen, 1990; Podgursky, Monroe, and Watson, 2004), then the backloaded structure of pension-wealth accrual will be unattractive. Thus, we would not expect a DB pension system to entice entry by high-ability individuals, especially when compared to more mobile retirement benefits such as 401k plans, or simply higher salaries.

Teacher Turnover

Even if the pension incentives have a neutral effect on workforce quality through their effects on the pattern of exits, it is still possible that they could affect workforce quality by affecting the overall level of turnover. In a steady state, higher teacher turnover would mean more novice teachers in the workforce. Because novice teachers are less effective on average, this would mean a lower level of workforce quality. This leads to arguments along the lines of those by Weller (2011), who postulates that teacher pension systems raise workforce quality by lowering teacher turnover.[33]

We are not aware of any direct evidence on how teacher pension systems affect turnover (a key reason, again, is the lack of an observed counterfactual). Some of the best indirect evidence comes from Harris and Adams (2007), who compare job mobility in teaching and several other professions over the course of the career cycle (nursing, social work, accounting). They show that job mobility for teachers is similar to mobility in other professions, with the exception that exits from the labor force among teachers begin at earlier ages. Their analysis suggests a minimal role for the retention effects of teacher pension systems and a larger role for the push-out effects (which is consistent with our findings), with the net result being higher turnover.

Costrell and McGee (2010) also evaluate pension-system effects on turnover indirectly and reach a similar conclusion. They estimate a model of Arkansas teacher exits as a function of pension

[33] Weller's claim is based on general labor market studies comparing workers with and without pensions. However, the "no pension" condition does not seem to be the relevant counterfactual. More relevant would be fiscally equivalent compensation schemes with: a) higher salaries and less generous pensions, and/or b) less backloaded pensions like defined contribution, cash balance, or "hybrid" mixes of DB and DC.

wealth accrual, and use the model to simulate the effect of a fiscally equivalent "cash balance" plan that has smooth wealth accrual and no push or pull incentives. They find that the transition to such a plan would modestly increase average teacher tenure.

We noted earlier that incentives of the current system concentrate teacher retirements at a relatively early age (57 years). It is costly to support a retirement system with such an early retirement age. If these same plans were designed to align retirement to more traditional ages (e.g., at the Medicare-eligible age of 65 or the minimum Social Security retirement age of 62), not only would benefit costs fall dramatically due to fewer years of retirement benefits, but there would be fewer novices in the steady state workforce, thus increasing overall effectiveness.[34]

District Fiscal Savings

A common argument made for the strong "push" incentives in teacher pension systems is that they produce savings for school districts as higher-salaried senior teachers are replaced by less-expensive new teachers. Indeed, in addition to the early retirement incentives built into most state plans, one routinely sees language in teacher collective bargaining agreements providing incentives, either in lump sum payments or salary increases, to educators who pre-commit to retire by a certain date.

Even if these early retirement plans produce fiscal savings, we have noted in the previous section that they come at a cost: more novice teachers in the workforce. However, simple back-of-the-envelope calculations suggest that the fiscal gains are illusory as well. Suppose that an early retirement incentive induces senior teachers with salary W_r to retire one year earlier. These early retirees are replaced by new teachers earning W_n. If $W_r = aW_n$, then the salary savings from inducing the retirement can be written as $(1 – (1/a))W_r$. Under the pension formula in Missouri, the salary replacement rate for a teacher with 30 years of experience is 75 percent. Thus, early retirements will

[34] Our estimates in Tables 3 and 4 show that novice teachers perform worse in the classroom. This results has been well-documented elsewhere as well – for example, see Clotfelter et al. (2006).

only pay off fiscally, accounting for the retiree's pension, if a > 4. This means that in a district with a salary schedule setting starting teacher pay at $30,000, the salary for retiring teachers would need to be at least $120,000. We are not aware of any salary schedules that are this steep. In fact, the average within-district value of the ratio W_r / W_n is close to two in Missouri, which is consistent with our review of the teacher salary schedules for the 50 largest school districts nationwide.[35] This suggests that the district savings from inducing early retirements *do not* reflect system-wide savings. Put differently, encouraging early retirements may save individual districts money, but the mechanism is that the burden is shifted to the entire system and overall costs rise. The ease with which school districts can shift costs to the larger system raises concerns about moral hazard.

VIII. Conclusion

We examine the link between the pull and push incentives in teacher pension systems and teacher quality using longitudinal micro data from Missouri. We find no evidence to suggest that the pension incentive structure increases teacher quality. While inference from our analysis is limited because we do not observe a true counterfactual, our consistent inability to link teachers' pension incentives to classroom performance given available data is troubling, particularly in light of the prevalence of DB pension systems in the education sector and the substantial resources that are devoted to fund these systems.

The backloading of wealth accrual in teacher pension systems produces large penalties for mobile teachers and substantially redistributes pension wealth away from short-spell teachers (Costrell and Podgursky, 2010). Given that alternative compensation schedules may affect the composition of the teaching workforce in positive ways, most notably by favorably influencing initial selection into the profession, experiments with systems that are more equitable for short-term or mobile teachers, or even front-loaded, merit consideration in lieu of the current structure of

[35] Collective bargaining agreements and teacher salary schedules for the 50 largest school districts are available on the National Council on Teacher Quality website: www.nctq.org.

lucrative, but distant, defined benefits.[36] TIAA-CREF serves as one example and is used in much of higher education; and in states where it is permitted, many charter schools have begun to implement their own defined contribution (DC) plans (Olberg and Podgursky, 2011). A DC-type mobile benefit (or simply higher starting salaries and fewer deferred benefits) may serve as an attractive tool for shortage-area teachers (e.g., those in STEM fields) – particularly if these individuals are not ready to commit at a young age to a full career in education. At the other end of teaching careers, one could easily imagine DROP or other retirement reemployment options that are only open to highly effective teachers. In short, teacher retirement plans, and the revenues devoted to them, might be used in more strategic ways to improve the quality of the teaching workforce.

[36] See Vigdor (2008). Also, work by Fitzpatrick (2011) suggests that most teachers would likely prefer a swap of some retirement benefits for more salary.

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Figure 1. Pension wealth accrual over the career cycle for a representative teacher in Missouri who began her career at the age of 25 and is currently 37 years old. Two spikes in pension-wealth corresponding to the early-retirement provisions are marked.

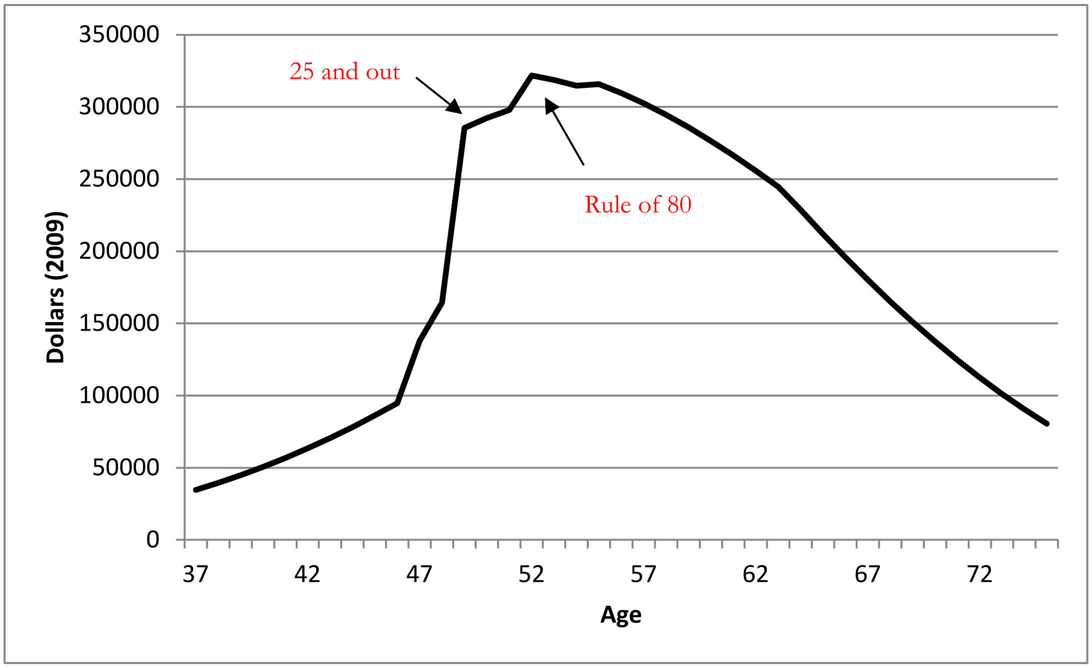

Table 1. Definitions for Groups of Exiting Teachers.

Teacher Group	Definition
Premature Exits 1 (PE_{isgt}^{t+1})	(Age + Experience) < 80, Experience < 5
Premature Exits 2 (PE_{isgt}^{t+1})	(Age + Experience) < 80, 5 ≤ Experience < 10
Premature Exits 3 (PE_{isgt}^{t+1})	(Age + Experience) < 80, 10 ≤ Experience < 25
Retained Teachers (RT_{isgt}^{t+1})	(Age + Experience) < 80, Experience = 25 or 26
Typical Retirees (TR_{isgt}^{t+1})	80 ≤ (Age + Experience) ≤ 85
Pushed-Out Teachers (PO_{isgt}^{t+1})	(Age + Experience) > 85

Note: There is a very small group of teachers who retire several years after reaching the 25-and-out provision, but before reaching the rule of 80, who are missed by the categorizations listed here. For completeness we control for these teachers as a separate group in the models, which allows us to retain our well-defined comparison groups. The parameter estimate corresponding to this group of teachers is estimated very imprecisely and is not of independent interest.

Table 2. Data Details.

<u>Data for Primary Model:</u>	
Schools	942
Unique teachers	7,275
Unique students	209,092
Total student test-score-gain records	299,478 (math) / 298,953 (com arts)
Fraction of test-score records that are dropped because a lagged score is unavailable for the student	5.55%(math) / 5.55%(com arts)
<u>Share of teachers classified as:</u>	
Exiters – premature 1	0.109
Exiters – premature 2	0.059
Exiters – premature 3	0.072
Retained teachers	0.003
Typical retirees	0.026
Pushed out teachers	0.022
<u>Age and experience information for non-exiting teachers in Missouri:</u>	
25^{th}, 50^{th} and 75^{th} percentiles of age distribution	29, 36, 45
25^{th}, 50^{th} and 75^{th} percentiles of MO exp. distribution	2, 7, 13

Table 3. Teacher Performance by Exit and Experience Categories. Math Models.

	Math-1	Math-2	Math-3	Math-4	Math-5	Math-6	Math-7	Math-8
All Retirees	0.012	--	--	--	0.008	--	--	--
	(0.014)				(0.014)			
Strictly Retained	--	-0.010	-0.017	-0.036	--	-0.064	-0.073	-0.103
		(0.046)	(0.046)	(0.047)		(0.041)	(0.041)†	(0.041)*
Typical Retiree	--	0.007	0.000	-0.018	--	0.015	0.007	-0.017
		(0.017)	(0.017)	(0.018)		(0.017)	(0.017)	(0.017)
Pushed Out	--	0.020	0.013	-0.006	--	0.006	-0.003	-0.028
		(0.025)	(0.025)	(0.026)		(0.023)	(0.023)	(0.024)
<u>Non-Retiree Exiters</u>								
Premature Exit 1	--	--	-0.040	-0.025	--	--	-0.052	-0.031
			(0.013)**	(0.013)†			(0.012)**	(0.012)*
Premature Exit 2	--	--	-0.002	-0.001	--	--	-0.022	-0.018
			(0.016)	(0.016)			(0.014)	(0.014)
Premature Exit 3	--	--	-0.016	-0.021	--	--	-0.019	-0.027
			(0.013)	(0.013)			(0.012)	(0.013)*
<u>Teacher Effects by Experience in Missouri</u>								
5-9 years	--	--	--	0.020	--	--	--	0.026
				(0.007)**				(0.006)**
10-14 years	--	--	--	0.012	--	--	--	0.022
				(0.008)				(0.007)**
15+ years	--	--	--	0.034	--	--	--	0.048
				(0.008)**				(0.007)**
<u>In final year of work:</u>								
All Retirees	-0.024	--	--	--	-0.018	--	--	--
	(0.015)				(0.015)			
Strictly Retained	--	0.004	0.005	0.005	--	0.032	0.034	0.035
		(0.059)	(0.059)	(0.059)		(0.056)	(0.056)	(0.056)
Typical Retiree	--	-0.034	-0.034	-0.034	--	-0.038	-0.037	-0.037
		(0.021)†	(0.021)	(0.021)		(0.021)†	(0.021)†	(0.021)†
Pushed Out	--	-0.012	-0.012	-0.012	--	0.002	0.003	0.003
		(0.025)	(0.025)	(0.025)		(0.024)	(0.024)	(0.024)
Premature Exit 1	--	--	-0.017	-0.017	--	--	-0.017	-0.017
			(0.014)	(0.014)			(0.013)	(0.013)
Premature Exit 2	--	--	-0.016	-0.022	--	--	-0.003	-0.012
			(0.017)	(0.017)			(0.016)	(0.016)
Premature Exit 3	--	--	-0.021	-0.022	--	--	-0.021	-0.023
			(0.014)	(0.014)			(0.014)	(0.014)
Student Covariates	X	X	X	X	X	X	X	X
School Covariates	X	X	X	X				
School Fixed Effects					X	X	X	X
R-Squared	0.62	0.62	0.62	0.62	0.63	0.63	0.63	0.64
N	299,478	299,478	299,478	299,478	299,478	299,478	299,478	299,478

Notes: Standard errors are in parentheses and clustered at the teacher level. The "final year of work" coefficients are estimated using data from the year preceding the observed exit. All models in columns 2, 3, 4, 6, 7 and 8 also include an indicator for teachers' retention eligibility.

** / * / † Indicates statistical significance at the 1/5/10 percent levels.

Table 4. Teacher Performance by Exit and Experience Categories. Reading Models.

	Read-1	Read-2	Read-3	Read-4	Read-5	Read-6	Read-7	Read-8
All Retirees	0.017	--	--	--	0.014	--	--	--
	(0.012)				(0.012)			
Strictly Retained	--	0.090	0.086	0.068	--	0.061	0.056	0.036
		(0.070)	(0.070)	(0.070)		(0.073)	(0.073)	(0.073)
Typical Retiree	--	0.002	-0.002	-0.019	--	0.002	-0.002	-0.020
		(0.016)	(0.016)	(0.017)		(0.017)	(0.017)	(0.018)
Pushed Out	--	0.024	0.020	0.002	--	0.023	0.018	0.001
		(0.019)	(0.019)	(0.019)		(0.018)	(0.018)	(0.018)
Non-Retiree Exiters								
Premature Exit 1	--	--	-0.031	-0.016	--	--	-0.041	-0.028
			(0.010)**	(0.010)			(0.010)**	(0.010)**
Premature Exit 2	--	--	0.007	0.011	--	--	0.004	0.008
			(0.012)	(0.012)			(0.012)	(0.012)
Premature Exit 3	--	--	0.002	-0.005	--	--	-0.001	-0.008
			(0.011)	(0.011)			(0.010)	(0.010)
Teacher Effects by Experience in Missouri								
5-9 years	--	--	--	0.016	--	--	--	0.012
				(0.005)**				(0.005)*
10-14 years	--	--	--	0.019	--	--	--	0.017
				(0.006)**				(0.006)**
15+ years	--	--	--	0.032	--	--	--	0.032
				(0.006)**				(0.005)**
In final year of work:								
All Retirees	-0.012	--	--	--	-0.010	--	--	--
	(0.014)				(0.014)			
Strictly Retained	--	-0.123	-0.123	-0.123	--	-0.109	-0.109	-0.108
		(0.079)	(0.079)	(0.079)		(0.079)	(0.079)	(0.079)
Typical Retiree	--	-0.002	-0.001	-0.001	--	-0.001	-0.001	-0.001
		(0.019)	(0.019)	(0.019)		(0.019)	(0.019)	(0.019)
Pushed Out	--	-0.008	-0.008	-0.008	--	-0.005	-0.005	-0.005
		(0.022)	(0.022)	(0.022)		(0.021)	(0.021)	(0.021)
Premature Exit 1	--	--	-0.011	-0.011	--	--	-0.008	-0.007
			(0.011)	(0.011)			(0.011)	(0.011)
Premature Exit 2	--	--	-0.029	-0.034	--	--	-0.025	-0.029
			(0.014)*	(0.014)*			(0.014)†	(0.014)*
Premature Exit 3	--	--	-0.025	-0.027	--	--	-0.022	-0.024
			(0.013)*	(0.013)*			(0.012)†	(0.012)†
Student Covariates	X	X	X	X	X	X	X	X
School Covariates	X	X	X	X				
School Fixed Effects					X	X	X	X
R-Squared	0.61	0.61	0.61	0.61	0.62	0.62	0.62	0.62
N	298,953	298,953	298,953	298,953	298,953	298,953	298,953	298,953

Notes: Standard errors are in parentheses and clustered at the teacher level. The "final year of work" coefficients are estimated using data from the year preceding the observed exit. All models in columns 2, 3, 4, 6, 7 and 8 also include an indicator for teachers' retention eligibility.

** / * / † Indicates statistical significance at the 1/5/10 percent levels.

Table 5. Robustness of Findings to Alternative Definitions for Retirees.

	Math-2	Math-6	Read-2	Read-6
<u>Exit Category</u>				
Strictly Retained	0.019	-0.012	0.056	0.031
	(0.036)	(0.038)	(0.047)	(0.047)
Typical Retiree	0.007	0.016	0.002	0.002
	(0.017)	(0.017)	(0.016)	(0.017)
Pushed Out	0.003	-0.011	0.014	0.014
	(0.026)	(0.025)	(0.020)	(0.019)
Residual Late Exits	0.081	0.068	0.059	0.056
	(0.066)	(0.054)	(0.043)	(0.041)
<u>In final year of work:</u>				
Strictly Retained	0.013	0.032	-0.058	-0.044
	(0.045)	(0.045)	(0.055)	(0.054)
Typical Retiree	-0.035	-0.038	-0.002	-0.001
	(0.021)†	(0.021)†	(0.019)	(0.019)
Pushed Out	0.006	0.024	0.012	0.015
	(0.026)	(0.026)	(0.025)	(0.024)
Residual Late Exits	-0.078	-0.072	-0.072	-0.071
	(0.064)	(0.056)	(0.045)	(0.043)†
Student Covariates	X	X	X	X
School Covariates	X		X	
School Fixed Effects		X		X
R-Squared	0.62	0.63	0.61	0.62
N	299,478	299,478	298,953	298,953

Notes: Standard errors are in parentheses and clustered at the teacher level. The column labels indicate the baseline models from which the estimates are obtained and reference the model numbers from Tables 3 and 4. The "final year of work" coefficients are estimated using data from the year preceding the observed exit. All models also include an indicator for teachers' retention eligibility.

Retained redefined as: exit occurs when experience = 24, 25 or 26 and (age+experience) < 80

Pushed-Out redefined as: exit occurs 4-7 years after reaching the rule of 80

Residual Late Exit: exit occurs later than for pushed-out teachers based on updated definition.

** / * / † Indicates statistical significance at the 1/5/10 percent levels.

Table 6. Estimates from Models where Typical Retirees are Divided into Two Groups: Those Who Retire Immediately Upon Attaining Rule-of-80 Eligibility and Those Who Do Not.

	Math-2	Math-6	Read-2	Read-6
Exit Category				
Strictly Retained	-0.010	-0.063	0.090	0.061
	(0.046)	(0.041)	(0.070)	(0.073)
Typical Retiree				
Immediate Retirement	0.033	0.051	0.002	0.005
	(0.038)	(0.035)	(0.027)	(0.029)
Non-Immediate Retirement	-0.003	0.002	0.002	0.001
	(0.018)	(0.018)	(0.020)	(0.021)
Pushed Out	0.020	0.006	0.024	0.023
	(0.025)	(0.023)	(0.019)	(0.018)
In final year of work:				
Strictly Retained	0.004	0.032	-0.123	-0.109
	(0.059)	(0.056)	(0.079)	(0.079)
Typical Retiree				
Immediate Retirement	-0.054	-0.073	-0.030	-0.025
	(0.040)	(0.037)*	(0.028)	(0.029)
Non-Immediate Retirement	-0.027	-0.025	0.010	0.008
	(0.024)	(0.025)	(0.024)	(0.024)
Pushed Out	-0.012	0.002	-0.008	-0.005
	(0.025)	(0.024)	(0.022)	(0.021)
Student Covariates	X	X	X	X
School Covariates	X		X	
School Fixed Effects		X		X
R-Squared	0.62	0.63	0.61	0.62
N	299,478	299,478	298,953	298,953

Notes: Standard errors are in parentheses and clustered at the teacher level. The column labels indicate the baseline models from which the estimates are obtained and reference the model numbers from Tables 3 and 4. The "final year of work" coefficients are estimated using data from the year preceding the observed exit. All models also include an indicator for teachers' retention eligibility.
** / * / † Indicates statistical significance at the 1/5/10 percent levels.

Table 7. Robustness Test for Student-Teacher Sorting Bias: Time-Inconsistent Models for Teachers in Grades 5 and 6 Only.

	Math-6 Actual	Math-6 Time-Inconsistent	Read-6 Actual	Read-6 Time-Inconsistent
Exit Category				
Strictly Retained	-0.046	-0.022	0.022	-0.053
	(0.041)	(0.084)	(0.064)	(0.076)
Typical Retiree	0.006	-0.019	0.009	-0.012
	(0.022)	(0.021)	(0.027)	(0.023)
Pushed Out	0.033	0.000	0.004	-0.012
	(0.028)	(0.021)	(0.020)	(0.018)
In final year of work:				
Strictly Retained	0.054	-0.032	-0.004	-0.011
	(0.068)	(0.069)	(0.076)	(0.063)
Typical Retiree	-0.052	0.037	0.002	-0.018
	(0.030)†	(0.031)	(0.028)	(0.028)
Pushed Out	-0.032	0.008	0.014	0.001
	(0.031)	(0.029)	(0.026)	(0.028)
Student Covariates	X	X	X	X
School Covariates				
School Fixed Effects	X	X	X	X
R-Squared	0.67	0.63	0.63	0.62
N	159,145	151,762	158,881	151,450

Notes: Standard errors are in parentheses and clustered at the teacher level. The column labels indicate the baseline models from which the estimates are obtained and reference the model numbers from Tables 3 and 4. The estimates in the columns labeled "Actual" are from equation (2), excluding grade-4 teachers (for whom we do not observe their students' lagged achievement gains). The estimates in the columns labeled "Time Inconsistent" use year-*t* teacher types to predict test-score growth between years (*t-2*) and (*t-1*). Some students are missing second-lagged scores, which is why the sample sizes are not identical between the actual and time-inconsistent models. All models also include an indicator for teachers' retention eligibility

** / * / † Indicates statistical significance at the 1/5/10 percent levels

Appendix A
Pension-Wealth Calculations

Our pension-wealth calculations are for a representative female teacher in Missouri who was 37 years old in 2009 and began as a teacher at the age of 25. To calculate her pension wealth we use the following information: (1) age, (2) system experience and (3) earnings, or expected earnings, for the three years prior to exit.

We determine the representative teacher's survival probabilities over the life cycle using the Cohort Life Tables provided by the Social Security Administration. We project out future wages using a growth function that depends on teaching experience. The parameters of the growth function come from a regression based on an 18-year data panel from Missouri where we regress teacher wages on a cubic function of experience. The function captures real wage growth, and wages are also adjusted for inflation. The representative teacher in Figure 1 starts with the base wage typical of a 37-year-old teacher in Missouri, and the growth function adjusts the wage profile moving forward so that *FAS* can be calculated after each possible exit date.

Our PDV calculations also require that we specify a real discount rate. We use a real discount rate of 4 percent in our calculations, which allows for a positive real interest rate and some time preference in earnings.[37] Our calculations are sensitive to adjustments to the discount rate. For example, halving the real discount rate roughly doubles the peak-value of pension wealth in Figure 1. But substantively, our findings depend on the presence of the pension-wealth spikes, and the subsequent decline in pension-wealth late in the career cycle. As long as the true discount rate isn't so large as to negate the economic meaning of these features of the pension system, an accurate characterization of the actual discount rate is not important for our work.

[37] Our choice of a four-percent real discount rate falls somewhere in between what others have used in the literature. For example, Coile and Gruber (2007) use 6 percent, and Costrell and Podgursky (2009) use 2.5 percent.

For the representative teacher in Figure 1, after each year of work we identify the optimal collection age assuming that the teacher exits after that year, then calculate the PDV of the expected stream of pension payments over the life cycle. An individual's pension-wealth at time *s*, with collection starting at time *j*, where $j \geq s$, can be written as:

$$\sum_{t=j}^{T} Y_t * P_{t|s} * d^{t-s} \qquad \text{(A.1)}$$

In (A.1), Y_t is the annual pension payment in period *t*, $P_{t|s}$ is the probability that the individual is alive in period *t* conditional on being alive in period *s*, and *d* is the discount factor.[38]

[38] In our calculations we set T = 101, although after accounting for the impact of discounting and the survival probabilities the calculations are qualitatively insensitive to reasonable adjustments to this threshold.

Appendix B
Supplementary Tables

Appendix Table B.1. Key Parameters of the Missouri Pension System, 1995 – 2009 (there were no changes after 2002). Initial Parameters as of 1995 are Reported in Row 1.

	PSRS
1995*	Formula factor 0.023, early retirement by 55-25 rule, COLA cap 65 percent
1996	Implement unrestricted "25 and out"
1997	COLA cap increased from 65 to 75 percent
1998	
1999	Formula factor raised to 0.025 for full retirement (with corresponding upward adjustments for early retirement)
2000	Implement Rule of 80, FAS changed to highest three years of salary
2001	COLA cap increased to 80 percent
2002	Formula factor increased to 0.0255 if YOS $\geq$ 31 (new factor applies to *all service years* for eligible individuals)

* Notes: The 55-25 rule is a more-restrictive version of the rule of 80. It requires a teacher to have at least 25 years of service and be at least 55 years old to retire.

Appendix Table B.2. Estimates for the Other Coefficients from Equation (2).

	Math-6	Read-6
Lagged Score	0.717	0.708
	(0.002)**	(0.002)**
American Indian	-0.051	-0.027
	(0.015)**	(0.017)
Asian	0.148	0.115
	(0.009)**	(0.009)**
Black	-0.114	-0.090
	(0.004)**	(0.004)**
Hispanic	-0.014	-0.011
	(0.006)*	(0.006) †
Female	-0.004	0.043
	(0.002)*	(0.002)**
Free Lunch Eligible	-0.103	-0.108
	(0.002)**	(0.002)**
Special Education	-0.197	-0.224
	(0.004)**	(0.004)**
English as Second Language	-0.065	-0.102
	(0.009)**	(0.009)**
Mobile Student (in building less than one year)	-0.069	-0.057
	(0.011)**	(0.011)**
Teacher is Retention Eligible	-0.008	-0.003
	(0.004)†	(0.004)
Student Covariates	X	X
School Covariates		
School Fixed Effects	X	X
N (student test-score records)	299,478	298,953

Notes: Standard errors are in parentheses and clustered at the school-by-grade-by-year level. These estimates are from the models shown in column (6) in Tables 3 and 4, but similar estimates are obtained in the other specifications. The school-fixed-effects models omit the time-varying school level controls. See text for details.

** Indicates statistical significance at the 1 percent level.

* Indicates statistical significance at the 5 percent level.

† Indicates statistical significance at the 10 percent level.

Appendix Table B.3. An Investigation of Classification Errors for Teacher Types Using Data for teachers from the 2008-2009 and 2009-2010 Cohorts Only.

Exit Classification	Exits Determined Using Personnel Data Through 2010-2011 Only	Exits Verified Using Personnel Data Through 2011-2012
Premature Exits 1 (PE_{isgt}^{t+1})	9.76%	9.05%
Premature Exits 2 (PE_{isgt}^{t+1})	5.03	4.55
Premature Exits 3 (PE_{isgt}^{t+1})	5.95	5.30
Retained Teachers (RT_{isgt}^{t+1})	0.31	0.29
Typical Retirees (TR_{isgt}^{t+1})	1.75	1.73
Pushed-Out Teachers (PO_{isgt}^{t+1})	1.81	1.80

Notes: Estimates are from the 2008-2009 and 2009-2010 cohorts of teachers only.

Appendix Tables B.1 and B.2 are self-explanatory. In Appendix Table B.3 we examine the extent to which there are likely to be misclassification errors in the teacher-type designations in our main dataset. A key concern is that teachers' exit behaviors are coded based on whether they disappear from the data panel, but some teachers who disappear in the final year of the panel may return at a later time (teachers who disappear and return in earlier years are not miscoded, but for teachers who disappear in the last year we cannot observe their returns if they occur).

We investigate the extent to which this issue is likely to result in misclassification errors, and subsequently attenuation bias in our estimates, by focusing on the subsample of teachers who are observed teaching during the 2008-2009 and 2009-2010 school years. First, we code the exit and retirement variables for these teachers using information only through 2010-2011 to determine who exited. This replicates the conditions under which teachers in our main analysis are classified. Then we use an additional year of post-analysis data – 2011-2012 – to look for misclassification errors in the teacher categorizations. So, for example, if a teacher left after the 2009-2010 school year as a premature exiter and did not show up in the 2010-2011 data, but then returned in 2011-2012, this would be a case where the teacher's type would have been misclassified using the main classification system (e.g., she may not be a premature exiter – she may have simply taken a one-year leave).

Appendix Table B.3 shows the shares of teachers from the 2008-2009 and 2009-2010 school years who are classified into each exit category, with and without the extra year of data to confirm their exit behaviors. The results are intuitive – younger teachers are more likely to move in and out of the workforce, and therefore there are more errors for these teacher-types. However, there are few errors for the retiree groups because retirement-eligible teachers rarely leave and come back. We conclude that our primary findings for retirees are essentially unaffected by misclassification errors in the data.