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## Pensions and Late Career Teacher Retention

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## **Pensions and Late Career Teacher Retention**

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### **Abstract**

A vast research literature is devoted to analyzing causes of and potential remedies for early-career teacher attrition. However, much less attention has been paid to late-career attrition among experienced teachers, which is driven primarily by retirement plan incentives. Although there is some variation across states, it is generally the case that late-career teachers retire at much younger ages than their professional counterparts. Moreover, given the well-documented returns to teaching experience, late-career exits are on average more costly to students in K-12 schools than early-career exits. This study uses structural estimates from a dynamic retirement model to simulate the effect of targeted retention bonuses for senior teachers rated as effective or teaching in high-need fields. While the cost per incremental year of instruction is expensive in the short run, it declines over time. Moreover, because labor supply decisions are forward-looking, a temporary bonus has much smaller effects than a permanent one. These findings highlight the value of stability in policies aimed at extending teachers' careers. Overall our results suggest that carefully-targeted retention bonuses can be useful tool in raising the quality of the teaching workforce and closing achievement gaps.

## Introduction

A large empirical literature finds substantial, persistent differences in teacher effectiveness within and between schools. High quality teachers have large effects not only on test scores, but also longer term outcomes such as matriculation to college and wages (Chetty et al., 2014). This elevates the importance of recruiting, cultivating, and retaining better teachers, particularly in low performing schools. Similar concerns have been raised about the STEM teaching workforce, with emphasis as well on high-need schools. A challenge in developing policies to improve teacher quality in high-need schools is the inelastic labor supply response of teachers. For example, a recent IES-sponsored experiment providing incentives for highly effective teachers to move to low performing schools found very inelastic responses (Glazerman et al., 2012), corroborating the broader finding in the literature that teachers are not particularly responsive to pay differentials favoring high poverty schools (Feng, 2009; Clotfelter et al., 2006).<sup>1</sup> In fact, the vast majority of research on teacher turnover and mobility has focused on young teachers, and a general finding is that it is difficult, and very costly, to alter their retention patterns. Another literature, based on several randomized experiments, suggests an inelastic behavioral response of incumbent teachers to performance incentives, making it challenging to “grow” high performing teachers within the system (Yuan et al., 2013).<sup>2</sup>

While research suggests that labor supply decisions of early and mid-career teachers aren’t very malleable, it also suggests that labor supply decisions of senior teachers are quite responsive to pension

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<sup>1</sup> The lack of response to financial incentives of relocating teachers is consistent with status quo bias, a well known phenomenon in behavioral science – e.g., Kahneman et al. (1991) survey decision-making experiments showing that individuals tend to irrationally stick to the status quo (for specific examples see Samuelson and Zeckhauser, 1988; Hartman et al., 1991). The behavioral bias literature suggests that financial incentives for retaining high value teachers at their current positions should be more effective than incentives that recruit teachers to the most needed schools.

<sup>2</sup> Another proposal to raise teacher quality is to more aggressively screen untenured teachers, making it more difficult for novice teachers to earn tenure (Rockoff and Staiger, 2010). Rothstein (2015) notes that labor supply effects may undermine both the performance pay and aggressive dismissal policies.

system incentives. Traditional teacher pension plans contain strong incentives designed to “pull” teachers to certain combinations of age or experience, and then “push” them into retirement. Studies have shown that senior teachers are responsive to these incentives. Retirement rates tend to spike at “regular” or “early retirement” cells in age-experience grids. Moreover, when retirement incentives change across the cells in these grids, retirement rates change accordingly (Furgeson et al., 2006; Costrell and McGee, 2010; Brown, 2013; Fitzpatrick and Lovenheim, 2014; Ni and Podgursky, 2016; Knapp et al., 2016).

The elastic response of teachers to retirement incentives and the powerful “pull” and “push” incentives built into most teacher retirement plans suggests an alternative route to teacher staffing in high-need schools or fields – namely, enticing effective senior teachers to postpone retirement by using salary bonuses to offset or dampen the “push” incentive. To date there seems to be little recognition of the potential for such policies, as the empirical research on the effects of pension incentives on teacher quality and school performance is limited.<sup>3</sup> This is particularly relevant because available data suggest that, on average, teachers retire at relatively young ages compared to other professional workers (e.g., see Harris and Adams, 2007).

In most private sector firms, and in other areas of government employment, retirement benefits are seen as useful tools for reshaping the workforce and upgrading quality. For example, the US armed services has for decades manipulated retirement incentives to reshape the workforce to meet manpower requirements (Warner and Pleeter, 2001; Asch et al., 2015).<sup>4</sup> In the private sector, professionals are primarily covered by defined contribution (DC) pension plans, which do not have the

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<sup>3</sup> Exceptions include Koedel et al. (2013) who study the effects of push and pull incentives on workforce quality, Fitzpatrick and Lovenheim (2014) who examine the effect of an early retirement incentive in Illinois on student test scores, and Chingos and West (2015) who examine the relationship between teacher quality and preferences for retirement plan structure.

<sup>4</sup> See also: <http://www.leatherneck.com/forums/archive/index.php/t-45263.html>.

“push” incentives for retirement that are typical of teacher plans. Nonetheless, private sector firms will routinely use bonuses to discourage or encourage retirements by senior professional staff.

For administrators in traditional public schools, there is no ability to experiment with alternative retirement plans because educators in all of the school districts in a state are required to participate in the state’s teacher plan.<sup>5</sup> This is in sharp contrast to other dimensions of compensation policy, such as performance pay, where local experimentation is feasible. While there is variation across states in the parameters or rules for teachers’ defined-benefit (DB) retirement plans, there is essentially no natural experimentation with alternative retirement compensation models or policies. While some states have adopted DC and/or hybrid plans for teachers in recent years, these new structures typically apply only for new hires and have not been in place long enough to assess their effects on retirement behavior.

In the absence of sufficient policy variation and data to undertake a traditional evaluation, we use structural estimates from a Stock-Wise “option value” retirement model to simulate the effect of targeted, late-career retention bonuses for high-need senior teachers designed to offset the strong “push” incentives of current retirement plans and lengthen their careers. Since these are salary bonuses, and not changes in the rules of the retirement plans, they should not run afoul of legal or political issues involving changes to pension rules for incumbent teachers. We assess the efficacy of various bonus schemes using administrative data for two states: Missouri and a second, anonymous mid-western state (hereafter, “OTHER”). After first establishing the very good out-of-sample fit of the model for teacher retirements in the two states, we turn our attention to evaluating targeted policies to retain retirement-eligible teachers of high quality and in high-need positions. Specifically, we focus on STEM teachers and teachers rated as highly effective. We show that permanent, targeted bonuses aimed at teachers in the

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<sup>5</sup> Charter schools in 14 states are allowed to opt out of state teacher plans. However, there has been no research to date on the effect on teacher retirement behavior in charter schools that exercise that option (Olberg and Podgursky, 2011). A few cities (e.g., Chicago, NYC, St. Louis, Kansas City) have municipal teacher plans. In these cases all educators in district operated schools are required to participate in the municipal plan.

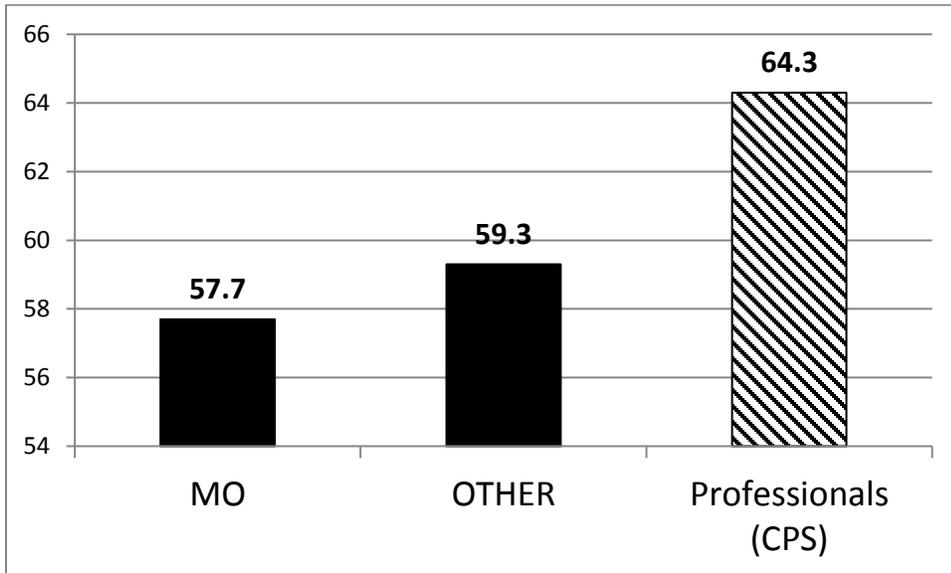
“retirement window” of traditional pension plans are more cost effective than otherwise analogous temporary bonuses. The latter generate a much smaller behavioral response and as a result end up being more costly per additional year of retained experienced teaching. Although permanent bonuses are more cost effective, both permanent and temporary bonuses are expensive because (a) any bonus program will necessarily award bonuses to some infra-marginal teachers whose behavior is unaffected (e.g., teachers who would have continued teaching even without a bonus) and (b) the pecuniary value of the “push” incentives the bonuses aim to offset is large.

## **Patterns of Retirement and Pension Plan Rules**

Before undertaking our simulation of policy alternatives, it is useful to review some descriptive data on teacher retirements, generally and in our two states, and the rules of teacher pension plans. Harris and Adams (2007) use data from the Current Population Survey (CPS) from 1992-2001 to compare career attrition rates of teachers to those of accountants, nurses and social workers. Despite the intensive focus in research on early-career teacher attrition (e.g., see Goldhaber et al., 2011; Ingersoll, 2001), Harris and Adams show that early-career teachers behave similarly to early-career workers in comparable professions. The divergence between teachers and other workers comes later in the career, where the authors note that “teacher turnover is relatively high among older teachers reflecting the fact that they retire considerably earlier than other professionals” (Harris and Adams, 2007, p. 326).

In Figure 1 we compare the conditional mean age of retiring teachers in our two states to the average retirement age for college-educated professionals from a more current CPS sample covering 2008-2014. In both states teachers retire at a considerably younger age than their non-teacher professional counterparts.

**Figure 1. Mean Retirement Ages: Two States and Professionals in the Current Population Survey**



Notes: These are the conditional mean ages for teachers and college-educated (non-teacher) professionals, aged 50-65 who were employed in year  $t$  and left the workforce in year  $t+1$ . For two states this is the average for teachers employed 2008-2013; for the professionals, years 2008-2014.

What factors are driving these high late-career attrition rates for teachers? While individuals' workforce participation decisions are caused by a variety of factors, pension plan incentives certainly play an important role. Table 1 summarizes key pension plan rules in the two states.<sup>6</sup> In the Missouri plan, which excludes teachers in Kansas City and St. Louis but covers all other teachers in the state, there are three conditions under which teachers become eligible to collect unreduced pension benefits (i.e., eligible for "full retirement"): (1) the sum of age and experience is 80 or above ("Rule of 80"), (2) the number of in-system service years is 30 or above, or (3) age is 60 or above with at least 5 years of service. The modal age of entry into teaching in Missouri is age 24, which means that with continuous work a modal entrant would first become eligible for full retirement under the rule of 80 at age 52.

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<sup>6</sup> In this paper we restrict our analysis to teachers in the state retirement plan. This excludes teachers in the St. Louis and Kansas City school districts, who have their own municipal plans. The state plan covers more than 90 percent of Missouri teachers.

**Table 1. Key Teacher Pension Plans Rules in Two States.**

	<u>Missouri (PSRS)</u>	<u>OTHER</u>
Replacement Factor	2.5% if Exp $\leq$ 30 2.55% if Exp $>$ 30	2.0%
Eligibility - Regular	Age 60, Exp 30, A+E $\geq$ 80	Age 62, Exp = 30
Eligibility - Early	Exp 25, Age 55 (Exp $\geq$ 5)	Exp 25, Age 55 (Exp $\geq$ 5)
Social Security	No	Yes

Source: Pension plan reports. Note that Missouri PSRS does not cover teachers in Kansas City and St. Louis – who are covered by separate plans – but covers all other teachers in the state.

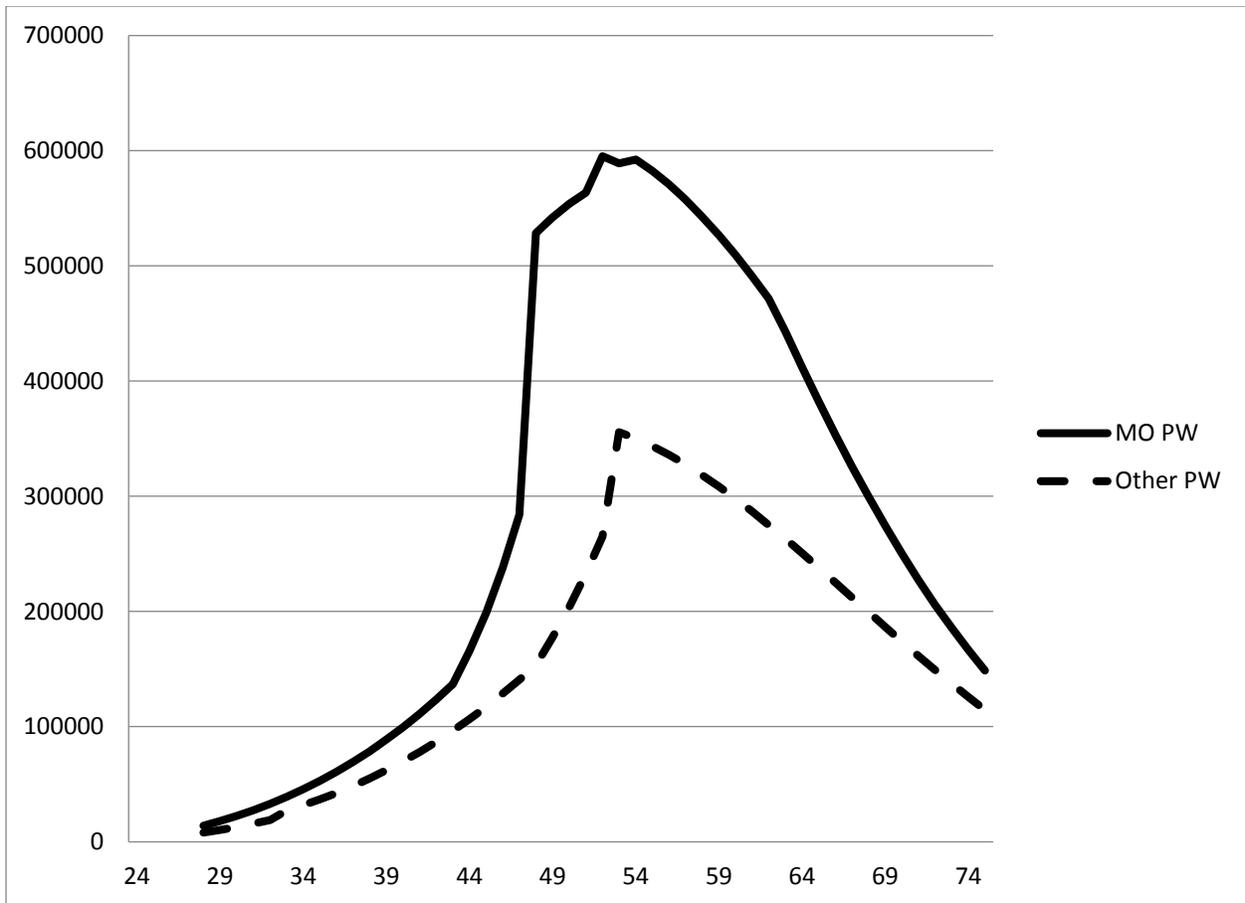
OTHER state shares conditions (2) and (3) with Missouri, but does not have an “age-plus-experience” rule. Still, an age-24 OTHER entrant becomes eligible for unreduced benefits at age 54 (30 years of service) with continuous work. OTHER state teachers are additionally nudged to a later retirement age because they are in the Social Security system, with a minimum retirement age of 62, while Missouri teachers are not in Social Security. Thus, both state systems facilitate teacher retirements at relatively early ages, which is common for the pension plans that cover public school teachers across the United States (Doherty et al., 2012).

Figure 2 shows the pension-accrual profile for a representative age-24 entrant in each plan over the career cycle assuming continuous work. Social Security wealth accrual is suppressed for OTHER state teachers.<sup>7</sup> Projected earnings profiles during work in each state are generated using a wage function that is a cubic of experience. The graphs in the figure show the back-loading of pension-wealth accrual, and highlight the sharp retirement incentives created by the plan rules. For example, pension wealth

<sup>7</sup> Adding in Social Security pension wealth would displace the OTHER graph upward in a roughly uniform manner (the Social Security system does not share the features of the state plans that generate the spikes in wealth accrual). At age 55, including Social Security pension wealth would close 58 percent of the MO-OTHER pension wealth gap.

peaks for the representative teacher at the “rule of 80” in Missouri and at 30 years of service in the other state. The peaks coincide with collection eligibility, which dramatically changes the opportunity cost of continued work.

**Figure 2. Pension Wealth Accrual in Missouri and OTHER**

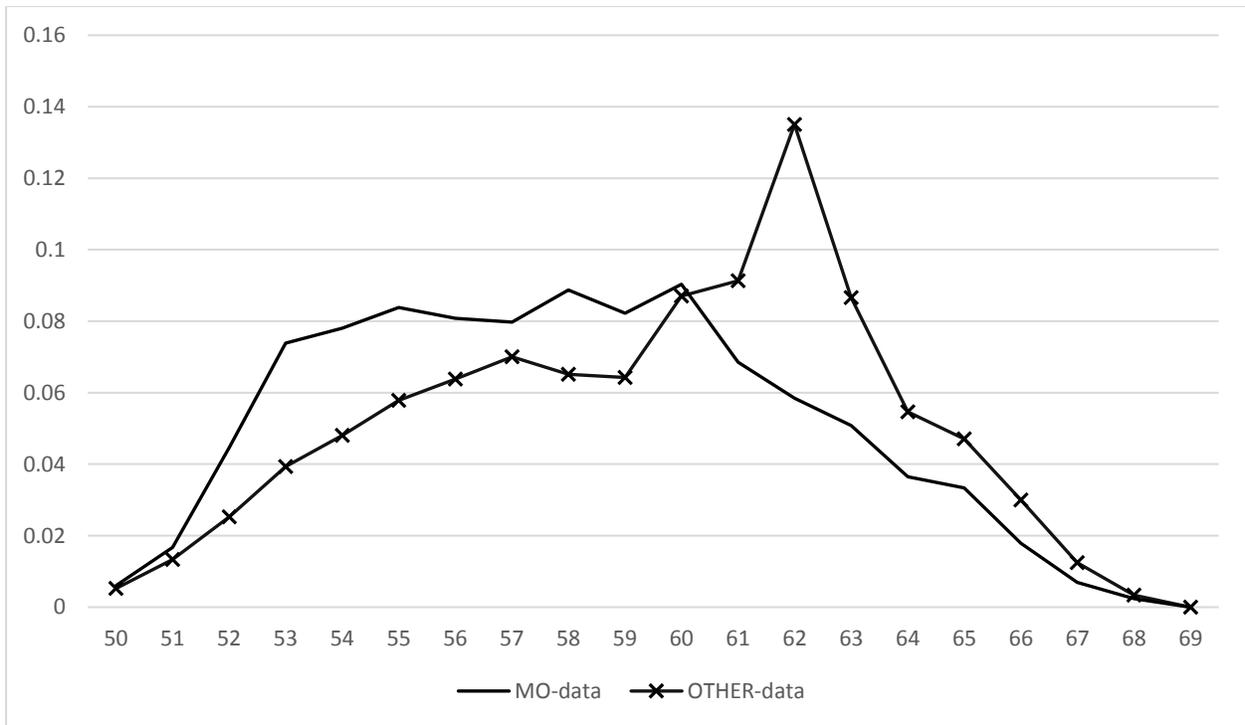


Source: Simulations based on pension rules in each state and estimates of entry and career growth in teacher salaries. For other assumptions see text. Pension wealth is the future value at age 55. MO teachers are not in Social Security but teachers in the OTHER state are. The pension wealth of the OTHER state does not include the Social Security benefit.

Figure 3 presents actual retirement data by age for the two states. The sample includes all public school teachers aged 50-65 with at least ten years of teaching experience. The two states are fairly similar in size and urbanicity, yet the age distributions of retirees are strikingly different. We take this as

prima facie evidence, with much more to follow, that teachers in these two states are responsive to their different pension incentives. In order to measure the effects of these pension incentives on labor supply, in the next section we develop a dynamic option-value model of retirement decisions.

**Figure 3. Age Distribution of Retirees in Missouri and OTHER**



Note: MO data includes 14356 teachers who were 50-65 year old and have ten or more years teaching experience in 2008. OTHER data includes 16707 teachers who were 50-65 year old and have 10 year or more teaching experience in 2008.

## Analytic Framework

We model teacher retirements following Stock and Wise (1990), who develop a structural model to explain the recurring decision to work or retire at later stages of the career cycle. The model incorporates the option value of continued work at any given point in the career.

A teacher's expected utility in period  $t$  is a function of expected retirement in year  $m$  (with  $m=t, \dots, T$  and  $T$  is an upper bound of the teacher's lifetime). In period  $t$ , the expected utility of retiring in period  $m$  is the discounted sum of pre- and post-retirement expected utility

$$E_t V_t(m) = E_t \left\{ \sum_{s=t}^{m-1} \beta^{s-t} [(k_s(1-c)Y_s)^Y + \omega_s] + \sum_{s=m}^T \beta^{s-t} [(B_s)^Y + \xi_s] \right\} \quad (1)$$

where  $0 < k_s < 1$  captures disutility of working,  $Y$  is salary, and  $B$  is income during retirement (i.e., the pension benefit and social security), both expressed in real dollars. The unobservable factors that change the utility of teaching and retirement are modeled as innovations to preferences. The unobserved innovations in preferences for teaching relative to retiring,  $v_s = \omega_s - \xi_s$ , follow an AR(1) process:

$$v_s = \rho v_{s-1} + \varepsilon_s \quad (2)$$

where  $\varepsilon_s$  is iid  $N(0, \sigma^2)$ .

This specification assumes that the disutility of work,  $k_s$ , changes monotonically with age:  $k_s = \kappa \left( \frac{T_0}{age} \right)^{\kappa_1}$  where  $T_0$  is the maximum age in the first year of the sample, and  $\kappa, \kappa_1$  are unknown constants.

The expected gain from retirement in period  $m$  over retirement in the current period  $t$  is

$$G_t(m) = E_t V_t(m) - E_t V_t(t) = g_t(m) + K_t(m)v_t.$$

There are three sources of uncertainty in the model: the uncertainty of future earnings and benefits (which we ignore here, given that teacher pay is largely driven by fixed salary schedules), uncertainty of survival, and uncertainty in the aforementioned preference shocks. To make survival

uncertainty explicit, for a teacher alive in year  $t$  we denote the probability of survival to period  $s > t$  as  $\pi(s|t)$ . Thus we can write,

$$g_t(m) = \sum_{s=t}^{m-1} \pi(s|t) \beta^{s-t} (k_s(1-c)Y_s)^\gamma + \sum_{s=m}^T \pi(s|t) \beta^{s-t} (B_s)^\gamma - \sum_{s=t}^T \pi(s|t) \beta^{s-t} (B_s)^\gamma.$$

Let  $m_t^\dagger = \text{argmax } g_t(m)/K_t(m)$ , then the probability that the teacher retires in period  $t$

$$(G_t(m) \leq 0 \text{ for all } m > t) \text{ is: } \text{Prob} \left( \frac{g_t(m_t^\dagger)}{K_t(m_t^\dagger)} \leq -v_t \right).$$

In previous work, Ni and Podgursky (2016) estimate this model on a panel of Missouri teachers using administrative data from the Missouri Department of Elementary and Secondary Education (MODESE) linked to retirement data from the state teacher pension plan (MOPSRs). The panel file included teachers aged 47-59 in 2002. These teachers were followed to 2008. The details of the estimation are provided in Ni and Podgursky (2016). Their work shows that the model provides excellent out-of-sample fit in modeling teacher responses to a series of pension enhancements enacted between 1995 and 2001. For the analysis in this paper, we use the estimated behavioral parameters from Ni and Podgursky (2016) and apply them to an analysis of the effect of retention bonuses for high-need teachers in the two states. In the next section we examine in some detail the goodness of fit of this model for targeted groups of teachers in the two states in more recent years.

## STEM Teachers in Missouri

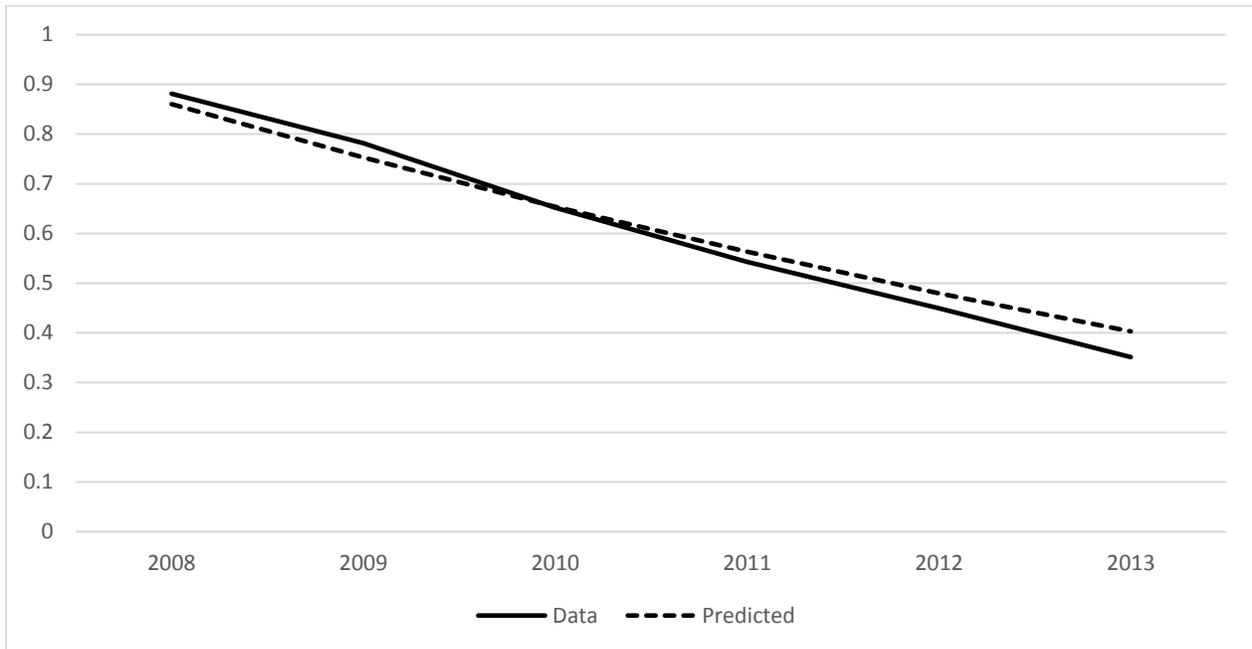
School districts, particularly those with mostly low-SES students, regularly report difficulties in recruiting fully-qualified math and science (STEM) teachers (Podgursky, 2010). The median retirement age for Missouri STEM teachers is 57 years, suggesting one feasible approach to reducing staffing pressures would be to lengthen the typical STEM-teacher career. In order to do this we will explore policies designed to weaken the “push” incentive in the pension plan for these teachers.

As a first step, we examine the ability of our Stock-Wise model to fit the out-of-sample behavior of STEM teachers in Missouri. We use the Stock-Wise model parameters estimated by Ni and Podgursky (2016) from Missouri data for 2002-2008 to fit the retirement behavior of 1,566 STEM teachers aged 50-65 in 2008 who have at least ten years of experience. We track these teachers forward in time for six years through 2013. The technical details are given in the appendix. Data on the actual and predicted employment survival rates for these teachers are presented in Figure 4. Over the six-year period roughly 65 percent of the teachers in our sample retire. Overall, the model does a good job fitting employment survival for this out-of-sample group. Figures 5 and 6 report the age distributions of retired and non-retired teachers. The non-retired teachers are those teachers who had not retired by 2013. The model provides an excellent fit to the age distribution of both groups.

Before we report simulation results of retention bonus policies, we first explain the set of policies we explore. The retention bonuses are one-time payments to teachers who reach specific career targets. The design of the most efficient bonus policies – i.e., the selection of the age and/or experience of the targeted teachers – depends on particular parameters of the pension plan in place. In general, a teacher in the targeted age-experience group has three possible responses to the bonus, each of which has different implications for the efficacy of the policy. A marginal teacher takes the bonus and thus postpones retirement. Her behavior results in an increase in cost and an increase in years of teaching. Then there are two types of infra-marginal teachers. The first retires anyway and foregoes the bonus, which changes neither the cost nor the years of teaching. However, the second type takes the bonus but would have continued teaching anyway. A fiscally effective policy design aims to minimize the third type of response. Since we cannot tell how any particular teacher would respond to a hypothetical bonus, we rely on the predictions from the structural model. The good out-of-sample fit of the model lends credence to its predictions of aggregate responses.

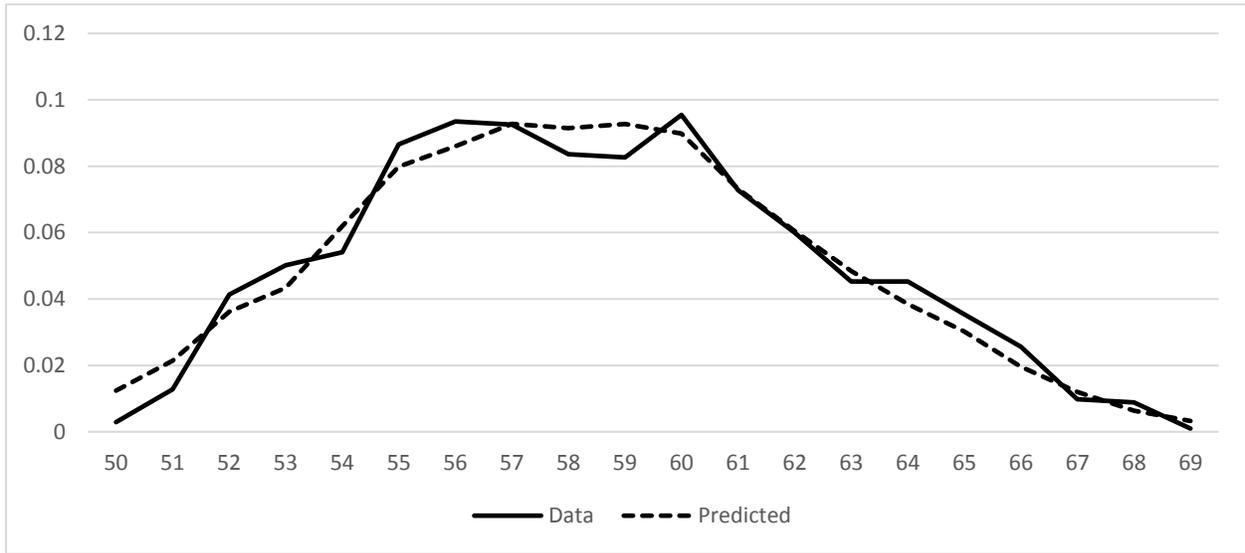
A theoretical analysis, omitted here for brevity, shows that retention bonuses offered to teachers with a high ex ante retirement probability are more cost effective. Thus, for each state we aim to target age and/or experience groups that are densely populated and have the highest retirement probabilities. Since the retirement probability depends on the pension rules, the targeted groups differ by state. We experiment with bonus amounts of \$5,000 and \$10,000.

**Figure 4. Percent of Sample Remaining Employed: Missouri STEM Teachers.**



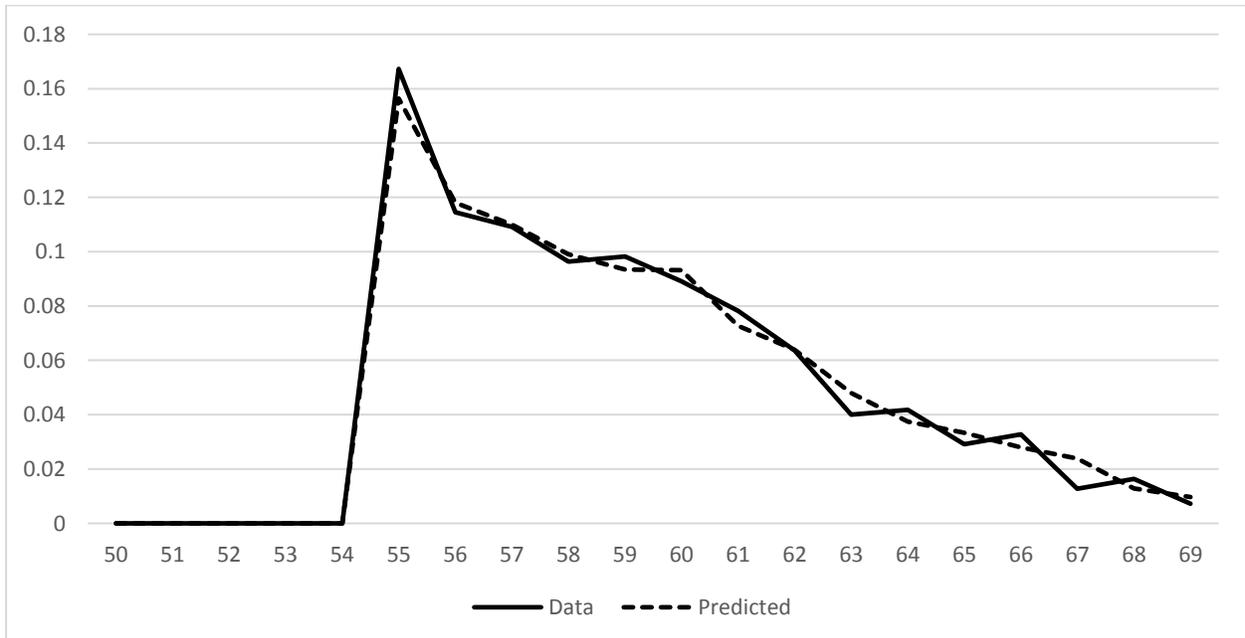
Note: The observed and predicted survival rates are for all the MO STEM teachers in Missouri from 2008-2013 (excluding teachers in Kansas City and St. Louis, who are covered by different pension plans). The predicted survival rates are based on simulated data from the structural model described in the text. Details of the simulations are given in Appendix 1.

**Figure 5. Age Distribution of Missouri STEM Retirees**



Note: The observed and predicted distribution by age at the time of retirement for MO STEM teachers aged 50-65 in 2008. The observed MO data from 2008-2013 are compared with simulated data from the structural model described in the text. Details of the simulations are given in Appendix 1.

**Figure 6. Age Distribution of Missouri STEM Teachers, Non-Retirees**



Note: The observed and predicted distribution by age for continued employment to the end of the period (2013). The observed MO STEM teachers aged 50-65 in 2008 are compared with simulated data from the structural model described in the text. Details of the simulations are given in Appendix 1.

The bonuses are designed to retain STEM teachers working in the retirement window by partially offsetting the “push” incentives in the pension plan. They are not entered into the calculation of the retirement annuity (i.e., they are not part of the salary used by the pension fund to compute final benefits). Based on the Missouri plan rules, we award bonuses to teachers in the 50-65 age window if they complete 32 years of experience or reach a point where the sum of age and experience is 82 or 83. These values are just past the key thresholds that are associated with retirement spikes in Missouri. For example, the formula-factor bump that comes with completing the 31<sup>st</sup> year of service in Missouri (Table 1) results in a retirement spike after the completion of that year. A bonus for teachers who complete the 32<sup>nd</sup> year of teaching nudges them past a point where retirements are already high so that there are fewer teachers who would have continued working independent of the bonus program. A similar logic applies for the bonus after completion of the “Rule of 82/83” year, which is one year after a significant retirement spike associated with the attainment of “Rule of 80.”<sup>8</sup>

Table 2 reports the simulated effect up to ten years after implementation of a range of permanent retention bonus schemes offered to STEM teachers in our analytic sample. By permanent we simply mean that once the bonus is announced, all teachers in the relevant group (in our case, teachers in our sample who are age 50-65 with experience  $\geq 10$ ) become eligible for the bonus regardless of when they might actually attain it. This is in contrast to a temporary bonus, which is available only to teachers who attain the key threshold in the current year (we examine the efficacy of a temporary bonus program below).

The first two columns of Table 2 report the effect of two different one-time bonuses (\$5,000 and \$10,000) paid to all STEM teachers reaching 32 years of experience. The next two columns report

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<sup>8</sup> Recall that the “Rule of 80” applies to the sum of age and experience. Depending on the starting age and continuity of work, some teachers reach the threshold at exactly 80 (e.g., age-52 with 28 years of service), and others reach it at exactly 81 (e.g., age-52 with 29 years of service). The “Rule of 82/83” gives the bonus to teachers who work one year past attaining full retirement eligibility under “Rule of 80.”

the effect of bonuses paid at “Rule of 82/83.” Because the bonuses are permanent, all teachers know that they will receive the bonus if they reach the relevant threshold in the future, thus allowing the implementation of the bonus to affect work/retirement decisions for less experienced teachers in our sample as well. The table reports cumulative retention effects and costs per year of retained experience of the various bonus programs after 1 year (top panel), 5 years (middle panel), and 10 years (bottom panel) of program operation. As the time horizon increases the total retention effects and costs increase, partly because annual retention effects for initially treated teachers cumulate over time and partly because new cohorts of teachers enter the age 50-65 eligibility window. Most of the increases are from the former effect – roughly two-thirds in each ten-year scenario – but the two effects combined are most relevant to policymakers.

Within any time horizon, the first row reports the estimated total gain in teacher-years of work resulting from the bonus program in our sample. The second and third rows report the average gross and net cost per incremental year of retained experienced teaching. The gross cost includes compensation in the form of salary and the bonus for senior teachers who are retained as a result of the bonus (marginal teachers), as well as bonus payments to senior teachers who would have continued employment in the absence of the bonus (infra-marginal teachers). For marginal teachers, there may be cost savings through the pension plan in the form of lower benefits, owing to the fact that these teachers delay retirement and forgo pension payments (see Figure 2). The gross/net distinction arises from the fact that each incremental year a senior teacher is retained is a year that a novice teacher is not hired. The net costs subtract the estimated savings from forgone new hires.<sup>9</sup> The last row reports estimates of elasticity of extra years of teaching with respect to the net cost.

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<sup>9</sup> Our net cost estimate is based on the average teacher salary after one, five, and ten years on the job; e.g., if bonus payments result in 100 additional teacher years over five years then 100 fewer novice (1-5 year experience) teachers will be hired. Note that this net cost estimate does not take into account differences in teacher effectiveness from replacing a senior with a novice teacher.

**Table 2. Effects of Various Retention Bonuses for Missouri STEM Teachers: After One, Five and Ten Years**

<b>One Year</b>	<b>Exp = 32</b>		<b>Rule of 82/83</b>	
	<b>Size of one year bonus</b>		<b>Size of one year bonus</b>	
	<b>\$5,000</b>	<b>\$10,000</b>	<b>\$5,000</b>	<b>\$10,000</b>
<b>Additional Years</b>	2.9	6.4	3.3	6.8
<b>Gross Cost/Year</b>	\$109,545	\$104,014	\$186,989	\$182,735
<b>Net Cost/Year</b>	\$73,140	\$67,609	\$150,584	\$146,330
<b>Elasticity</b>	1.34	1.41	0.78	0.80
<b>Five Year</b>				
<b>Additional Years</b>	21.8	49.5	31.3	61.3
<b>Gross Cost/Year</b>	\$93,093	\$88,771	\$125,614	\$128,031
<b>Net Cost/Year</b>	\$53,934	\$49,611	\$86,455	\$88,872
<b>Elasticity</b>	1.59	1.66	1.18	1.15
<b>Ten Year</b>				
<b>Additional Years</b>	47.6	117.5	84.7	167.4
<b>Gross Cost/Year</b>	\$89,040	\$82,396	\$112,861	\$114,187
<b>Net Cost/Year</b>	\$38,214	\$31,570	\$62,035	\$63,361
<b>Elasticity</b>	1.74	1.88	1.38	1.36

Source and notes: Simulations from the structural model described in the text. Details of the simulations are given in the appendix. Estimates are based on 1566 STEM teachers aged 50-65 in 2008.

Several patterns emerge. First, as expected, larger bonuses produce more incremental years of work. For example, after five years, a \$5,000 bonus at 32 years of experience produces 21.8 additional STEM teacher years, whereas a \$10,000 bonus yields 49.5 years. After ten years the same two bonus schemes yield 47.6 and 117.5 additional teaching years. Reading across the third row in the middle panel, at five years the incremental net cost per year is in the range of \$50-54,000 for bonuses at 32 years of experience. Bonuses provided just past the “Rule of 80” threshold are more costly at \$86-89,000 per additional teacher year. The reason the 32-year bonus program is more cost effective is that it is better targeted because the conditional retirement likelihood at experience=31 is larger than at the “Rule of 80.” Thus, fewer bonuses are given to teachers who would have continued working anyway. The differential cost results within Missouri highlight the importance of policy design around pension plan rules, a point that will be re-emphasized when we examine the other state.

For a given level of bonus, the additional teaching years gained over the five and ten year horizons are more than five and ten times as large as the one-year gains. This is because after just one year, most of the gains reflect the delay in retirement of those who happen to be bonus eligible in 2008, with a much smaller contribution from teachers prior to reaching the bonus window. Over five or ten years though, the cumulative effect on younger teachers becomes more important. In addition, as noted above, the bonus starts to affect teachers in more cohorts (see appendix for more details).

These cost and yield estimates are readily expressed as elasticities. In contrast to the aforementioned studies of early-career teacher responses to pecuniary incentives, the estimates in the last row show an elastic response to the net cost in the presence of the bonus payments. Moreover, as expected, the longer the time horizon, the more elastic the response. This is because younger cohorts of teachers, looking to the future, incorporate the bonus into their labor supply decisions.

## High Quality Teachers in OTHER State

An attractive feature of OTHER is that it has a state-wide teacher evaluation system that relies on multiple measures of performance, including classroom observations, and classroom-level value-added for teachers in tested grades and subjects. Teachers in the state receive a 1-5 score, with 5 being the top score. Table 3 presents ratings data on all teachers, novice teachers, and teachers in the “retirement window” aged 50-65 with at least ten years of experience from the 2011-12 school year. We focus our simulations on policies designed to retain senior teachers in the top performance category (5).

**Table 3. Distribution of OTHER Teachers by Performance Rating: 2011-12**

Rating	All Teachers		0-2 Yrs Exp		Age 50-65 and 10+ Years Experience		
	Number	%	Number	%	Number	%	
Lowest	1	228	0.4%	55	0.6%	71	0.4%
	2	4142	6.6%	725	7.5%	1157	7.0%
	3	11935	19.0%	1775	18.4%	3161	19.0%
Highest	4	18743	29.8%	3361	34.8%	4701	28.3%
	5	23623	37.6%	2704	28.0%	6319	38.1%
Missing	4219	6.7%	1027	10.6%	1188	7.2%	

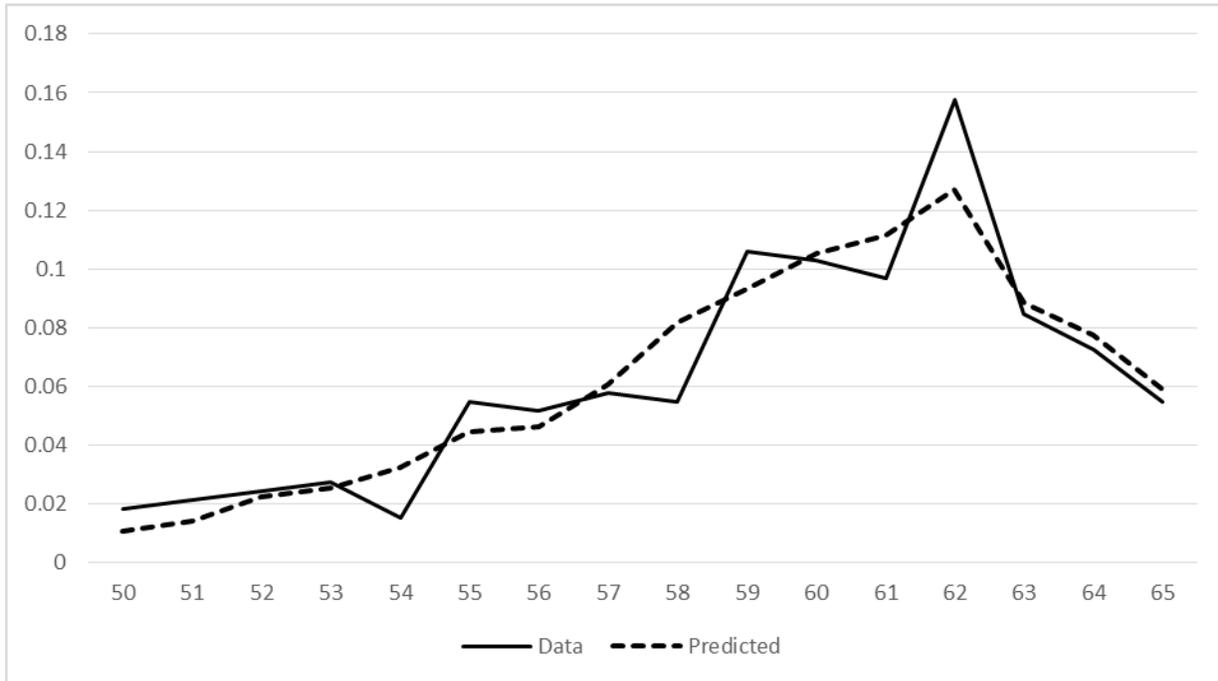
Source: Author calculations based on administrative data files.

Before turning to simulations, we first examine the out-of-sample fit of our structural model. Again we use the parameters estimated from the 2002-2008 MO sample, with a small adjustment to the variance parameter (see appendix). Based on a sample of teachers in OTHER aged 50-65 with ten or more years of experience in 2012, we forecast retirements one year ahead.<sup>10</sup> The actual and forecasted retirement rates are both roughly 8 percent. In Figures 7 and 8 we report the conditional distributions of age for retirees and non-retirees. Note that in taking the estimated parameters for Missouri teachers

<sup>10</sup> We exclude from our analysis teachers in 14 districts that were participating in a temporary U.S. Department of Education funded pilot program providing performance pay bonuses.

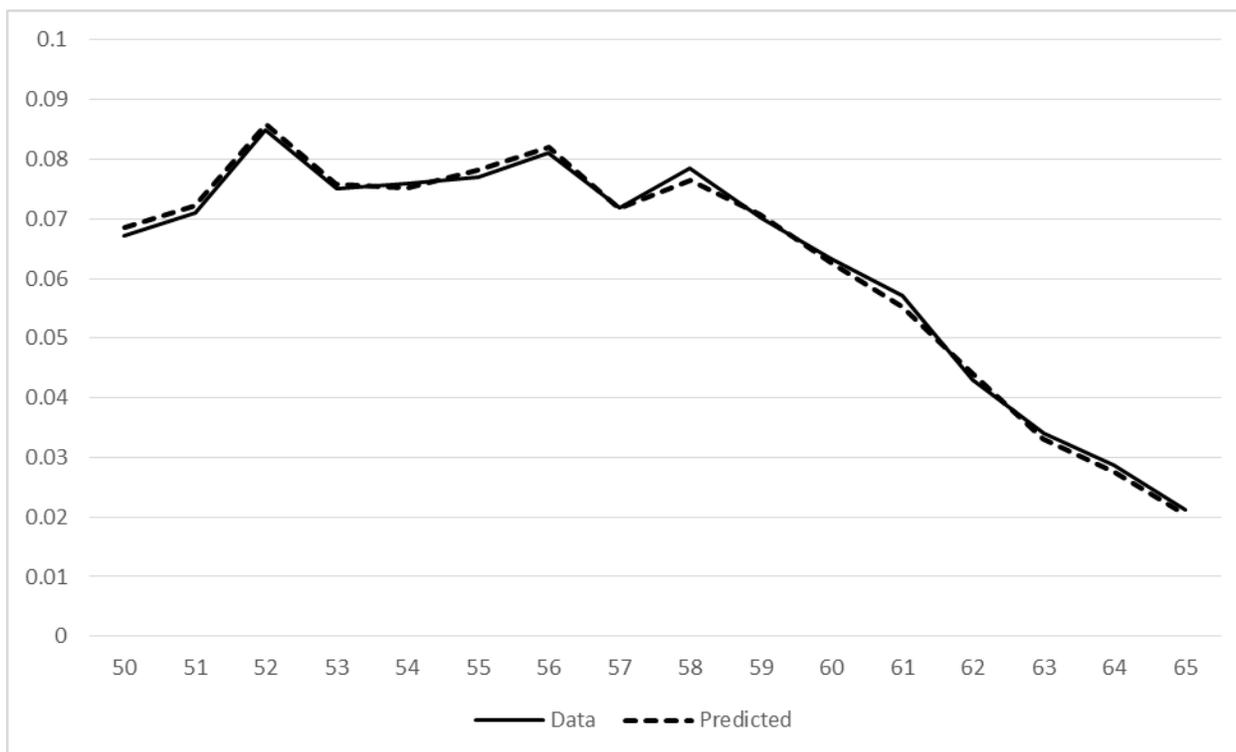
and applying them to OTHER state teachers we are going *far* out-of-sample (i.e., different teachers, different state, different time period). Nonetheless, the model fits both of these distributions well.

**Figure 7. Age Distribution of High Quality Retirees**



Note: The observed and predicted distribution by age at the time of retirement for OTHER teachers rated at level-5. The observed data are from 2011-2012 and compared with simulated data from the structural model described in the text. Details of the simulations are given Appendix 1.

**Figure 8. Age Distribution of High Quality Non-Retirees**



Note: The observed and predicted distribution by age for continued employment to the end of the period (2012) for OTHER teachers rated at level-5. The observed data are from 2011-2012 and compared with simulated data from the structural model in the text. Details of the simulations are given Appendix 1.

Table 4 reports policy simulations focused on the highest-rated teachers (level 5) in age-experience cells just past significant spikes in retirement rates driven by plan and Social Security rules. In OTHER, the key system age and experience benchmarks are (1) age = 63 due to the retirement spike induced at age 62 by Social Security and (2) experience = 31 due to the attainment of eligibility for full benefits with 30 years of service. For illustration, we also report simulation results at experience = 34. Returning to the point that system context is important for incentive design, the dual coverage of OTHER teachers in Social Security and the state plan results in a significant difference in the incentive structure relative to Missouri. In short, OTHER teachers are responding to two sets of incentives. The practical implication is that OTHER teachers' retirement behaviors are pulled away from the earlier spike, which is experience = 30 for most teachers, effectively dulling its aggregate impact. The

experience = 34 simulation shows much-improved targeting relative to experience = 31. We chose experience = 34 using a simple grid search over retirement rates, which is how we selected all other cells for targeted bonuses. However, in the other three cases (in Missouri: experience = 32, Rule of 82/83; in OTHER: age=63), the most prominent retirement spikes align with clear retirement-plan benchmarks.

As with the previous simulations, we consider two levels of bonuses – \$5,000, and \$10,000 – and a one, five and ten year time horizons. The response elasticities are smaller than for Missouri STEM teachers, however, over the 10-year horizon they still hover in the unit-elastic range (for the bonuses at age = 63 and experience = 34) and would yield a significant number of additional years of quality teaching. A \$5,000 bonus paid at age 63 to level-5 teachers would yield 76.8 additional teacher years over a five year horizon at an average net cost per teacher-year of \$69,027. A \$10,000 bonus would yield 149.1 additional teaching years at a net cost of \$71,099.<sup>11</sup> Over a ten year horizon, net costs for the age 63 bonus fall to \$44,672 and \$45,546, respectively, for \$5,000 and \$10,000 bonuses.

A bonus focused on experience rather than age has higher gross and net costs per induced year of experienced teaching and as noted above, the bonus at experience = 34 is much more efficient than the bonus at experience = 31. The reason is that the conditional retirement rate in the preceding year is much higher in the former case so fewer bonuses are awarded to teachers who would have remained in teaching anyway. Note that the total effect of the bonus program on years of retained teaching is similar at either experience threshold, it is the cost per retained year that changes.

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<sup>11</sup> The OTHER bonuses yield more years than Missouri STEM bonuses because they are provided to a larger number of teachers (i.e., 6,319 versus 1,566).

**Table 4. Effects of Various Retention Bonuses for Highly-Rated OTHER Teachers: After One, Five and Ten Years**

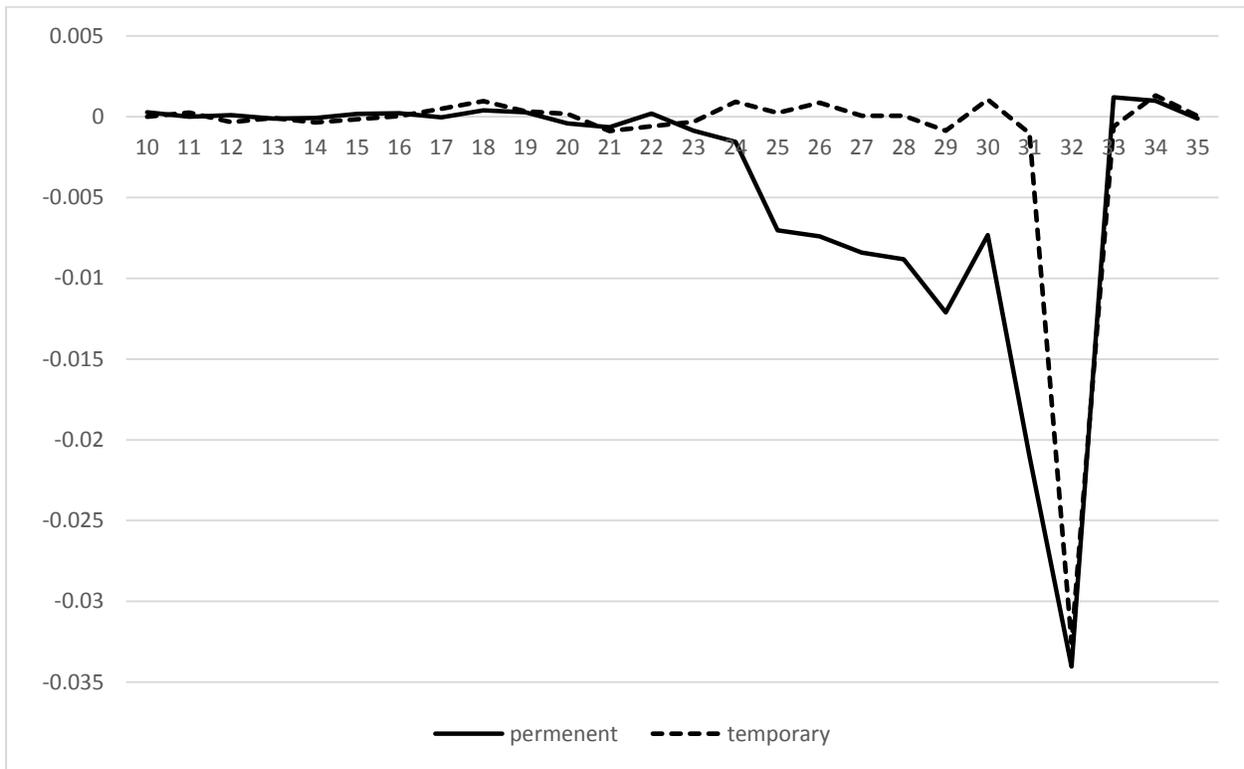
	<b>Age = 63</b>		<b>Exp = 31</b>		<b>Exp = 34</b>	
<b>One Year</b>	<b>Size of one year bonus</b>		<b>Size of one year bonus</b>		<b>Size of one year bonus</b>	
	\$5,000	\$10,000	\$5,000	\$10,000	\$5,000	\$10,000
<b>Additional Years</b>	8.2	16.0	4.4	8.0	4.7	8.9
<b>Gross Cost/Year</b>	\$148,056	\$151,320	\$295,197	\$316,408	\$199,091	\$209,361
<b>Net Cost/Year</b>	\$111,651	\$114,915	\$258,792	\$280,003	\$162,686	\$172,957
<b>Elasticity</b>	0.70	0.69	0.35	0.33	0.52	0.50
<b>Five Year</b>						
<b>Additional Years</b>	76.8	149.1	42.1	77.0	44.5	86.4
<b>Gross Cost/Year</b>	\$108,186	\$110,258	\$167,947	\$179,401	\$132,522	\$136,888
<b>Net Cost/Year</b>	\$69,027	\$71,099	\$128,788	\$140,242	\$93,363	\$97,729
<b>Elasticity</b>	0.96	0.94	0.62	0.58	0.78	0.76
<b>Ten Year</b>						
<b>Additional Years</b>	192.2	377.0	111.5	187.3	118.7	225.6
<b>Gross Cost/Year</b>	\$95,498	\$96,390	\$142,239	\$148,565	\$111,864	\$116,430
<b>Net Cost/Year</b>	\$44,672	\$45,564	\$91,413	\$97,739	\$61,039	\$65,604
<b>Elasticity</b>	1.13	1.12	0.76	0.72	0.96	0.92

Source and notes: Simulations from the structural model described in the text. Details of the simulations are given in the appendix. Estimates are based on 6319 level 5 teachers aged 50-65 in 2011.

## High Quality Teachers in OTHER State

Along with the permanent bonuses discussed in the previous sections, we also conduct simulations for a similar range of temporary bonus programs. These are programs in which the bonus would be available at the same thresholds as those described above, but only for 1-3 years. With temporary bonuses teachers further from eligibility will not respond at all – for example, a 55 year old teacher in OTHER would never be eligible for a temporary bonus at age 63. The effect of such programs is considerably smaller than what we simulate for the permanent bonus policies. This is illustrated in Figure 9, where we simulate the one year effect of a temporary versus a permanent \$10,000 bonus for teachers with 32 years of experience. The effect for teachers in the affected cell is identical in either case. However, the permanent bonus increases retention for teachers with years of experience less than 32, who anticipate the bonus and alter retirement plans accordingly. Interestingly, these findings suggest that a temporary experiment or pilot program providing retention bonuses, however well designed from a research point of view, would significantly understate the long run impact of a permanent scheme. The temporary program will also be more costly. Simulation results omitted for brevity show a gross cost of over \$250,000 to gain an incremental year of teaching using a temporary \$10,000 bonus for teachers with 32 years of experience in Missouri, which is much larger than the gross cost estimates shown in Table 2 for permanent bonuses.

**Figure 9. Change in Retirement Rates of Missouri STEM Teachers in the First Year of Temporary and Permanent \$10,000 Bonus Schemes, by Experience**



Note: Simulations are from the structural model described in the text. Details of the simulations are given in the appendix. The data used for baseline and bonus simulations are from the 2008 panel of MO STEM teachers aged 50-65 in 2008. The permanent \$10,000 bonus will be given to teachers who reach experience of 32 years. A temporary bonus of \$10,000 is given to teachers with experience of 32 years in 2008 only.

The simulation illustrated in Figure 9, along with the results in Tables 2 and 4, are informative in understanding the challenges of evaluating changes in retirement benefit systems. The simple takeaway is: “time matters.” First, the estimates from a one-time pilot program (e.g., such as the IES-supported experiments in teacher performance pay) would seriously underestimate the effect of a permanent program. This is because forward looking teachers change their behavior in response to the program. A short-term pilot misses these effects. Second, over time the effects compound – a two percent increase in annual retention cumulates to a 22-percent larger cohort after ten years.

## Conclusion

Traditional DB pension plans create strong “pull” and “push” incentives that have tended to concentrate teacher retirements at relatively early ages. Legal and political factors have prevented reform of these systems for incumbent teachers and what limited reforms have occurred have focused on new teachers. However, the benefits of reforms for new hires will not be seen for many decades. To date policy-makers have ignored the potential for improving the teaching workforce in the meantime by neutralizing the strong “push” incentives built into these plans in a selective way through targeted retention bonuses for late career teachers. In this paper we simulated the effect of late career bonuses designed to postpone retirement for STEM teachers, and highly-rated teachers generally, using administrative data from two states. We show that selectively neutralizing the “push” incentives for these groups over a period of ten years using a well-targeted bonus would cost \$30-50,000 per incremental teacher year. For example, over ten years, the net cost per incremental year for a senior STEM teacher in Missouri can be as low as \$32,000.

Is such a policy worth the cost? Recent research has highlighted the large economic returns to effective teachers. If the bonuses were targeted to the most effective STEM teachers, then this plan would surely pass a cost-benefit test, particularly since the counterfactual would be replacing a year of instruction by an exceptionally effective senior teacher with a year of instruction from a novice. Indeed, based on the estimates of Chetty et al. (2014), one year of instruction by a teacher in the 95<sup>th</sup> percentile (as compared to the mean) yields a discounted benefit of roughly \$212,000. Thus, any of the bonuses considered in this paper, while seemingly expensive on a per year basis, would pass a cost-benefit test if targeted to high quality teachers.

The problem that the bonus programs are designed to ameliorate – that many highly-effective teachers and teachers in high-needs fields retire at young ages relative to their professional

counterparts in other occupations – are the product of strong incentives built into teacher pension plans across the nation (Costrell and Podgursky, 2009). Nonetheless, and despite major fiscal problems in these plans in many states, there is currently no indication of a shift away from them in most states. Moreover, even in states where reforms have been undertaken, they do not affect incumbent teachers. Thus, working within the constraints of the current plans, states might consider exploiting teachers' powerful retirement incentives in a strategic manner to improve workforce quality. This strategy has been used for decades by the U.S. military and might have benefits for public schools as well. As the saying goes: when life gives you lemons, make lemonade.

## References

- Asch, Beth J., Michael G. Mattock and James Hosek. (2015). Reforming Military Retirement: Analysis in Support of the Military Compensation and Retirement Modernization Commission. RR-1022-MCRM. Rand National Defense Research Inst., Santa Monica, CA.
- Brown, Kristine M. (2013). The link between pensions and retirement timing: Lessons from California teachers. *Journal of Public Economics*, 98, 1-14.
- Chetty, Raj, John N Friedman and Jonah E Rockoff. (2014). Measuring the Impacts of Teachers II: Teacher Value-Added and Student Outcomes in Adulthood. *American Economic Review*, 104 (9), 2633–2679.
- Chingos, Matthew M. and Martin R. West. (2015). Which Teachers Choose a Defined Contribution Pension Plan? Evidence from the Florida Retirement System. *Education Finance and Policy* 10(2), 193-222.
- Clotfelter, Charles T., Helen F. Ladd and Jacob L. Vigdor. (2006). Teacher-student matching and the assessment of teacher effectiveness. *Journal of human Resources*, 41(4), 778-820.
- Costrell, Robert and Joshua McGee. (2010). Teacher Pension Incentives, Retirement Behavior, and Potential for Reform in Arkansas. *Education Finance and Policy*, 5(4), 492-518.
- Costrell, Robert and Michael Podgursky. (2009). Peaks, Cliffs, and Valleys: The Peculiar Incentives of Teacher Retirement Systems and their Consequences for School Staffing. *Education Finance and Policy*, 4(2), 175-211.
- Doherty, Kathryn M., Sandi Jacobs, and Trisha M. Madden. (2012). “No One Benefits: How Teacher Pension Systems are Failing both Teachers and Taxpayers.” Washington, DC: National Council on Teacher Quality.
- Feng, Li. (2009). Opportunity wages, classroom characteristics, and teacher mobility. *Southern Economic Journal*, 1165-1190.
- Fitzpatrick, Maria and Michael Lovenheim. (2014). Early Retirement Incentives and Student Achievement. *American Economic Journal: Economic Policy*, 6, 120-154.
- Furgeson, Joshua, Robert Strauss and William Vogt. (2006). The Effects of Defined Benefit Pension Incentives and Working Conditions on Teacher Retirement Decisions. *Education Finance and Policy*, 1(3), 316-348.
- Glazerman, Steven, Ali Protik, Bing-ru Teh, Julie Bruch, Neil Seftor. (2012). Moving High-Performing Teachers: Implementation of Transfer Incentives in Seven Districts (NCEE 2012-4051). Washington, DC: National Center for Education Evaluation and Regional Assistance, Institute of Education Sciences, U.S. Department of Education.
- Goldhaber, Dan, Bethany Gross and Daniel Player. (2011). Teacher Career Paths, Teacher Quality and Persistence in the Classroom: Are Public Schools Keeping their Best? *Journal of Policy Analysis and Management*, 30(1), 57-87.
- Harris, Douglas and Scott Adams. (2007). Understanding the level and causes of teacher turnover: A comparison with other professions. *Economics of Education Review*, 26, 325-337.
- Hartman, Raymond S., Michael J. Doane and Chi-Keung Woo. (1991). Consumer rationality and the status quo. *Quarterly Journal of Economics*, 106, 141-162.

- Ingersoll, Richard M. (2001). Teacher Turnover and Teacher Shortages: An Organizational Analysis. *American Educational Research Journal*, 38(3), 499-534.
- Kahneman, Daniel, Jack L. Knetsch and Richard H. Thaler. (1991). Anomalies: The endowment effect, loss aversion, and status quo bias. *Journal of Economic Perspectives*, 5, 193-206.
- Koedel, Cory, Michael Podgursky and Shishan Shi. (2013). Teacher Pension Systems, the Composition of the Teaching Workforce, and Teacher Quality. *Journal of Policy Analysis and Management*, 32(3): 574–596.
- Knapp, David, Kristine M. Brown, James Hosen, Michael G. Mattock and Beth J. Asch. (2016). Retirement Benefits and Teacher Retention: A Structural Modeling Approach. RR-1488-RC. Santa Monica: RAND (February).
- Ni, Shawn and Michael Podgursky. (2016). How Teachers Respond to Pension System Incentives: New Estimates and Policy Applications. *Journal of Labor Economics*, forthcoming.
- Olberg, Amanda and Michael Podgursky. (2011). Charting a New Course to Retirement: How Charter Schools Handle Teacher Pensions. Washington DC: Fordham Institute.
- Podgursky, Michael. (2010). Teacher Compensation and Collective Bargaining. in R. Hanushek, S. Machin and L. Woessman (eds.). *Handbook of the Economics of Education*. Volume 3 Amsterdam: North-Holland, pp. 279-313.
- Rockoff, Jonah and Douglas Staiger. (2010). Searching for Effective Teachers with Imperfect Information. *Journal of Economic Perspectives*, 24, 97- 117.
- Rothstein, Jesse. (2015). Teacher Quality When Supply Matters. *American Economic Review*, 105, 100-130.
- Samuelson, William and Richard Zeckhauser. (1988). Status quo bias in decision making. *Journal of Risk and Uncertainty*, 1, 7-59.
- Stock, James and David Wise. (1990). Pensions, the Option Value of Work, and Retirement. *Econometrica*, 58(5), 1151-1180.
- Warner, John T., and Saul Pleeter. (2001). The personal discount rate: Evidence from military downsizing programs. *American Economic Review*, 91(1), 33-53.
- Yuan, Kuh, Vi-Nhuan Le, Daniel McCaffrey, Julie Marsh, Laura Hamilton, Brian Stecher and Matthew Springer. (2013) Incentive Pay Programs Do Not Affect Teacher Motivation or Reported Practices: Results from Three Randomized Studies. *Education Evaluation and Policy Analysis*, 35, 3-22.

## Appendix

### Calibration of the Structural Model

The out-of-sample predictions and policy simulations are based on frequentist draws. For each teacher we draw 10,000 sequences of  $v_t$ 's, (for  $t=1, \dots, T$ ). The frequency of the simulated retirement decisions gives rise to the predicted probabilities. We aggregate the probabilities over teachers in the 2008 sample to obtain the aggregate predicted retirement. The simulations under the proposed bonus policies are computed in a similar manner.

The parameters used for the out-of-sample and bonus policy simulations are taken from estimates in Ni and Podgursky (2016) based on Missouri data covering years 2002-2008 for teachers aged 47-59. Because teachers in OTHER are in Social Security and we do not have data on their credits accumulated for Social Security, we adjust  $\sigma$  upwards. Specifically, instead of using the estimated value of 3660 in Ni and Podgursky (2016), for the OTHER state we adjust  $\sigma$  to 5000. We continue to use 3660 for  $\sigma$  for MO STEM teachers. Experiments with moderate changes in  $\sigma$  produce similar predictions.

In the option-value model, the retirement condition for teachers in each year is as shown in inequality (1). The preference shock  $v_s$  follows an AR(1) process in equation (2). The key question is how to assign the initial value  $v_1$ . The sample in the initial year 2008 includes all teachers aged 50-65 in that year. Thus, the dataset includes teachers who were eligible for retirement but who chose to stay, but excludes those who chose to retire prior to 2008 (or  $t=1$ ). For the "stayers" in 2008 we know that

$\frac{g_t(m_0^\dagger)}{K_t(m_0^\dagger)} > -v_0$ , which implies that the initial value  $v_1$  differs from the unconditional stationary

distribution  $N(0, \sigma^2/(1 - \rho^2))$ . Drawing the initial value  $v_1$  from the unconditional stationary distribution without taking this sample selection bias into account will result in over-predicting retirement in the initial years.

We adjust for sample selection bias using the following procedure:

Suppose a teacher in the 2008 sample was eligible to retire  $J$  years prior to 2008 and chose to stay. We back-track the retirement decision in each of the  $J$  years. We draw  $v_{-J}$  from  $N(0, \sigma^2/(1 - \rho^2))$ , and generate  $v_t$  for  $t=-J+1, \dots, 0$  based on the AR(1) process in equation (2). If the draws of  $v_t$  prior to 2008 satisfy  $\frac{g_t(m_t^\dagger)}{K_t(m_t^\dagger)} > -v_t$ , for  $t=-J, \dots, 0$  (i.e., the draws imply the teacher did not retire by year 2008), we then keep the draws of  $v_0$ , and draw  $v_t$  for  $t=1, \dots, T$  based on equation (2). We repeat the draws until the number of kept draws reaches a pre-set number (10,000) and then compute the retirement probabilities by year.

## Simulation of Multi-year Effects of Permanent Bonuses

Tables 2 and 4 report the simulated multi-year effects of a permanent retention bonus for teachers with high predicted retirement probabilities and a state-dependent choice. The one-year change in experienced teaching years is measured by the decrease in predicted retirement due to the bonus for all teachers in the 2008 sample of teachers eligible for retirement. To simulate the effect over a five year horizon, we first track the 2008 cohort forward for five years and calculate the decrease in predicted retirement for these teachers during that time. Then we track the teachers who are included in the sample in 2009 forward for four years (these are teachers who were first at least 50 years old with at least 10 years' experience in 2009), the cohort included for the first time in 2010 for three years, the cohort included for the first time in 2011 for two years, and lastly the cohort included for the first time in 2012 for one year. We assume that the new cohorts of teachers who enter the retirement window are identical to the 2008 cohort.

The increase in retention of senior teachers changes the mix of the teacher labor force if every retirement is replaced by a novice teacher somewhere in the system. We calculate the total cost of

senior teachers and the novice teachers who replace them. These costs include salary, pension, and retention bonuses. In Tables 2 and 4, the increase in the cost of the senior teachers for extra years of teaching is labeled gross cost. The gross cost minus the reduced cost associated with needing fewer novice replacements is labeled net cost. The objective is to retain senior teachers with known quality, given the fixed number of total teacher years, at a minimum total cost. To measure the effectiveness of the retention policy, in Tables 2 and 4 we report the elasticity of teaching years of senior teachers with respect to total payroll cost, i.e., the percentage increase in teaching by targeted senior teachers for each percent increase in total payroll cost.