The Labor Market for Teachers Under Different Pay Schemes*

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Abstract

Compensation of most US public school teachers is rigid and solely based on seniority. This paper studies the effects of a reform that gave school districts in Wisconsin full autonomy to redesign teacher pay schemes. Following the reform some districts switched to flexible compensation. Using the expiration of pre-existing collective-bargaining agreements as a source of exogenous variation in the timing of changes in pay, I show that the introduction of flexible pay raised salaries of high-quality teachers, increased teacher quality (due to the arrival of high-quality teachers from other districts and to increased effort), and improved student achievement. Finally, I discuss the possible consequences of the introduction of flexible pay in all districts (as opposed to just a few) and argue that the observed increase in quality would be more muted.

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1 Introduction

Teachers are a key input for the production of student achievement (Rockoff, 2004; Rivkin et al., 2005) and their impact persists through adulthood (Chetty et al., 2011, 2014b). Attracting and retaining high-quality teachers to the profession can thus have far-reaching positive effects on students. More attractive compensation packages are sometimes proposed as a tool to achieve this goal. The salary schemes used in most US public schools, however, do not allow for the payment of financial rewards for effectiveness. If allowed to determine salaries in a more flexible way, could school districts improve the quality of their teaching workforce? Answering this question has beens challenging because variation in pay practices among public school districts is rare: The vast majority of districts pay teachers according to lock-step schedules, often very similar within a state.[1] This implies that all teachers with the same seniority and academic credentials are paid identically, regardless of their effectiveness or the demand for their labor (Podgursky, 2006).

This paper studies the consequences of flexible pay by taking advantage of a reform of collective bargaining, which generated unique variation in teachers' pay schemes across school districts in Wisconsin. In June 2011 the state legislature passed Act 10, a bill that discontinued collective bargaining requirements over teachers' salary schedules. Previously, each district was forced to negotiate its schedule with the teachers' union, and pay was determined solely by seniority and education. Act 10 gave districts full autonomy to determine compensation without union consent and allowed them to negotiate salaries with individual teachers.

Districts used this autonomy in multiple ways. Hand-collected data on districts' employee handbooks (documents listing district-specific workplace policies and procedures) reveal that approximately half of all districts took advantage of their new-found discretion and replaced seniority-based schedules with flexible salary schemes that allowed for pay differences among teachers with similar seniority and academic credentials. I refer to these districts as "flexible pay" (FP). The other half, which I call "seniority pay" (SP), maintained the use of seniority-based schedules. Comparing these two sets of districts I show that, in the five years following Act 10: (i) FP districts raised salaries for high-quality teachers, (ii) high-quality teachers moved from SP to FP districts, and (iii) teacher quality increased in FP districts relative to SP, due to

[1] Other works have used other changes in various aspects of teachers' labor markets to learn about teacher supply and demand. For example, Hensvik (2012) studies the effect of private vouchers, Jackson (2009) examines the impact of school de-desegregation, and Fitzpatrick and Lovenheim (2014) study the impact of an early teacher retirement policy.

both changes in workforce composition and an increase in teachers' effort.

The cross-district differences in pay schemes introduced by Act 10 create a unique setting to learn about the effects of changes in teacher pay. The identification of these effects, however, involves some challenges. First, post-expiration pay schemes were chosen by district administrators and could have been driven by unobservable district characteristics correlated with outcomes. To mitigate this concern I exploit the fact that districts were allowed to switch to flexible pay at different points in time. The collective bargaining agreements (CBAs) signed before Act 10, which mandated the use of a salary schedule, remained valid until their expiration; due to long-standing differences in the negotiation calendars, the CBAs of different districts expired in a staggered fashion between 2011 and 2013. To identify the effects of flexible pay, I thus leverage the quasi-randomness of the timing of expiration and I perform event studies around the expiration of the CBAs. With this strategy, in order for any observed differences in outcomes between FP and SP districts after a CBA expiration to be driven by unobservables, the timing of the change in these unobservables would have to coincide with the timing of the expiration.

A second challenge is that Act 10 was a large reform. Aside from changing teachers' salaries, it also increased employees' contributions to pensions and health care and reduced the power of unions. I show, however, that all these other changes took place immediately following the passage of the Act in 2011, and that pay schemes were the only element that changed after the expiration of the CBAs. I also demonstrate that measures of union power and spending on healthcare and retirement were comparable across FP and SP both before and after Act 10, and that all the results are unchanged when controlling for these variables.

Analyses of salary data show that, following the expiration of the CBAs in FP districts, large differences in pay arose among teachers who would have been paid exactly the same amount under the pre-Act 10 regime. To shed light on what drove these differences I correlate pay with teachers' value-added (VA), a widely used test scores-based measure of effectiveness. Since the Wisconsin data only allow teachers and students to be linked up to the grade level (instead of the classroom level), I use an estimator based on teacher turnover as in Rivkin et al. (2005), who face a similar data limitation. I validate this estimator using data on teachers and students from New York City, which include classroom identifiers, and show that it is a strong and unbiased predictor of teacher quality.

Event study estimates indicate that salaries of high-VA teachers rose more than those of low-VA teachers in FP districts after an expiration, but not in SP districts. Given that school districts in Wisconsin do not calculate VA nor use it to evaluate teachers, this finding suggests that districts can identify highly effective teachers and choose to pay them more when given the possibility of doing so.[2] Salaries rose even more for middle-school teachers with high VA, presumably because their outside option is higher.

The changes in pay schemes that followed the expiration of the CBAs could have changed teachers' incentives to work in a given district, potentially affecting each district's workforce composition. To see this, consider for example the school districts of Appleton (FP) and Oshkosh (SP), located in the same commuting zone in eastern Wisconsin and whose pre-Act 10 agreements expired in 2011. Prior to Act 10, a teacher with a Master's degree and 4 years of experience would earn between $46,500 and $49,000 in Appleton and between $42,000 and $49,000 in Oshkosh, according to each district's pay schedule. After the expiration of the CBAs, the same teacher could earn up to $68,000 in Appleton, and only between $39,000 and $43,000 in Oshkosh. If salaries were related to teachers' quality in Appleton, this change in pay should have induced high-quality teachers to move from Oshkosh to Appleton, and low-quality teachers to move from Appleton to Oshkosh. Indeed, although in the four years prior to the reform only four teachers moved from Oshkosh to Appleton, in the four years after the expiration of the CBA ten teachers moved; all of them ranked above the median VA and experienced an average pay increase of 16 percent ($6,500). By contrast, the five teachers who moved from Appleton to Oshkosh after the expiration all ranked below median VA and did not experience any significant increase in pay.

Event studies of movers across districts around the expiration of the CBAs confirm these patterns. The VA of teachers who moved to a FP district after an expiration was more than one standard deviation higher compared with the VA of teachers who moved before the expiration; these teachers also had lower seniority and academic credentials, and enjoyed a significant pay increase upon moving. The VA of teachers who moved to SP districts, on the other hand, was not significantly higher, and these teachers did not experience any change in pay. By the same token, the VA of teachers who left public schools from FP districts after the expiration was 60 percent lower compared with VA of those who left SP districts. These changes in the composition of movers and leavers produced a 0.04 standard deviation increase in average teacher quality in FP districts after each CBA expiration, relative to SP districts. These results demonstrate that higher pay is an effective tool to attract and retain talented teachers.

[2] This finding is in line with Rockoff et al. (2008) and Jacob et al. (2018), who suggest that schools are able to detect and screen talented applicants when given enough information about them.

In addition to affecting the composition of the teaching workforce, the introduction of flexible pay increased teachers' effort. To show this I allow the VA of each teacher to vary before and after Act 10, and I estimate the FP-SP difference in this time-varying measure around the expiration of districts' CBAs. I find that VA increased by 0.09 standard deviations in FP districts relative to SP, and I calculate that approximately one third of this increase can be ascribed to changes in effort. Student achievement (measured by test scores) also rose in FP districts relative to SP after a CBA expiration, by 0.06 and 0.04 standard deviations in math and reading respectively.

My findings indicate that the introduction of flexible pay in a subset of Wisconsin districts led to an improvement in the composition of the teaching workforce in those districts compared with the rest of the state. The magnitude of these changes is small because movements and exits of teachers tend to be rare events.[3] The composition of movers and leavers, however, changed quite dramatically within a short time period. This implies that the compositional change could become much more pronounced in the future, as more low-quality teachers leave the market from FP districts and more high-quality teachers enter the profession, and especially if pay becomes more strongly correlated with teacher effectiveness over time.

This scenario, however, relies on the assumption that SP districts remain with seniority pay in the long run. What would happen if flexible pay were adopted by *all* districts instead? Extrapolating from the partial-equilibrium results described above can be misleading. When flexible pay is introduced everywhere, the value of staying in the home district relative to both (a) moving to another district or (b) leaving public schools will be different for a given teacher relative to the case in which flexible pay is available only in some districts. This will affect vacancies, the demand for teachers, and the equilibrium allocation of teachers to districts.

To more clearly discuss the general-equilibrium effects of flexible pay I build and estimate a simple model of teachers' labor markets. Districts (the demand side) maximize a payoff depending on the attributes of teachers they hire, and teachers (the supply side) have preferences over a job's attributes (including salary). Districts make offers to teachers taking into account budget, capacity constraints, and the probability that a given offer is accepted, which depends on teachers' preferences and on the offers made by all the other districts.

While very stylized, the model can be used to gauge the effects of the introduction of flexible pay in *all* districts on sorting of teachers with different quality. This exercise reveals a much

[3] This finding is confirmed by Mansfield (2015) and Feng and Sass (2017), among others.

smaller compositional improvement in the quality of the teaching workforce: When all districts reward quality at the same rate teachers have lower incentives to move across districts, and any compositional improvement is entirely driven by exits of low-quality teachers. The observed improvements in FP districts' workforce quality could therefore be short-lived. The model and simulation results, however, do not account for adjustments in the quality of novice teachers, nor for changes in effort. A full-blown analysis of the equilibrium effects of flexible pay that incorporates these features is left to future research.

This paper makes three main contributions. First, it is among the first to study the effects of a newly-available, large-scale policy which gave school districts flexibility over teacher pay. Previous studies have been limited to small bonuses awarded on top of regular pay (Hanushek et al., 2004; Clotfelter et al., 2008; Dee and Wyckoff, 2015), limited cross-sectional variation in salaries (Stinebrickner, 2001; Boyd et al., 2013), and across-the-board salary increases (Figlio, 2002). Other works have exploited differences in teachers' outside option (Hensvik, 2012; Britton and Propper, 2016) as well as episodes of decentralization of pay decisions, using evidence from Sweden (Willén, 2018) and England (Burgess et al., 2019).

This paper can also be seen as an exploration, in the personnel economics tradition, of how pay affects the selection and incentives of a particularly important class of workers (Lazear, 2000a,b; Bandiera et al., 2005; Abramitzky, 2009; Khan et al., 2015). Financial incentives for teachers have had a significant impact on student achievement outside the US.[4] Evidence from the US, however, is mixed (see Jackson et al., 2014; Neal et al., 2011, for a review).[5] This paper also provides new evidence that school districts are willing to compensate high VA teachers when given the opportunity to do so, and that teachers respond to these incentives by exerting more effort in the classroom.

Lastly, this paper is one of the first to study the effects of a recent *decline* in union powers. Most studies of teachers' unions have analyzed increases in unionization (Eberts and Stone, 1987; Hoxby, 1996; Lovenheim, 2009), which are not necessarily symmetric.[6] The effects of a decline in unionization on teachers' labor markets are particularly interesting in the aftermath

[4]This literature includes studies conducted in India (Muralidharan and Sundararaman, 2011; Duflo et al., 2012), Israel (Lavy, 2002, 2009, 2020), England (Atkinson et al., 2009), and Kenya (Glewwe et al., 2010).

[5]Although some studies have found that teacher performance pay has positive effects on student test scores in the US (Ladd, 1999; Figlio and Kenny, 2007; Sojourner et al., 2014; Imberman and Lovenheim, 2015; Dee and Wyckoff, 2015; Brehm et al., 2017), others have shown that such incentives are ineffective at boosting achievement (Dee and Keys, 2004; Figlio and Kenny, 2007; Springer et al., 2011; Goodman and Turner, 2013; Fryer, 2013).

[6]Notable exceptions are Han (2016), Litten (2016), Roth (2017), and Baron (2018), who study the effects of recent episodes of de-unionization on outcomes such as teacher turnover, teacher salaries, retirement, and student achievement.

of *Janus v. AFSCME*, as more states could be affected in the future.

2 Teacher Compensation Before and After Act 10

In most US public school districts teacher salaries are determined using a salary schedule, based on teaching experience and academic credentials (Podgursky, 2006, and Appendix Figure A1). In states with collective bargaining (CB) for public sector employees, these schedules are negotiated between school districts and teachers' unions and are part of a CBA.[7] CBAs usually prevent districts from adjusting pay at the individual level; experience and education are the only determinants of salaries, and pay is not directly related to teacher effectiveness (Podgursky, 2006).

2.1 Wisconsin's Act 10

In 1959, Wisconsin became the first state to introduce CB for public sector employees (Moe, 2013). Teachers' unions have since gained considerable power and have been involved in negotiations with school districts over the key aspects of a teaching job.[8] Until 2011, teacher pay was set using salary schedules, part of each district's CBA.

On June 29, 2011, the state legislature passed the Wisconsin Budget Repair Bill, also known as Act 10. Intended to address a projected $3.6 billion budget deficit through cuts in public-sector spending, Act 10 introduced a number of changes for teacher unions, school districts, and their employees. First and most importantly, Act 10 limited the scope of salary negotiations to base pay, preventing unions from negotiating salary schedules and allowing school districts to set pay more flexibly. Second, it capped the annual growth in base pay to the rate of inflation. Third, it requires unions to hold yearly recertification elections requiring the absolute majority of all employees in the bargaining unit, it limits the validity of future CBAs to one year, and it prohibits the automatic collection of union dues from employees' paychecks.[9] Lastly, Act 10 raised employees' contributions to pensions and health care. In July 2011, the state also passed Act 32, which reduced state aid to school districts and decreased their revenue limit.[10]

[7] In states without CB, salary schedules are instead typically determined at the state level (e.g. Georgia). Schools are generally unionized on a district-by-district basis.

[8] 428 public school districts in Wisconsin typically serve either one city or one or more towns and villages. They operate public schools, hire teachers, and allocate teachers to schools. Each district enrolls an average of 1,900 students. Sixteen urban districts enroll 15,000 students per district on average (with Milwaukee Public Schools enrolling 67,000 students and the Madison Metropolitan School District enrolling 26,500 students), 63 suburban districts enroll 3,000 students per district, and 344 rural districts enroll 1,000 per district.

[9] Union membership dropped by nearly 50 percent in Wisconsin in the 5 years after the passage of Act 10. See D. Belkin and K. Maher, *Wisconsin Unions See Ranks Drop Ahead of Recall Vote*, The Wall Street Journal. Retrieved from https://www.wsj.com/articles/SB10001424052702304821304577436462413999718.

[10] Act 32 was passed on July 1, 2011. Revenue limits are the maximum level of revenues a district can raise through general state aid and local property taxes.

Timing of Activation of Act 10's Flexible Pay Provisions Even if the provisions of Act 10 went into effect immediately, districts became able to use their newly acquired flexibility at different points in time. The two-years-long CBAs stipulated between each district and the teachers' union prior to 2011 remained valid until their expiration; because districts had been on different negotiation calendars starting from several years prior to Act 10, the timing of these expirations differed. For a majority of the districts and 81.9 percent of all teachers the CBAs expired in 2011. For five districts, employing 11.6 percent of all teachers and including the large urban district of Milwaukee and the small rural district of Clintonville, they expired in 2012.[11] Lastly, for three districts and 6.5 percent of teachers, including the school district of Madison and the smaller suburban district of South Milwaukee, the CBAs expired in 2011 but before the activation of Act 10. These districts were thus able to negotiate a new CBA before Act 10 went into effect and their final agreement expired in 2013. Figure 1 summarizes the timing of expiration of districts' pre-existing CBAs.

Act 10 and Teacher Salaries: Flexible Pay vs. Seniority Pay With salary schedules no longer part of union agreements, at the expiration of their CBAs school districts gained the possibility to reward teachers for attributes other than seniority and academic credentials, and to adjust salaries on an individual basis without union consent.

To check whether districts took advantage this newly gained flexibility I collected school districts' employee handbooks, documents which list the duties and rights of all teachers and which, until 2011, contained the schedule negotiated between the district and the union (these data are described in Section 3). As of 2015, approximately half of all districts still included a schedule in their handbook and did not mention any other bonuses or increments. I call these seniority-pay districts (SP). The remaining districts, on the other hand, did not list any schedule. I refer to them as flexible-pay districts (FP).

The Racine Metropolitan School District, one of the state's largest urban districts, is an example of a SP district. Its 2015 handbook contains a salary schedule and specifies that movements along steps and lanes are determined solely on the basis of seniority and academic credentials (Appendix Figure A1).[12]

The Green Bay Area Public School District, the fifth largest in the state, is an example of a FP district. Its 2015 handbook does not contain a schedule, and it explicitly states that "[t]he District

[11] For example, the school district of Janesville negotiated a contract in March 2008 (https://www.schoolinfosystem.org) and one in September 2010 (https://www.tmcnet.com).

[12] See the Racine School District website (http://www.rusd.org) for the most recent version of its teacher salary schedule.

will determine the starting salary for a new employee."[13] The handbook also specifies that "[a]n employee may be held to the previous year's step for less than satisfactory performance." This language, common among FP districts, refers to districts' full autonomy to set teacher pay on an individual basis and to adjust it every year as they see fit.

3 Data and Measurement

The main data set contains information on the universe of Wisconsin teachers, linked to student test scores to calculate teacher VA. I combine it with information on districts' post-Act 10 salary schemes, drawn from employee handbooks, and with information on the expiration dates of districts' CBAs, obtained from a variety of sources. Lastly, I use district-level characteristics as controls. Data are reported by academic year, referenced using the calendar year of the spring semester (e.g. 2007 for 2006-07).

Teacher Data Information on the population of Wisconsin teachers is from the *PI-1202 Fall Staff Report - All Staff Files* for the years 2007–2016, made available by the Wisconsin Department of Public Instruction (WDPI). These files list all employees of the WDPI in each year and include personal and demographic information, education, years of teaching experience, and characteristics of job assignments (including total salary, grades and subject taught, full-time equivalency (FTE) units, and school and district identifiers). I restrict the sample to non-substitute teachers with FTE above 50, in FP and SP districts with non-missing CBA expiration dates.[14]

District Information District-level covariates include budget data from the WDPI, including revenues by source and expenditures by item, available for the years 2008–2015, and information on union election outcomes from records of the Wisconsin Employment Relation Commission (WERC).

Student Test Scores and Demographics Student-level data include math and reading test scores in the Wisconsin Knowledge and Concepts Examination (WKCE, 2007–2014) and Badger test (2015–2016), for all students in grades 3 to 8, as well as demographic characteristics such as gender, race and ethnicity, socio-economic (SES) status, migration status, English-learner status,

[13]See the Green Bay Area Public School District website (http://www.gbaps.org) for the most recent version of its employee handbook.

[14]I exclude long- and short-term substitute teachers, teaching assistants and other support staff, and contracted employees since salaries for these workers are calculated differently from those of permanent teachers. Due to evident mistakes in the reporting of salary information, I discard information for teachers in the school district of Kenosha, as well as for those in the school district of Milwaukee for the year 2015.

and disability.[15]

CBA Expiration Dates I a information on districts' pre-Act 10 CBAs from three main sources. The first are districts' pre-Act 10 union contracts. The second are school boards' meeting minutes from 2011, 2012, and 2013; these documents describe whether each district's CBA was set to expire in 2011, whether an extension was granted, and for how long. The third are local newspaper articles from 2011; many of these articles reported on the negotiations taking place and offered enough information to discern when the district's agreement was slated to expire. Using these three sources, I was able to derive the expiration and extension dates for 211 out of 426 school districts, employing 79 percent of all teachers. I give priority to information from union contracts, complementing it with the other two sources when unavailable.

Employee Handbooks and Salary Schedules I collected information on districts' pay schemes from their 2015 employee handbooks, available for 224 out of 428 districts and for 164 districts with CBA information.[16] I classify a district as SP for the entire post-Act 10 period if its 2015 handbook contains a salary schedule and does not mention rewards for performance or merit, and as FP otherwise. If the handbook contains a schedule but also mentions bonuses linked to performance, I classify the district as FP. The final sample contains 74 FP districts, 90 SP districts, and covers 72 percent of all teachers.

3.1 Measurement: Teacher Value-Added

I measure teacher quality using value-added (VA), defined as a teacher's effect on test scores conditional on other determinants of achievement, such as past test scores, student demographics, and school effects. Albeit not a perfect measure of talent (Rothstein, 2010), VA is generally considered a good signal of a teacher's effectiveness (Rockoff, 2004; Rivkin et al., 2005; Kane and Staiger, 2008; Chetty et al., 2014a).[17]

VA is usually estimated using datasets that make it possible to link teachers to the pupils they taught through classroom identifiers. Information on students' and teachers' classrooms was not maintained by the WDPI before 2017. This implies that I can link a teacher to all the

[15]The WKCE was administered in November of each school year, whereas the Badger test was administered in March. To account for this change, for the years 2007–2014 I assign each student a score equal to the average of the standardized scores for the current and the following year.

[16]Handbooks are published on each district's website. Unclassified districts (i.e., those for which handbooks are not available) either do not have a website or do not make their handbook public. Appendix Table A2 compares FP and SP districts with unclassified districts. The latter are smaller, enroll more disadvantaged students, pay lower salaries, and are disproportionately located in rural areas.

[17]A growing body of evidence (Kraft, 2017; Jackson, 2018; Petek and Pope, 2016) shows that teachers can affect a large host of student outcomes beyond test scores. Here, I restrict my attention on the effects on test scores due to the unavailability of other outcomes.

students enrolled in her school and grade in a given year, but not to the specific students she taught. To obtain a measure of teacher effectiveness in the presence of this data limitation I leverage the identification approach of Rivkin et al. (2005), who face the same issue using data from Texas, and I combine it with the estimation method of Kane and Staiger (2008). The starting point is the following model of achievement:

$$A_{kt} = \beta X_{kt} + \nu_{kt}, \text{ where } \nu_{kt} = \mu_{i(kt)} + \theta_{c(kt)} + \varepsilon_{kt} \tag{1}$$

A_{kt} is a standardized measure of test scores for student k in year t, X_{kt} is a vector of student and school-specific controls, and $i(kt)$ denotes student k's teacher in t.[18] VA is the estimate of $\mu_{i(kt)}$, the teacher-specific component of test score residuals. Kane and Staiger (2008) estimate this quantity using an empirical Bayes estimate constructed using the residuals from equation (1), $\hat{\nu}_{it}$, aggregated at the teacher-by-year level.

When teachers and students can only be linked up to the grade level, directly constructing $\hat{\nu}_{it}$ is not possible. The best approximation is $\hat{\nu}_{gst}$, i.e., residuals aggregated at the level of teacher i's school and grade in year t. Appendix B, however, shows how in the presence of teacher turnover one can use $\hat{\nu}_{gst}$ to obtain a consistent estimator for μ_i. The identification argument follows Rivkin et al. (2005) and relies on teacher turnover across grades and/or across schools. In the absence of turnover, all teachers in the same grade and school would be assigned the same average residual every year, and identifying their effects would be impossible. With multiple years of data and in the presence of turnover, teacher switches across schools or grades make it possible to isolate the effect of the individual teacher, by comparing grade test score residuals before and after her arrival. Importantly, teacher turnover helps with the identification of the VA not only of the teacher who switches, but also of all other teachers in her same grade and school at any point in time (Appendix B illustrates the identification argument with a simple example).[19] To check that the unavailability of teacher-student links is not driving my results, I show that my main estimates are largely unchanged if I restrict the sample to teachers in schools

[18] In my model, X_{kt} includes the following: school and grade-by-year fixed effects; cubic polynomials of past scores interacted with grade fixed effects; cubic polynomials of average past scores for the students in the same grade and school, interacted with grade fixed effects; student k's demographic characteristics, including gender, race and ethnicity, disability, English-language earner status, and socioeconomic status; the same demographic characteristics, averaged for all students in the same grade and school as student k in year t; and the student's socioeconomic status interacted with the share of low-socioeconomic status in her grade and school in t.

[19] The aggregation of test scores at the grade level also overcomes one of the most problematic form of selection, which occurs within schools and grades and across classrooms (Rivkin et al., 2005). The (forced) use of grade-school estimates circumvents this form of selection and is in practice equivalent to an instrumental variable estimator based on grade rather than classroom assignment.

and grades with at most three teachers per subject (60 percent) and to teachers whose VA is exactly identified from that of their colleagues due to teacher turnover (62 percent, Appendix Tables A7 and A11).

Limitations of VA Estimates and a Validation Exercise. Because students are linked to teachers at the grade-school level, and because not all teachers switch grade or school, the VA of a teacher could also be a function of test scores of students she never taught. This will likely introduce measurement error in the estimates. In addition, the VA of teachers who are always in the same grade-school will never be separately identifiable (and each of them would be assigned an average of their true effects). Classical measurement error would undermine the efficiency of the parameter estimates (when used as the dependent variable) or generate attenuation bias (when used as an explanatory variable). This noise, however, can be even more problematic when it is non-classical, i.e., correlated with other variables in a model. This could happen, for example, if estimates are more precise for teachers who move and if movements are not random (e.g. they could be correlated with a district's pay scheme).

To assess the performance of my measures relative to standard estimates, I use data from New York City (NYC) teachers and students, which include classroom links. I estimate VA using the standard approach (which exploits classroom links, CL hereafter) as well the approach described above, which links students to teachers on the basis of grade and school (GL hereafter). A comparison of these two sets of estimates yields the following findings:

1. Although less precise than CL, GL still explains a substantial portion of the variance in test scores. In the Wisconsin data, the standard deviation of GL is 0.12 for Math and 0.075 for Reading (Appendix Figure B2).

2. GL is a forecast-unbiased estimator of CL; the estimated bias (one minus the slope of the fit line in Appendix Figure B3) is equal to 0.01 and it is indistinguishable from zero.

3. GL is a forecast-unbiased estimator of a teacher's future student achievement. Using teacher switches as a quasi-experiment (Chetty et al., 2014a) yields an estimated bias of 0.022 (Appendix Table B1).

4. The difference between CL and GL is uncorrelated with student or teacher observables (including the probability of turnover) in the NYC data (Appendix Table B2), mitigating concerns for non-classical measurement error.

An additional limitation of my estimates is that, since they are identified off of teacher switching posts, they could be more precise for teachers who move across districts, especially if compared with teachers who never switch. This could raise concerns when studying teacher sorting across districts. Appendix Table A7, however, shows that the magnitude of the main estimates is unchanged when I restrict attention to teachers who switch at least once, which should mitigate this concern.

VA estimates are available for 25,021 teachers of math and reading in grades 4 through 8, including the final sample of 18,856 teachers in 164 FP and SP districts with non-missing CBA expiration dates (see Appendix Table A3 for a summary). My empirical analyses use two measures of VA. The first is *ex ante* VA, calculated using test scores for the years 2007–2011 and used to single out the effects of Act 10 on teachers' composition. The second is a time-varying measure, allowed to differ before and after Act 10 for each teacher and used to study changes in effort.[20]

4 Indentifying The Effects of Changes in Pay Schemes

The goal of my empirical strategy is to isolate the effects of changes in the structure of teacher salaries, generated by Act 10, on pay, the composition of the teaching workforce, teachers' effort, and student achievement. Doing so requires overcoming a set of challenges.

Other provisions of Act 10 The first challenge is that Act 10 was a large reform, which affected teachers in many ways beyond the change in pay schemes: it changed employees' health and retirement benefits and reduced the power of teacher unions. A simple comparison of outcomes before and after the reform would likely confound the effects of changes in pay structures with the effects of all these other changes.

To overcome this issue I take advantage of the fact that, while all provisions of Act 10 were activated immediately after the passage of the law in June 2011, districts were only allowed to discontinue the use of the salary schedules after the expiration of existing CBAs. The timing of these expirations varied across districts (Figure 1), reflecting long-standing misalignments in the negotiation calendars. For example, while most districts typically negotiated agreements bi-yearly on odd years, the school district of Janesville negotiated contracts in March 2008 and September 2010.[21] Off-calendar districts include both large, urban districts like Milwaukee and Madison and smaller, suburban and rural districts like Clintonville and South Milwaukee. Ap-

[20]By construction, *ex ante* VA is only available for the subsample of teachers who were already in the system before 2011. Appendix Table A4 shows that teachers with *ex ante* VA have higher experience than teachers without it; *ex post* VA, however, is not statistically different among these two groups of teachers.

[21]See https://www.schoolinfosystem.org and (https://www.tmcnet.com.

pendix Table A1 shows that no observable characteristics of school districts can predict the timing of the expiration.[22]

To confirm that all other provisions of Act 10 had an effect in 2011, regardless of the timing of expiration of districts' CBAs, Appendix Figure A2 compares time trends of various district attributes likely affected by Act 10 (such as expenditures on teacher salaries, retirement, and health benefits, and trends in the share of districts whose unions managed to recertify, top panel) with event studies of the same variables around a CBA expiration, controlling for year effects (bottom panel). If the assumption that these variables were unaffected by the CBA expiration holds, one would observe a discontinuity in the trends between 2011 and 2012, but no discontinuity after the expiration of districts' CBAs when controlling for year effects. The evidence in the figure confirms this. Given this, event studies of outcomes around the expiration of these agreements which control for years after Act 10 should isolate the effects of changes in pay schemes.

Endogeneity of the choice of pay schemes The second challenge is that the ultimate decision on whether to discontinue the use of a salary schedule was made by school district administrators, and could be endogenous.[23] A comparison of outcomes between FP and SP districts over time could therefore yield biased results if the choice of the pay scheme is correlated with other time-varying, unobserved school district characteristics that directly affect the outcomes.

This challenge, too, can be addressed exploiting the exogeneity of the timing of expiration of districts' CBAs. A comparison of outcomes between FP and SP districts around the expiration of districts' CBAs allows me to isolate the effects of changes in pay, provided that the timing of changes in any unobservables related to districts' choices of pay schemes does not exactly coincide with the timing of the expiration of districts' CBAs. If the timing of CBA expiration is as good as random, the bias from unobservables is likely to play a small role. To further confirm this, I complement my main event studies results with estimates obtained using the approach of Altonji et al. (2005), which allow me to bound the effects accounting for the role of unobservables.

[22]The table shows OLS estimates of a number of characteristics of districts, teachers, and students, measured in 2011, on indicators for the CBAs expiring in 2011, 2012, and 2013.

[23]Possible drivers of this decision include fiscal concerns, the desire to compensate high-quality teachers or to preserve teachers' morale, and the increased pressure to compete with other districts for talented teachers (Kimball et al., 2016).

5 Salary Responses to Act 10

Act 10 gave districts considerable flexibility over the design of teacher pay. In this section I describe how salaries in FP and SP districts changed after the expiration of the CBAs, focusing on salary dispersion and on the correlation between pay and teacher quality.

5.1 Dispersion in Salaries

Figure 2 shows median salaries and 90-10 percentile ranges, by three-year experience classes and for teachers with a master's degree, in two among the largest urban districts: Madison (top panel), a SP district whose agreement expired in 2012, and Green Bay (bottom panel), a FP district whose agreement expired in 2011.

Before Act 10, the salary distribution appears very similar across the two districts. For example, median pay was equal to $43,092 in Madison (with a 90-10 percentile range of $8,464) and to $42,345 in Green Bay (with a range of $6,000) for teachers four to six years of experience, and to $ 59,260 in Madison (with a 90-10 percentile range of $7,848) and $57,195 in Green Bay (with a range of $8,990) for teachers with 13 to 15 years of experience. After Act 10 and the expiration of districts' CBAs, pay dispersion for low-seniority teachers becomes much larger in Green Bay, while it remains stable in Madison. The 90-10 percentile range equals $13,700 in Green Bay and $6,217 in Madison for teachers with four to six years of experience, and $17,588 in Green Bay and $8,549 in Madison for teachers with seven to nine years of experience.

To more systematically quantify the changes in pay dispersion across all districts, I perform an event study of the coefficient of variation of salaries (CV) around each district's CBA expiration. The CV is calculated as the ratio between the standard deviation and the mean for teachers in the same district, with the same experience and the same education. The CV is on a flat trend the years leading to a CBA expiration, and it increases by 0.009 two years after the expiration (or 10 percent compared with an average coefficient of variation of 0.09 in the years before an expiration, Figure 3, top panel, solid line). The increase is similar when restricting attention to teachers who never move (dashed line), indicating that the salary dispersion is not just driven by new hires.

To understand which districts are driving the observed increase in pay dispersion, the bottom panel of Figure 3 shows the difference in the CV between FP and SP districts by time-to-expiration. The difference is on a flat trend in the years leading to an expiration, and it increases by 0.009 in the year following the expiration (or 10 percent compared with a pre-expiration average coefficient of variation equal to 0.087 for SP districts).

This increase in pay dispersion indicates that the departure from a salary schedule regime in FP districts generated differences in pay among teachers with the same experience and education working in the same district. This suggests that FP districts used their newly-acquired flexibility to compensate teachers for attributes not directly rewarded by a standard schedule.

5.2 Salaries and Teacher Quality

What drove the post-Act 10 increase in salary dispersion in FP districts? To answer this question, the ideal test would estimate the correlation between pay and those teacher attributes, not rewarded under seniority pay, that districts could compensate under a FP scheme, including (but not limited to) effectiveness, progress, leadership, and professional development. Most of these attributes, however, are only observable to principals and other school administrators. I hence settle on a more modest task and study the correlation between salaries and teacher VA, conditional on experience and education. While districts do not observe nor explicitly use VA to evaluate teachers, this measure could be correlated with other attributes that districts can observe and value.

I estimate this correlation using the following model:

$$\log(w_{it}) = \delta_0 VA_{it} + \delta VA_{it} * \mathbb{1}(t > Exp_{j(it)}) + \beta X^w_{it} + \theta_{j(it)t} + \varepsilon_{it} \qquad (2)$$

where w_{it} is the salary earned by teacher i year t, VA_{it} is teacher VA (allowed to vary before and after 2011 and standardized to have mean 0 and variance 1) and Exp_j is the year of expiration of district j's CBA. The vector X^w_{it}, which includes indicators for years of experience interacted with indicators for the highest education degree and with an indicator for years after 2011, allows me to examine the correlation between salaries and VA among teachers with comparable credentials. The inclusion of a vector of district-by-year fixed effects θ_{jt} allows me to compare teachers who work in the same district in each year. I estimate the equation using OLS; since VA is an estimated variable, I bootstrap standard errors clustering them at the district level. In this specification, the estimate of δ_0 captures the correlation between salaries and VA before the expiration of each district's CBA; the estimate of δ captures the change in this correlation after the expiration.

In FP districts, the correlation between salaries and VA is very small and indistinguishable from zero before the expiration of districts' CBA, and it becomes positive and significant after the expiration (with an estimate of δ equal to 0.004, Table 1, column 1, significant at 5 percent). This implies that a one-standard deviation higher VA is associated with a 0.4 percent higher salary. In SP districts, on the other hand, the estimate is virtually zero (Table 1, column 2, with a p-value equal to 0.83; the difference between FP and SP districts is shown in column 4 and is significant at 5 percent). Estimates of δ are larger in FP districts for middle-school teachers, presumably because they have a higher outside option (columns 4-6, FP-SP difference equal to 0.007 and significant at 1 percent). Estimates are robust to restricting the sample to tenured teachers (i.e., those with at least three years of experience, Table A5), teachers in schools and grades with at most three teachers per subject (Appendix Tables A7, columns 1-3), and teachers whose VA is exactly identified from that of their colleagues due to teacher turnover (Appendix Table A7, columns 4-6). Estimates also hold when the districts of Madison and Milwaukee are excluded (Table A6) and when I control for teaching assignment (grade and subject, Table A8).

To assess how the correlation between salaries and teacher quality changed over time and to check for the existence of pre-trends, I allow the parameter δ to vary by time-to-CBA expiration, in an event-study framework. These estimates, shown in Figure 4, are indistinguishable from zero and very similar in both FP and SP districts in the years leading to an expiration. In line with Table 1, estimates become positive and statistically significant in FP districts after an expiration, reaching 0.5 percent in 2013 (Figure 4, solid line). They instead remain close to zero in SP districts in the four years following the expiration (Figure 4, dashed line). Estimates from a semi-parametric version of equation (2) show that the increase in the correlation in FP districts is driven by teachers with VA in the top three quintiles (Appendix Figure A3).

Although positive, estimates of δ are small in magnitude. It might therefore seem surprising that such small differences in salaries could produce any change in teacher behavior. It should be emphasized, however, that districts do not use VA when making decisions over teacher pay. In fact, school districts do not even calculate VA; interviews with superintendents reveal that post-Act 10 schemes in FP districts are designed to reward teachers for a number of attributes, including (but not limited to) their preparation, leadership, learning, and professional development.[24] If these characteristics have a positive but small correlation with VA, this could result in low estimates of δ due to attenuation bias.[25] Estimates of δ should therefore be interpreted as

[24]Interviews with superintendents of a subset of 12 FP and SP districts were conducted by phone in December 2017.

[25]Papay and Kraft (2015) show that professional development is associated with improvements in teacher quality. Dobbie (2011) demonstrates that teacher leadership is a good predictor of future student test scores among Teach for America corps members. Jackson et al. (2014) provide a review of the literature on teacher attributed associated with VA.

suggestive evidence that districts use their post-Act 10 pay flexibility to reward teacher characteristics that are, at least to some extent, positively correlated with VA, rather than as estimates of the actual salary premia enjoyed by teachers under the new pay scheme.

6 Movements, Exits, and Changes in Workforce Composition

How did teachers respond to the cross-district differences in pay that arose after CBAs expired? In this section, I focus on two types of responses: movements from one school district to another and exits from the state's public schools. I then quantify the implications of these responses for the composition of the teaching workforce across districts.

6.1 Teachers' Movements Across Districts

Teacher movements across districts became significantly more frequent after Act 10. While 1.3 percent of teachers moved each year until 2011, 2.9 percent moved after 2011 (Figure 5, top panel). The timing of these moves appears in line with the expiration of districts' CBAs, rather than with the mere passage of Act 10 in 2011. An event study of moving rates around an expiration that accounts for year effects indicates that moving rates increased by 1.6 percentage points one year after an expiration and by 4.6 percentage points four years after an expiration, relative to before (Figure 5, central panel).

Were these movements driven by the differences in pay schemes across FP and SP districts? The bottom panel of Figure 5 shows an event study of mobility by type of district of origin and destination (FP or SP). Movements across districts of different type increased by a large 1.9 percentage points four years after a CBA expiration (a 3-fold increase, significant at 1 percent). Movements across districts of the same type, on the other hand, only increased by 0.9 percentage points (a 112 percent increase, p-value equal to 0.15, Figure 5, bottom panel).

As demonstrated in the previous section, FP districts compensate teachers for their quality, whereas SP districts only reward them for seniority and academic credentials. This should create incentives for higher VA teachers (especially those with low seniority and academic credentials) to move to FP districts, where they would enjoy higher pay, and for lower-VA teachers with high seniority and academic credentials to move to SP districts.

To test this hypothesis I study how the attributes of teachers who moved to FP and SP districts changed after a CBA expiration. I focus on three attributes: VA, experience, and having a postgraduate degree (Master's or PhD). I estimate the following equation, separately for movers to FP and SP districts:

$$Y_{it} = \beta \mathbb{1}(t > Exp_{j(it)}) + \gamma X_{it} + \xi Z_{j(it)t} + \tau_t + \varepsilon_{it} \tag{3}$$

where Y_{it} is teacher i's characteristic in year t, and Exp_j is the year of expiration of the CBA agreement of district j. The index $j(it)$ denotes the district in which i teaches in t. A vector X_{it} of teacher observables, such as type of district they were teaching in at $t-1$ (FP or SP), accounts for different incentives to move based on the district of origin. A vector of district characteristics Z_{jt}, such as per teacher expenditure on various budget items, per pupil expenditure, and measures of union power, controls for the effects of other provisions of Act 10 on the composition of movers. In this specification, the coefficient β captures the post-expiration change in the characteristics of teachers who move to each type of district.

OLS estimates of equation (3) indicate that teachers who moved to FP districts after a CBA expiration had a 1.12 standard deviations higher VA relative to those who moved before the expiration (Table 2, panel A, column 1, significant at 1 percent). They also had 1.6 fewer years of experience (34 percent less compared with a pre-2011 average of 4.7, panel B, column 1, significant at 5 percent) and were 15 percentage points less likely to have a postgraduate degree (or 49 percent, panel C, column 1, significant at 5 percent). These estimates are robust to controlling for the type of district of origin (column 2). Movers to SP districts after a CBA expiration, on the other hand, have slightly lower VA and years of experience compared with movers before the expiration, although these differences are indistinguishable from zero (Table 2, panels A and B, column 2, p-values equal to 0.45 and 0.30 respectively), and are 9 percentage points (27 percent) more likely to hold a postgraduate degree (Table 2, panel C, column 2, significant at 5 percent). Columns 5 and 6 test for differences in the characteristics of movers to FP and SP districts in a difference-in-differences fashion. Importantly, in these specifications I control for an interaction between *FP* and an indicator for years after 2011, to account for any observable and unobservable factors, specific to FP and SP districts and whose timing coincides with the passage of Act 10, that could affect the selection of movers. The inclusion of this control implies that β is essentially estimated using the variation from districts districts whose agreements expired after 2011. These estimates confirm that movers to FP districts after a CBA expiration have higher VA, lower experience, and are less likely to hold a postgraduate degree compared with movers to SP districts (estimates on *FP* $\times$ *post-CBA expiration*, Table 2, column 6, significant at 1, 10, and 1 percent respectively).

To test for the presence of pre-trends in the average characteristics of movers to FP and SP districts, in Figure 6 I perform an event study of the difference in VA, experience, and academic credentials between movers to FP districts and movers to SP districts, in the years around the expiration of each district's CBA. For all three characteristics, these differences are on flat trends in the years leading to an expiration. Immediately after the expiration the difference in VA becomes positive, whereas the differences in years of experience and in the likelihood of having a Master's or a PhD become negative. These estimates confirm the evidence in Table 2; the discontinuity in the trends also indicates that the timing of the changes in these variables coincides with the timing of expiration of districts' CBAs, which further confirms that the observed changes are driven by the introduction of flexible pay as opposed to other observable and unobservable changes associated with Act 10.

Salaries of Movers The bottom panel of Figure 5 shows a large increase in movements across districts offering different pay schemes after Act 10. This, combined with the evidence in Table 2 and Figure 6, suggests that the disproportionate movement of high-quality teachers to FP districts after a CBA expiration was driven by the promise of higher pay. I explore this hypothesis more directly by studying the relationship between salaries and VA of teachers who move to FP and SP districts, in the years surrounding a move. I estimate the following equation on the sample of teachers who move at least once between 2007 and 2016:

$$\begin{aligned}\log(w_{it}) = \quad & \sum_{k=-4}^{2} \beta_k^0 \mathbb{1}(t - Y_{m(ij)} = k) + \sum_{k=-4}^{2} \beta_k^1 VA_i * \mathbb{1}(t - Y_{m(ij)} = k) \\ & + \sum_{k=-4}^{2} \beta_k VA_i * \mathbb{1}(t - Y_{m(ij)} = k) * \mathbb{1}(Y_{m(ij)} > Exp_j) \\ & + \eta VA_{it} * \mathbb{1}(Y_{m(ij)} > Exp_j) + \gamma X_{it}^w + \theta_{jt} + \varepsilon_{it}\end{aligned} \tag{4}$$

where the variable $Y_{m(ij)}$ is the year in which teacher i moves to district j, and X_{it}^w and θ_{jt} are as in equation (2).[26] Normalizing β_{-1} to zero, each parameter β_k estimates the post-expiration change in salaries associated with a one-standard deviation higher VA k years from the move.

OLS estimates of β_k indicate that a one-standard-deviation higher VA is associated with a 2-percent higher salary for teachers who move to FP districts after an expiration, relative to before (Figure 7, solid line). Notably, no trends in salaries can be observed in the years leading to a move. A higher VA is instead not associated with any significant differences in salaries for

[26]For teachers who move more than once between 2007 and 2015, I consider only the earliest move. The results are robust to using the latest move.

movers to SP district after a CBA expiration (Figure 7, dashed line). These results support the hypothesis that, in the aftermath of Act 10, high-quality teachers were attracted to FP districts by the prospect of higher salaries.

6.2 Exit from Public Schools

The increase in movements of teachers across districts after Act 10 was accompanied by a surge in the share of teachers who left Wisconsin public schools (Figure 8).[27] In at the end of 2010, 5.1 percent of teachers left; at the end of 2011, 9.0 percent left (Figure 8, solid line). An event study of exit rates around CBA expiration dates that accounts for year effects indicates that part of this surge in exit rates followed the expiration of CBAs. Controlling for year effects, exit rates increased by 5 percentage points in the year following an expiration (Figure 8, bottom panel).

Which teachers decided to leave after the expiration of districts' CBA? The introduction of a pay scheme that rewards quality at the expense of experience and academic credentials should have induced teachers with low VA and high seniority and credentials to exit FP districts at a higher rate. To test this hypothesis I estimate the following equation on the sample of teachers who exit public schools at the end of each year:

$$Y_{it} = \beta \mathbb{1}(t \geq Exp_{j(it)}) + \gamma X_{it} + \xi Z_{j(it)t} + \tau_t + \varepsilon_{it} \tag{5}$$

As before, Y_{it} is teacher i's characteristic in year t, namely VA, years of experience, or an indicator for having a Master's or a PhD. A vector of teacher-level controls X_{it}, containing fixed effects for age and other teacher characteristics not included in Y_{it}, alone and interacted with an indicator for the years after 2011, allows me to flexibly account for the effects of other teacher observables on the decision to leave. As before, the inclusion of district characteristics Z_{jt} controls for the effects of other provisions of Act 10 on the composition of exiters. In this specification, the coefficient β captures the post-expiration change in the characteristics of teachers who exit public schools from districts of each type, compared with teachers who left before the expiration.

OLS estimates of equation (5) indicate that exiters from FP districts after a CBA expiration have a 0.5 standard deviations lower VA relative to exiters before the expiration, although this estimate is not distinguishable from zero (Table 3, panel A, column 1, p-value equal to 0.45). They also have 0.6 fewer years of experience (panel B, column 1, significant at 10 percent), and

[27] Exit rates are defined as the share of individuals who disappear from the records of employees in Wisconsin public schools. Reasons for exiting include retirement, dropping out of the labor force, or a move to a to private school or to another industry/occupation. The staff data does not allow me me to observe a teacher after she leaves, and I am thus unable to distinguish among these reasons.

they are not differentially likely to have a postgraduate degree (panel C, column 1, p-value equal to 0.23). These estimates are robust to controlling for district characteristics (column 2). Exiters from to SP districts after a CBA expiration, on the other hand, have a 0.26 standard deviations higher VA and 2.3 additional years of experience (Table 3, panels A and B, column 2, significant at 5 percent), and are not differentially likely to hold a postgraduate degree (panel c), column 2, p-value equal to 0.23). Columns 5 and 6 test for differences in the characteristics of exiters from FP and SP districts in a difference-in-differences fashion, again controlling for the interaction between *FP* and an indicator for years after Act 10. These estimates confirm that teachers who exit FP districts after a CBA expiration have lower VA, lower experience, and lower credentials (estimates on *FP* $\times$ *post-CBA expiration*, Table 3, panels A, B, and C, column 5, significant at 10, 5, and 10 percent respectively).

To test for the presence of pre-trends, in Figure 9 I estimate the difference in VA, experience, and academic credentials between exiters from FP and SP districts by time elapsed from each district's CBA expiration. For all three characteristics, these differences are on flat trends in the years leading to an expiration. Immediately after the expiration, the differences in VA and experience become negative. These findings confirm the evidence in Table 3, and also indicate that the timing of the changes in these variables is in line with the timing of expiration of districts' CBAs.

Salaries of Exiters Next, I test whether the disproportionate exit of low-quality teachers from FP districts is related to a decline in pay. I estimate the following model:

$$\begin{aligned} \log w_{it} \quad = \quad & \beta_0 e_{it} + \beta_1 e_{it} * \mathbb{1}(t \geq Exp_{j(it)}) + \beta_2 VA_{it} + \beta_3 VA_{it} * \mathbb{1}(t \geq Exp_{j(it)}) \\ & + \beta_4 VA_{it} * e_{it} + \beta_5 VA_{it} * e_{it} * \mathbb{1}(t \geq Exp_{j(it)}) + \beta X^w_{it} + \theta_{jt} + \varepsilon_{ijt} \end{aligned} \tag{6}$$

where the variable e_{it} equals one if teacher i leaves public schools at the end of year t and X^w_{it} and θ_{jt} are as in equation (2). I estimate this model separately for teachers in all districts and in FP and SP districts. In this equation, the parameter β_1 captures the change in salaries of teachers who leave after a CBA expiration, relative to stayers and to teachers who left before the expiration. Estimates of β_5 capture instead the extent to which this difference varies by teacher VA.

OLS estimates of the parameters in equation (6) on all districts, shown in column 1 of Table 4, indicate that teachers who left after the expiration of a district's CBA did not experience a significantly different salary (with an estimate of *exit * post-CBA expiration* equal to -0.003, Table 6, column 1, p-value equal to 0.53). Leavers with lower VA, however, experienced a 0.9 percent lower pay (with an estimate of *VA * exit * post-CBA expiration* equal to 0.009, Table 6, column 1, p-value equal to 0.15). The association between the VA of leavers and their pay is stronger in FP districts (with an estimate of *VA * exit * post-CBA expiration* equal to 0.017, Table 6, column 2, significant at 10 percent), and it is close to zero in SP districts (estimate equal to 0.002, Table 6, column 3, p-value equal to 0.58).

Taken together, these estimates suggest that the disproportionate exit of low-quality teachers from FP districts, compared with SP districts, is related to a decline in pay for these teachers.

6.3 Entry Into the Teaching Profession

The third margin through which changes in pay schemes following Act 10 could affect the composition of the teaching workforce is a change in the supply of new teachers. Figure 10 shows that, while the share of new teachers per year was on a downward trend in the years leading to Act 10 (and equal to 2.7 in 2010 and 2.4 in 2011), it increased rapidly after Act 10, to 4.8 in 2014 and 3.7 in 2016, possibly to fill in the larger number of vacancies left open by the teachers who left. The timing of these changes is in line with the expiration of districts' CBAs: An event study of entry rates around an expiration that accounts for year effects indicates that entry increased by 2.5 percentage points the year after an expiration and by 2.7 percentage points two years after, declining again in the following years (Figure 10, bottom panel).

Did the composition of the pool of individuals who chose to become teachers change after Act 10? On one side, the changes in pay schemes introduced in FP districts after the expiration of the CBAs could have induced better or more motivated teachers to enter the market in these districts (Hoxby and Leigh, 2004; Rothstein, 2014).[28] On the other side, the overall decline in pay levels and in benefits that followed Act 10 could have made teaching less attractive in the eyes of prospective teachers, discouraging them from entering. It is also possible that, as of 2016, the supply of new teacher had not yet reacted to the policy change: Becoming a teacher requires obtaining an education degree and a license, and this can take some time.

To isolate the effect of changes in pay schemes on the supply of new teachers, I again exploit differences in the expiration dates of districts' CBAs and compare new teachers in FP and SP districts in an event study setting. Unfortunately, VA is generally not available for new teachers;

[28] Hoxby and Leigh (2004) show that the decline in the entry rates of high-quality teachers in US public schools since 1960 can be attributed to increased compression in wages caused by the rise in unionization. Similarly, Rothstein (2014) demonstrates that higher salaries and lower tenure rates can improve the supply of new teachers.

building this measure requires observing teachers over multiple years (Bitler et al., 2019). To partially capture the quality of new teachers I use measures of selectivity of the institution where they obtained their most recent degree, among the few correlates of teaching quality (Ballou and Podgursky, 1997; Hoxby and Leigh, 2004; Clotfelter et al., 2010). I focus on two metrics: the 25th percentile ACT English score of admitted students and an indicator for whether the institution performs selective admissions.

Figure 11 shows an event study of measures of college selectivity for new teachers around the year of expiration of districts' CBAs, separately for FP and SP districts. In these specifications, I control for an indicator for the years following Act 10 and for districts' expenditures, budget items, and measures of union strength. Both in FP and SP districts, selectivity measures are flat in the years leading to an expiration. After an expiration, the average ACT score declines in an almost-identical way in SP and FP districts (Figure 11, panel A). The share of entrants with degrees from non-selective institutions slightly increases in FP districts and slightly decreases in SP districts; their difference, however, is not distinguishable from zero (Figure 11, panel B).

With the caveat that they are based on imperfect measures of teacher quality, these tests do not provide evidence of a differential change in the supply of new teachers in FP relative to SP districts following the changes in pay schemes after the expiration of districts' CBAs. Of course, this does not rule out the possibility that selection could change over a longer time period, giving prospective teachers enough time to make the appropriate educational investments.

6.4 Composition of the Teaching Workforce

Movements of teachers across districts and exits from public schools changed the composition of the teaching workforce in each district. To quantify this change, I compare *ex ante* teacher VA in FP and SP districts before and after expiration of districts' CBAs. I estimate:

$$VA_i = \beta_0 FP_{j(it)} + \beta FP_{j(it)} * \mathbb{1}(t > Exp_{j(it)}) + \gamma X_{it} + \eta Z_{j(it)t} + \tau_t + \varepsilon_{ijt} \tag{7}$$

In this equation, the parameter β captures the change in VA in FP relative to SP districts after Act 10. Estimates of β, shown in Table 5, indicate that *ex ante* teacher VA increased by 0.02 standard deviations in FP districts compared with SP after Act 10 (Table 5, column 1, significant at 5 percent). Importantly, this estimate is robust and it increases to 0.057 standard deviations when controlling for *FP * post* (column 3), to account for any observable and unobservable changes in FP and SP districts following the passage of Act 10. Estimates are robust to restricting attention to districts whose agreements expired after 2011 (employing 18 percent of all teachers, Appendix Table A9, columns 1 and 2);[29] to controlling for districts' budget items and for measures of union strength (columns 4-5); and to excluding the school districts of Milwaukee and Madison (Appendix Table A10). Estimates become slightly larger and more precise when the sample is limited to teachers in schools and grades with at most three teachers per subject (Appendix Table A11, column 1) and to teachers whose VA is exactly identified from that of their colleagues due to teacher turnover (Appendix Table A11, column 2).

Time-varying estimates of β around the date of expiration of districts' CBAs, shown in Figure 12, are on a flat trend in the years leading to the expiration. They become positive the year after the expiration, reach a peak at 0.052 standard deviations two years after the expiration, and remain high at this level four years after the expiration.

If the expiration date of districts' CBAs is as good as random, the difference in teacher composition across FP and SP districts around the time of expiration can safely be attributed to the effects of a change in pay; for this difference to be driven by unobservables, the timing of these would have to be identical to that of the expiration in each district. To rule out this possibility, I estimate an upper bound for the bias in β driven by unobservables using the methodology of Altonji et al. (2005). This exercise yields an upper bound for this bias equal to -0.025 standard deviations of VA, which implies that, at a maximum, unobservables would lead me to underestimating the compositional changes driven by changes in the pay scheme.[30]

While the estimated compositional improvement might seem small at a first glance, it should be kept in mind that it is triggered by the introduction of only a small return to VA in FP districts. Moreover, this change is driven by movements and exits which, over a post-reform time horizon of only four years, are rare events. Nevertheless, the results presented above show large changes in the composition of movers and leavers even within such a short time period. The compositional change driven by the introduction of flexible pay could therefore become much larger in the long run as more and more teachers move or exit, especially if FP districts make pay even more dependent on teacher quality and less on seniority and education. Crucially,

[29]Given the small number of districts, in Appendix Table A9 I conduct inference using a wild cluster bootstrap and I present t-statistics in brackets.

[30]This method relies on the assumption that the portion of a district's VA change related to unobservables and the portion related to the observables included as controls in column 5 of Table 5 have the same relationship with the post-expiration pay scheme. The approach relies on estimating the parameter ρ as defined by Altonji et al. (2005), which represents the correlation between the unobservable component of the independent variable of interest (in this case, *FP*post CBA exp*) and the unobservable component of the dependent variable. This parameter can be estimated using the estimates of a regression of Equation (7) (including all the controls) and a regression of *FP*post CBA exp* on the controls, as in Altonji et al. (2005). I estimate ρ to be equal to -0.34.

these long-run effects depend on districts' pay schemes in general equilibrium. I discuss this in Section 8.

7 Teachers' Effort and Student Achievement

The pay schemes adopted by FP districts after the expiration of their CBAs attracted high-VA teachers from other districts and led low-VA teachers to leave, triggering a change in the composition of the teaching workforce. A pay scheme that rewards quality, however, could affect *all* teachers (not only those who move or exit) through changes in the incentives to exert effort, with potentially large effects on students.

To test this hypothesis, I re-estimate a version of equation (7) where I allow the VA of each teacher to vary between the pre- and post-reform periods. In this equation, the coefficient β captures the *overall* change in teacher quality in FP relative to SP districts after the expirations of the CBAs, driven both by changes in composition and changes in effort.

OLS estimates of β indicate that the VA of teachers in FP districts increased by 7.6 percent of a standard standard deviation after a CBA expiration compared with the VA of teachers in SP districts (Table 6, column 2, significant at 5 percent). Controlling for an interaction between *FP* and indicators for years after 2011 (column 3) and for characteristics of the teachers and the districts (column 4) yields slightly less precise, but larger estimate equal to 0.09 (p-values equal to 0.15 and 0.05). Assuming that this overall change is simply the sum of a compositional change (shown in column 3 of Table 5) and a change in effort, these estimates imply that 37 percent of the overall increase in VA (shown in column 4 of Table 6) is due to changes in effort (0.0889 - 0.0566 divided by 0.0889), whereas the remaining 63 percent is driven by changes in composition.

Time-varying estimates of β in equation (7), shown in Figure 13, do not show any pre-trends and indicate that this increase happened in immediately after a CBA expiration. Estimates are robust to restricting attention to districts whose agreements expired after 2011 (employing 18 percent of all teachers, Appendix Table A9, columns 3 and 4), to the exclusion of the school districts of Milwaukee and Madison (Appendix Table A12), as well as to to limiting the sample to teachers in schools and grades with at most three teachers per subject (Appendix Table A11, column 3) and to teachers whose VA is exactly identified from that of their colleagues due to teacher turnover (Appendix Table A11, column 4).

To isolate changes in effort more directly, also I re-estimate equation (7) with teacher fixed effects. This estimate, shown in column 6 of Table 6, indicates that, within teacher, VA increased by

0.085 standard deviations after a CBA expiration for teachers in FP districts, relative to teachers in SP districts (significant at 10 percent).

Taken together, these results indicate that a change in teacher pay from one based on seniority and education to one that rewards quality affects both the composition of the teaching workforce and teachers' effort. The estimated increase in effort is in partial contrast with the findings that financial incentives do not affect teachers' effort and productivity (Goodman and Turner, 2013; Fryer, 2013; de Ree et al., 2018), but in line with Macartney et al. (2018). One should keep in mind, however, that my findings are based on a substantially different policy, which drastically and permanently changed the entire structure of teacher pay.

Student Achievement Increases in teacher VA have been shown to increase student test scores (Chetty et al., 2014a). I test the direct effect of flexible pay on achievement by estimating the following equation:

$$A_{sgt} = \beta \mathbb{1}(t > Exp_{j(s)}) + \gamma X^s_{sgt} + \eta Z_{j(s)t} + \sigma_{sg} + \tau_t + \varepsilon_{sgt} \tag{8}$$

where A_{sgt} is the average test score (in either math or reading) for students in grade g, school s, and year t, and X^s_{sgt} is a vector of student demographics (such as the share of students who are female, Black, Hispanic, economically disadvantaged, English-language learners, or migrants), which allows me to control for differences in student observables across school-grades and over time. The inclusion of school-by-grade fixed effects σ_{sg} controls for time-invariant characteristics of the schools that are specific to each grade. In this equation, the parameter β captures the change in test scores after the expiration of districts' CBAs relative to before.

Estimates of β on the sample of FP districts indicate that reading achievement increased by 0.06 standard deviations in these districts after a CBA expiration (Table 7, top panel, column 1, significant at 1 percent). This estimate is robust to controlling for the demographic makeup of students and for districts' budget components and measures of union power (column 2). By comparison, achievement did not significantly change in SP districts (Table 7, top panel, columns 3-4). Columns 5-6 of Table 7 confirm that the difference in the estimates for β between FP and SP districts is significant at 10 percent.

Math achievement also increased in FP districts after the expiration of the CBAs, although to a smaller (and noisier) extent: the estimate of β is equal to 0.05 percent of a standard deviation (Table 7, bottom panel, column 1, significant at 10 percent). Again the difference is indistinguishable from zero in SP districts (Table 7, bottom panel, column 4).[31]

These tests indicate that changes in the composition and effort of teachers in FP districts following the change in pay schemes led to a sizable increase in students' test scores. As a benchmark, the increase in reading scores in FP districts is equivalent to approximately one third of the increase (0.2 standard deviations) that would result from a reduction in class size from 35 to 30 students (Angrist and Lavy, 1999).

8 Flexible Pay in Some vs All Districts: Simulation and Discussion

The evidence presented so far shows that the introduction of flexible pay in a subset of Wisconsin districts led to an improvement in the composition of the teaching workforce in these districts, relative to the rest of the state. Albeit small in the short run, this effect could become larger over time as more low-quality teachers leave FP districts and more high-quality teachers move from SP to FP districts. This, however, assumes that SP districts maintain a seniority-based pay scheme in the medium and long-run.

What would happen if, instead, flexible pay were introduced in *all* districts? The answer to this question is key to assess the general-equilibrium effects of policies designed to attract and retain high-quality teachers. The selection patterns outlined above, however, are the combination of both demand and supply forces; it is therefore difficult to answer this question simply extrapolating from partial-equilibrium results.

To address the limitations of the reduced-form approach, I build and estimate a simple model of teacher demand and supply, which can be used to simulate the effects of the introduction of flexible pay in all districts (as opposed to just a few) on the composition of the teaching workforce. The model is not intended to fully characterize all features of teachers' labor markets, but rather to provide a simple framework to discuss the general-equilibrium effects of flexible pay on the sorting of teachers across districts and out of the market.

Model Setup Here, I summarize the key elements of the model; the details can be found in Appendix C. Districts (the demand side) extend job offers to teachers to maximize a payoff, and they face exogenous capacity and budget constraints. A district's payoff is the sum of the individual payoffs from each hired teacher, which in turn are linear functions of the teacher's experience, education, and VA. Teachers (the supply side) have preferences over a range of attributes of each job, including pay, distance, and student composition; they review the set of

[31] Baron (2018) estimates an overall negative effect of Act 10 on student achievement; these estimates, however, do not distinguish between FP and SP districts.

offers they receive, and either a) pick the one which maximizes their utility or b) exit the market. Importantly, when making offers, districts internalize that each offer will be accepted with a probability which depends on teachers' preferences; this feature allows the market to clear in equilibrium. Job vacancies and salaries are exogenously determined. In particular, salaries are modeled as district-specific functions of experience, education, and VA; I estimate these functions outside of the model using post-CBA expiration data. The extent to which salaries depend on VA captures the degree to which flexible pay is used in a district.

I estimate teachers' and districts' preferences using maximum likelihood on data from 2014, exploiting the cross-district variation in pay schemes (estimation and identification are described in depth in Appendix C; estimates of the parameters are shown in Appendix Table C2).

8.1 Alternative Pay Schemes and Workforce Composition

The model and its estimates can be used to simulate the effects of alternative salary schemes on the composition of the teaching workforce. I focus on two counterfactual policies. The first is an increase in the salary component associated with VA (denoted by δ in the model), which captures the extent of flexible pay, *only in one district*, with salaries unchanged in all other districts. The second is a change in δ *in all districts at the same time*, akin to a statewide adoption of flexible pay. In both cases, these policy changes are budget neutral.[32] In both cases, I first solve the model for values of δ ranging from zero to 1.5 standard deviations of its empirical distribution. I then calculate the change in the probability that teachers in different quartiles of the VA distribution move to, move out of, or exit from the district, as well as the change in the composition of the district's teaching workforce. For exposition, I perform the analysis on the school district of Ashland, an urban SP district whose agreement expired in 2011.[33]

Increase in Quality Pay in One District I start by simulating the effect of a change in δ only in one district. This change affects both teachers' labor supply and demand. First, it affects the budget and the salaries paid by the district. Second, it affects the preference ordering of *all* teachers, including those employed in other districts. This will, in turn, influence the probability that a teacher matches with *any* district, not only with the one affected by the policy.

Figure 14 illustrates the changes in the simulated probability of moving to, moving out of,

[32] To keep the budget neutral, I assume that base salaries adjust immediately depending on the new value of δ and the current composition of the district's teaching workforce.

[33] The school district of Ashland is located in the north-west part of the state. This urban district runs five schools, including four elementary and middle schools; it enrolled 2,101 students in 2014 year, 61 percent of whom are economically disadvantaged, and employs 35 teachers in my sample in 2014.

or exiting the school district of Ashland as δ increases, by quartile of VA. Teachers in the bottom quartile become less likely to move to Ashland when δ increases; teachers in the top quartile become instead more likely to move there (Figure 14, panel A). Teachers with VA in the bottom quartile also become more likely to move out, whereas those with VA in the top quartile become less likely (Figure 14, panel B). Lastly, teachers with VA in the bottom quartile become more likely to exit and teachers in the top quartile become less likely (Figure 14, panel C). As a results of these movements, the average VA of movers in the district increases slightly, while the average VA of movers out of the district decreases and the average VA of leavers from the district declines even more (Figure 15, panel A). The average VA of the district increases by 3 percent when δ increases by 1.5 standard deviations (Figure 15, panel B).

The results from this simulation exercise are in line with the reduced-form results: An increase in the share of salaries related to teacher quality is associated with an improvement in the composition of the district's teaching workforce.

Introduction of Quality Pay in All Districts Next, I simulate the compositional effect of a change in δ in *all* districts. It should be noted that the results from this second counterfactual do not follow trivially from the first. To see this, consider the decision of a teacher working in Ashland. She must decide whether to stay where she is, move to another district, or exit teaching. The first counterfactual directly affects the first option (staying). The second counterfactual directly affects two out of three options (because it affects salaries in all districts); it therefore also changes the value of leaving relative to remaining in public schools. It follows that the effect of a change in salaries in all districts on the exit behavior of teachers could in principle be very different from the one shown in the previous paragraph.

Results from this simulation indicate that teachers with VA in the three bottom quartiles become less likely to move to Ashland when δ increases *in all districts*, whereas teachers with VA in the top quartile become more likely (Figure 16, panel A). Teachers in the third quartile become however also more likely to move to Ashland (Figure 16, panel B). Lastly, teachers with VA in the bottom quartile become more likely to exit, and teachers with VA in the top quartile become less likely. As a result, when δ increases in all districts the the composition of the teaching workforce in Ashland remains essentially unchanged (Figure 17, panel B).

These simulations show that an increase in the quality component of salaries in all districts could lead to a much smaller change in the composition of a district's workforce compared with the case in which δ only increases only in one district. When quality pay increases only in one district, part of the resulting compositional improvement is driven by better teachers moving in and worse teachers moving out. When δ increases in all districts, this net inflow of high-quality teachers might not materialize because quality is rewarded at the same rate everywhere.

The results from the two counterfactuals suggest that the observed improvement in the composition of the teaching workforce in FP districts might be limited to the short run. If all districts eventually introduce merit pay in order to compete for the best teachers, the longer-term effects of Act 10 on the composition of the workforce in each district might be more limited in size. One should keep in mind, however, that the model does not fully capture all possible mechanisms through which flexible pay can affect the labor market. First, the new pay scheme could change workers' incentives to enter public school teaching, for example by attracting more talented workers (Tincani, 2020).[34] Second, the model does not allow effort to respond to changes in pay schemes; even if the compositional changes are smaller when more districts switch to FP, teacher quality could rise through an increase in effort. Lastly, salaries are assumed exogenous, which rules out the possibility that districts set them strategically. Developing a full-blown model of teachers' labor markets which combines all these features is left to future research.

9 Discussion and Conclusion

This paper studies the effects of substituting teachers' salary schedules with a flexible pay regime, focusing on the composition of the teaching workforce, on teachers' effort, and on student achievement. A switch away from seniority pay toward flexible pay in a subset of Wisconsin districts, following the interruption of CB on teachers' salary schedules mandated by Act 10 of 2011 and the expiration of pre-existing CBAs, resulted in high-quality teachers moving to FP districts and low-quality teachers either moving to SP districts or leaving the public school system altogether. As a result, the composition of the teaching workforce improved in FP districts compared with SP districts. Effort exerted by all teachers also increased and, subsequently, test scores improved.

As cross-district movements and exits are rare events, the magnitudes of these compositional changes (and the associated increase in student test scores) were limited in size in Wisconsin over the five years following Act 10, but they could become larger over time as more teachers move and exit each year, especially if salaries become more strongly related to teachers' quality and effort and if districts become better at identifying talented teachers. If, however, SP districts

[34] Tincani (2020) studies the Chilean public and private teacher market and shows that, when introduced in the public sector, merit pay increases student achievement by attracting talented teachers into public schools.

also switch to a FP scheme over time, the long-run effects of a policy change such as Act 10 could be very different: Simulations based on a simple model indicate that the introduction of flexible pay in all districts would lead to a much smaller (and possibly negative) compositional improvement than the one experienced by FP districts so far. The ultimate effects of a statewide policy, however, also depend on teachers' effort responses and on potential changes in the the supply of new teachers. A thorough investigation of these two channels represents an important avenue for future research.

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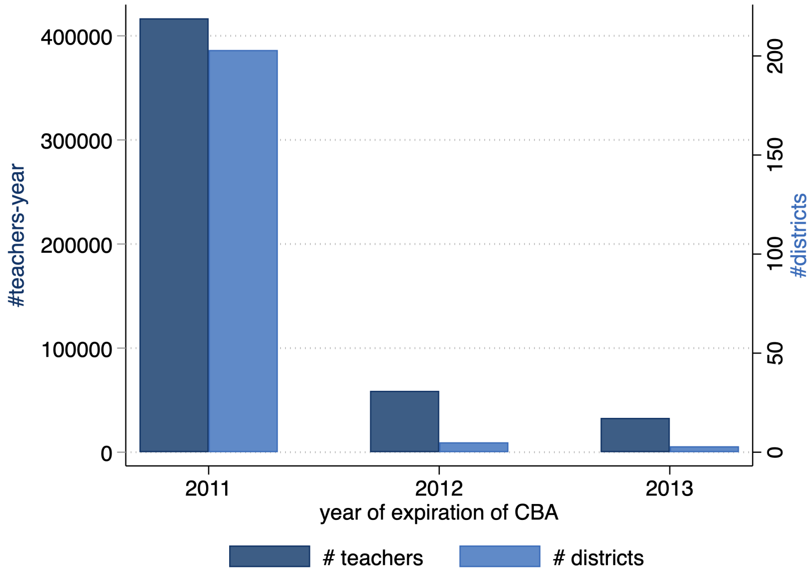
Figures

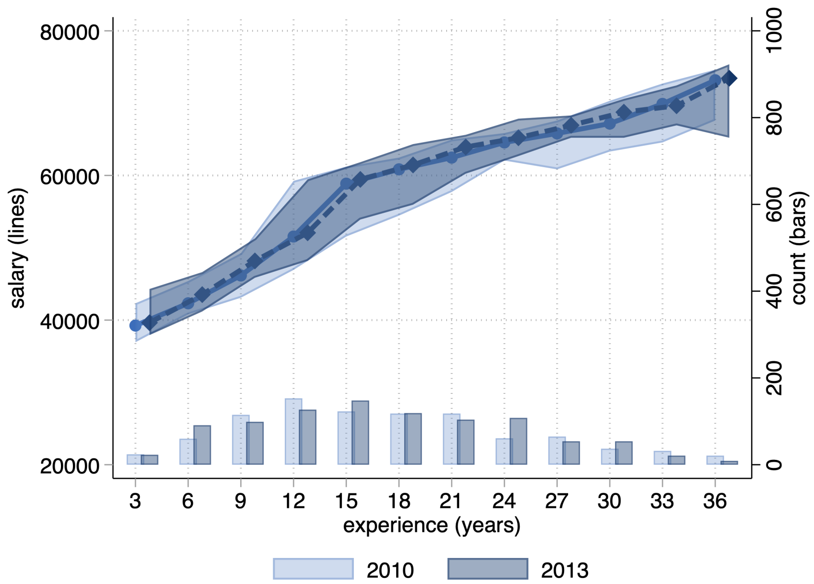
Figure 1: Number of Teacher-Years and Districts, by Year of Expiration of Districts' CBAs



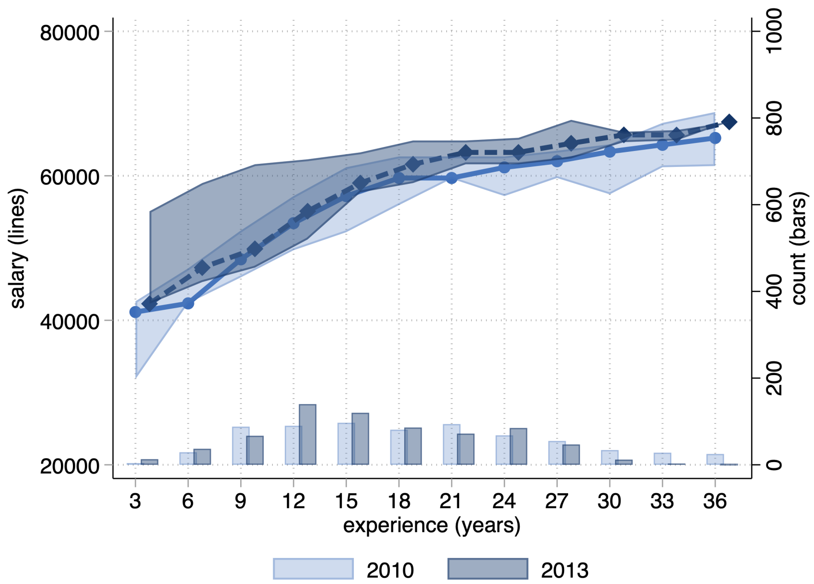
Note: Total number of teacher-year observations (darker bars) and districts (lighter bars), by year of expiration of districts' CBAs.

Figure 2: Empirical Salary Schedule - Median and 90-10 Percentile Range of Salaries, 2010 and 2013, School Districts of Madison and Green Bay

Panel A) Madison School District



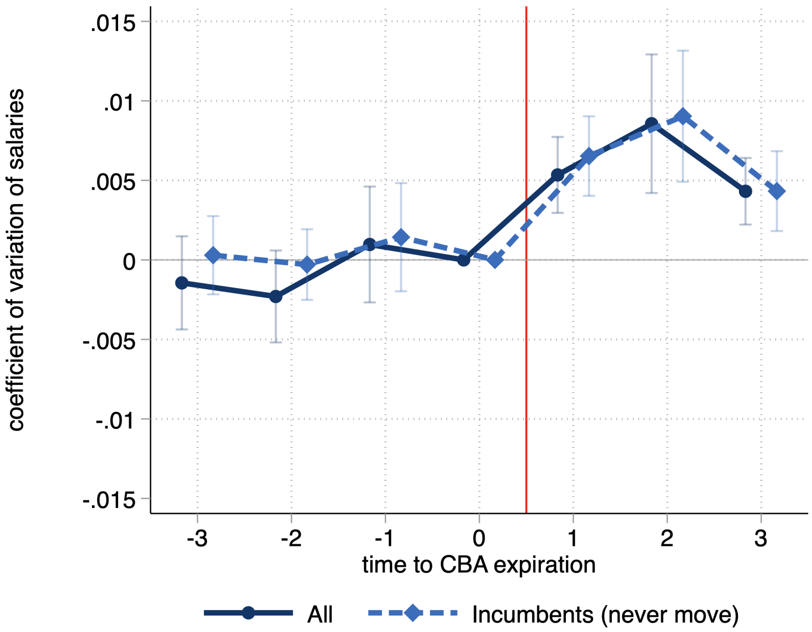
Panel B) Green Bay Area School District



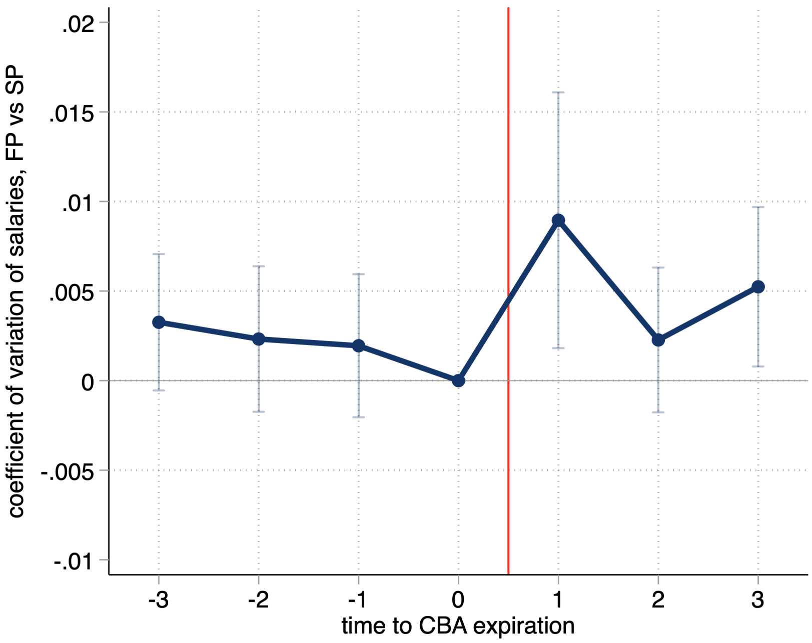
Notes: Median and 90-10 percentile range of salaries, by three-year experience classes, for teachers in the school districts of Madison (panel A) and Green Bay (panel B), for the years 2010 (lighter line and area) and 2013 (darker line and area). The bars correspond to counts of teachers in each experience bin. The sample is restricted to full-time teachers with a master's degree.

Figure 3: Coefficient of Variation of Salaries Around a CBA Expiration

Panel A: All districts

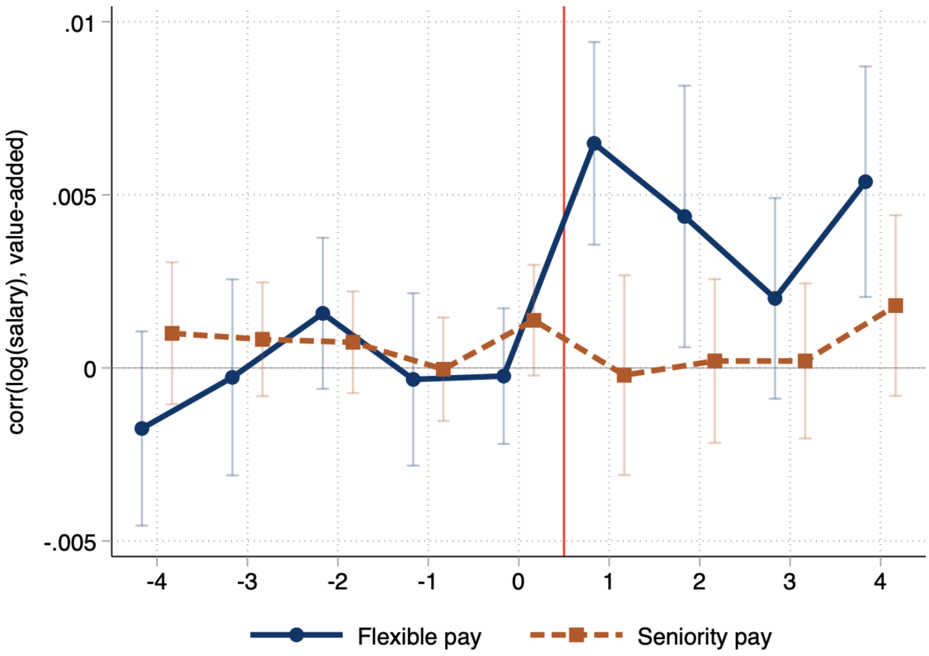


Panel B) FP vs SP districts



Notes: Panel A: Point estimates and 90 percent confidence intervals of the parameters δ_n in the equation $cv_{jt} = \sum_{-3}^{3} \delta_n \mathbb{1}(t - Exp_j = n) + \theta_j + \tau_t + \varepsilon_{jt}$. The variable cv_{jt} is the coefficient of variation of salaries in district j and year t, calculated as the ratio between the standard deviation of salary residuals (obtained from a regression of salaries on experience-by-education and district-by-year fixed effects) and average salary. The variable Exp_j is the year of expiration of district j's CBA, and θ_j and τ_t are district and year fixed effects, respectively. The coefficient δ_0 is normalized to zero. Panel B: Point estimates and 90 percent confidence intervals of the parameters η_n in the equation $cv_{jt} = \sum_{-3}^{3} \eta_n FP_j * \mathbb{1}(t - Exp_j = n)\theta_j + \sum_{-4}^{4} \delta_n \mathbb{1}(t - Exp_j = n) + \theta_j + \tau_t + \varepsilon_{jt}$. The variable FP_j equals one for FP districts, and everything is as above. The coefficient η_0 is normalized to zero. In both panels each observation is weighted by the number of teachers in each district and year and standard errors are clustered at the district level.

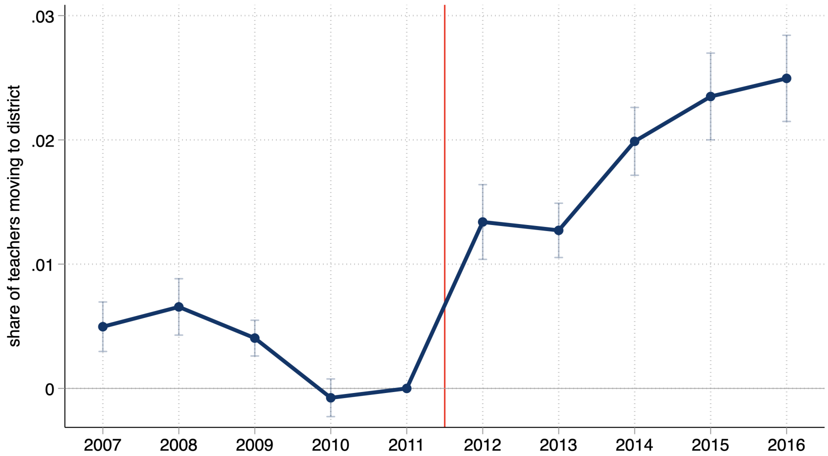
Figure 4: Correlation, Salaries and Value-Added: FP and SP Districts Around A CBA Expiration



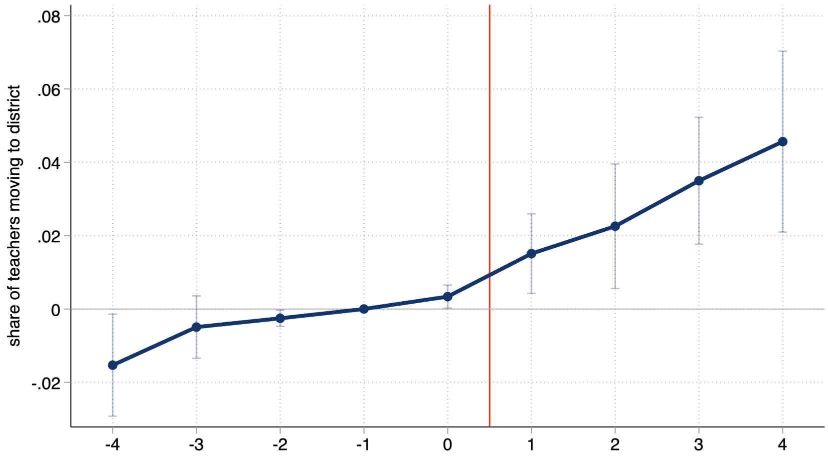
Notes: OLS estimates and 90 percent confidence intervals of the coefficients δ_s in the regression $log(w_{it}) = \sum_{s=-4}^{4} \delta_s VA_{it} * \mathbb{1}(t - Exp_{j(it)} = n) + \beta X_{it}^{w} + \theta_{j(it)t} + \varepsilon_{it}$. The variable $log(w_{it})$ is the natural logarithm of salary for teacher i in year t. The variable VA_{it} is teacher VA and the variable Exp_j is the year of expiration of district j's CBA. The vector X_{it}^{w} includes indicators for years of experience interacted with indicators for the highest education degree and with an indicator for years after 2011. The vector θ_{jt} contains district-by-year fixed effects. The coefficients δ_s are estimated and shown separately for FP and SP districts. VA is calculated separately for the years the years 2007–2011 and 2012–2016. Bootstrapped standard errors are clustered at the district level.

Figure 5: Moving Rates, by Year (Panel A) and by Time-to-CBA expiration (Panels B and C)

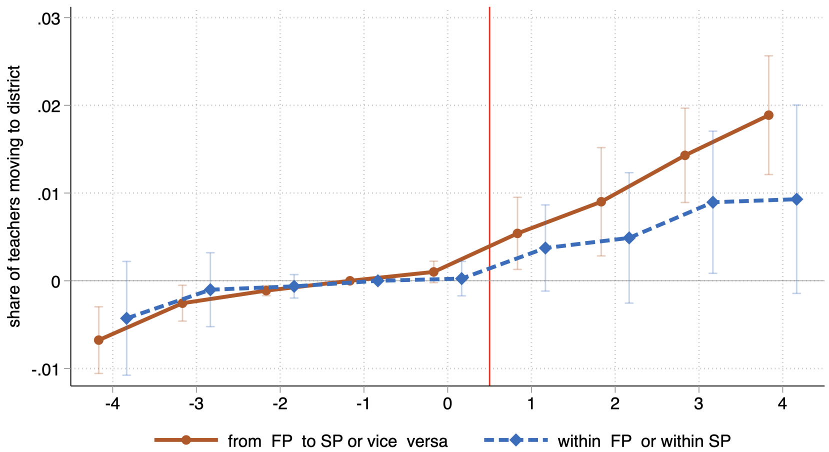
Panel A) By year



Panel B) By time-to-CBA expiration



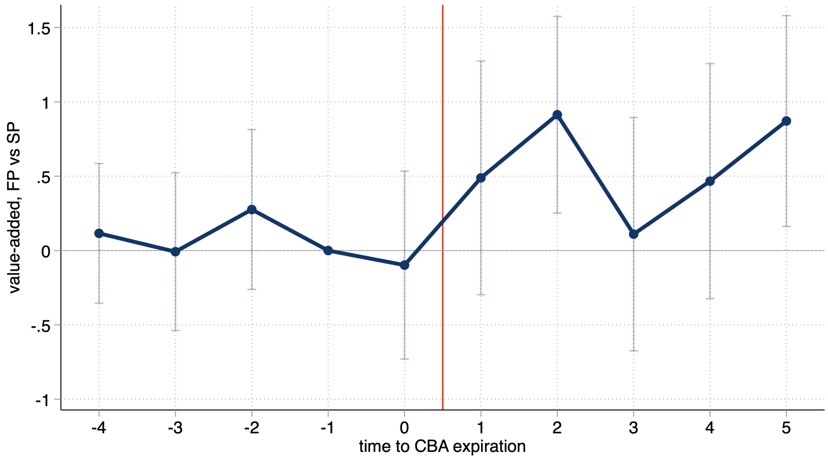
Panel C) By time-to-CBA expiration and district of origin and destination



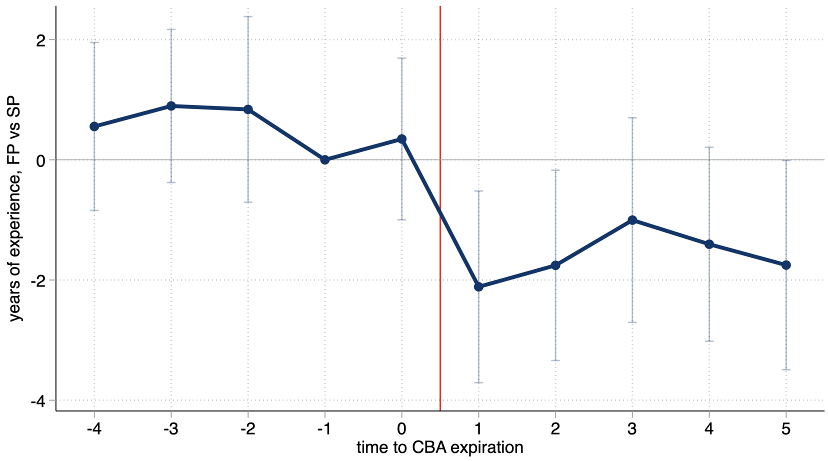
Notes: Shares of teachers changing district, by year (panel A) and by time elapsed from the expiration of each district's CBA (panels B and C). In panel A, rates are normalized with respect to 2011; in panels B and C, they are normalized with respect to the year before a CBA expiration, and obtained controlling for year fixed effects. In the bottom panel, moving rates are shown separately for teachers who move from a FP to a SP district or from a SP to a FP district ("from FP to SP or vice versa," solid line) and for teachers who move from a FP to another FP district or from a SP to another SP district ("within FP or within SP," dashed line). Standard errors are clustered at the district level.

Figure 6: Changes in The Characteristics of Movers Around a CBA Expiration

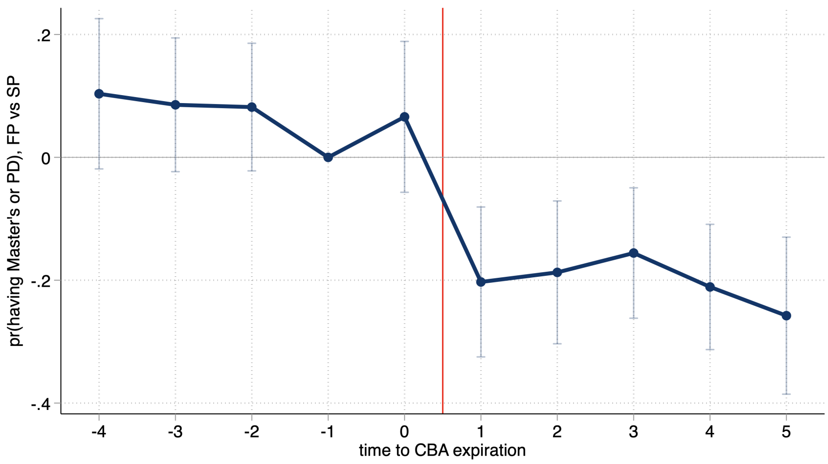
Panel A) Ex ante value-added



Panel B) Years of experience

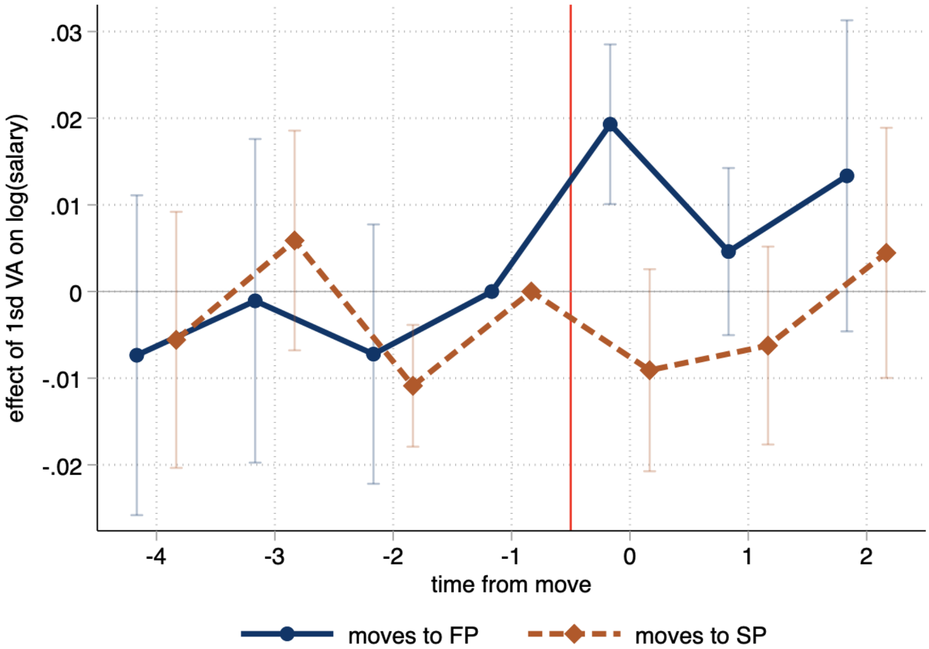


Panel B) Postgraduate degree



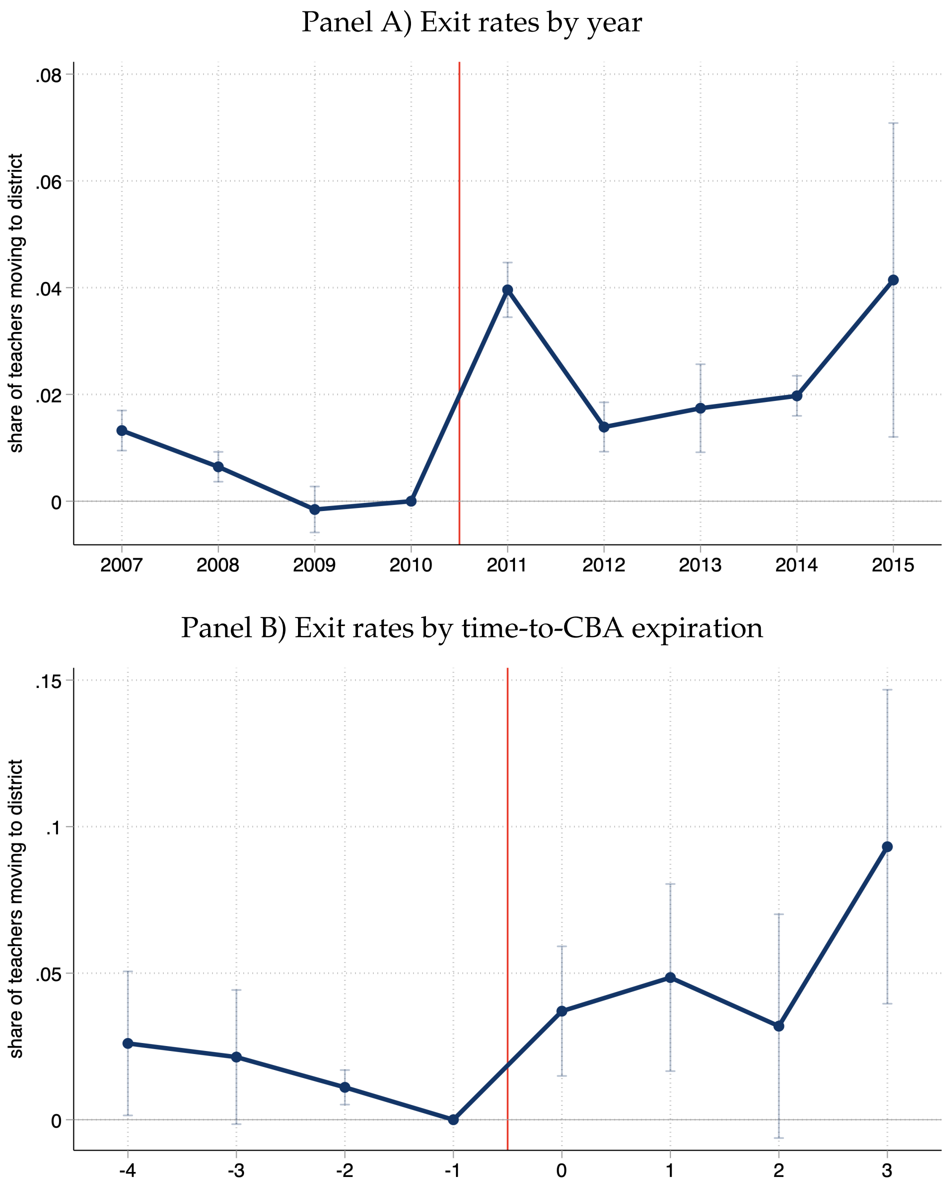
Notes: Estimates and 90 percent confidence intervals of β_k in the regression $Y_{it} = \sum_{-4}^{5} \beta_k FP_{j(it)} \mathbb{1}(t - Exp_{j(it)} = k) + \sum_{-4}^{5} \beta_{0k} \mathbb{1}(t - Exp_{j(it)} = k) + \gamma X_{it} + \tau_t + \varepsilon_{it}$, where Y_i is either ex ante VA (panel A), years of experience (panel B), or an indicator for having a postgraduate degree (panel C) for teacher i in year t; Exp_j is the year of expiration of district j's CBA; X_{it} includes indicators for the type of district in $t-1$ and t, alone and interacted with an indicator for years after 2011; and τ_t is a vector of year fixed effects. The sample is restricted to teachers who change district in each year. Standard errors are clustered at the district level.

Figure 7: VA and Salaries of Movers Around a Move, FP and SP Districts



Notes: OLS estimates and 90 percent confidence intervals of the coefficients β_k in equation (4). The coefficient β_{-1} is normalized to zero. The parameters are estimated separately for teachers in FP and in SP districts. Standard errors are clustered at the district level.

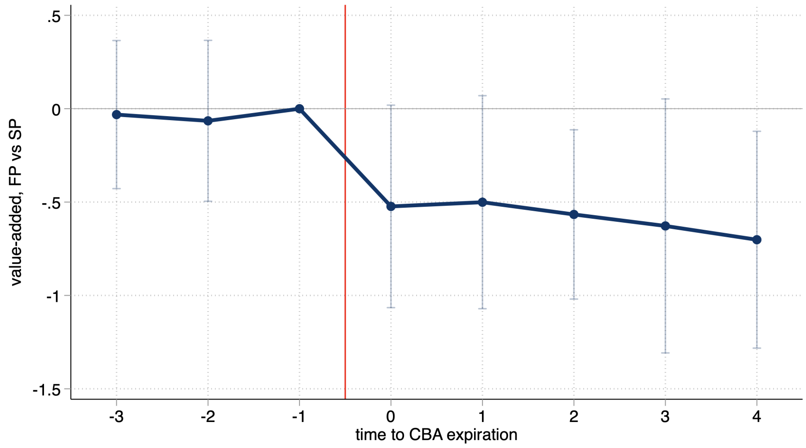
Figure 8: Exit Rates, by Year (Panel A) and by Time-to-CBA expiration (Panel B)



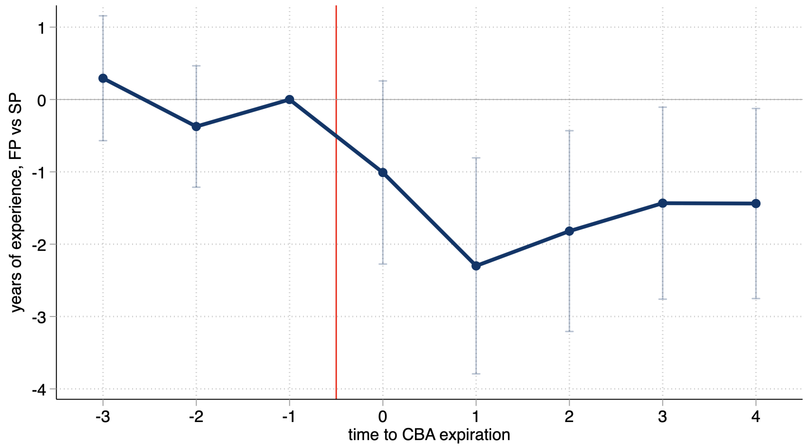
Notes: Shares of teachers leaving Wisconsin public schools, by year (panel A) and by time elapsed from the expiration of each district's CBA (panel B). In the top panel, rates are normalized with respect to 2010; in the bottom panel, they are normalized with respect to the year before a CBA expiration, and obtained controlling for year fixed effects. Standard errors are clustered at the district level.

Figure 9: Changes in The Characteristics of Teachers who Exit Around a CBA Expiration

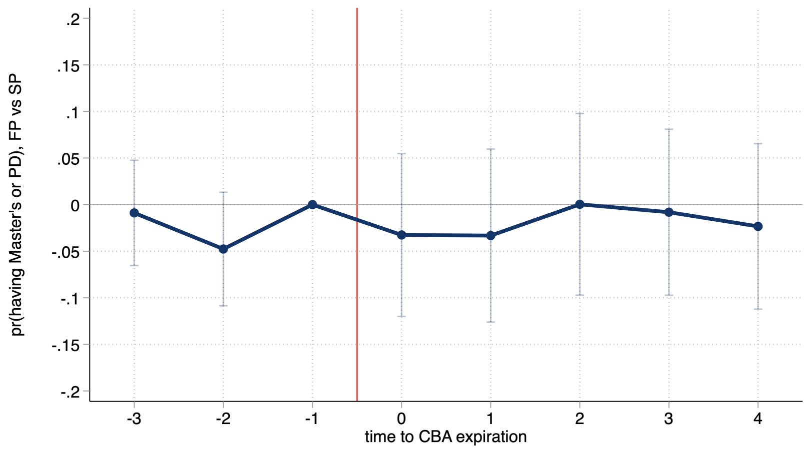
Panel A) Ex ante value-added



Panel B) Years of experience



Panel B) Postgraduate degree

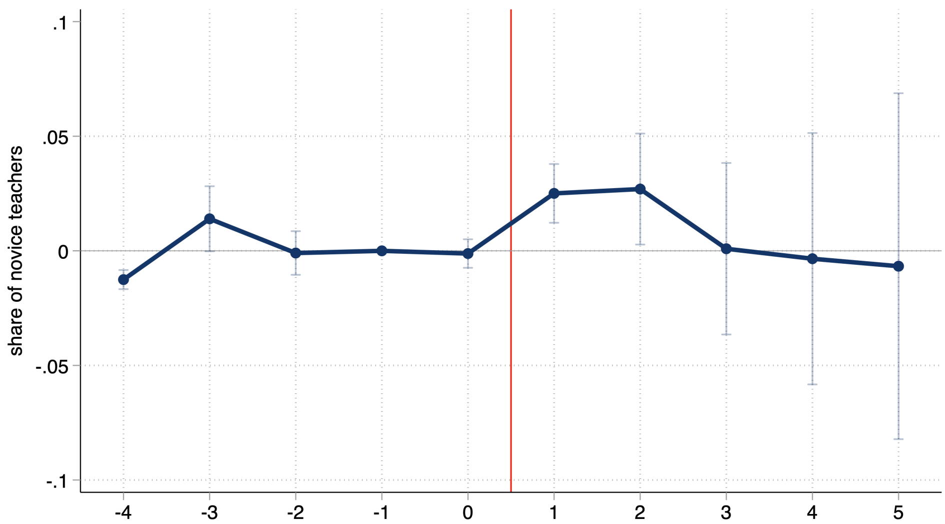


Notes: Estimates and 90 percent confidence intervals of β_k in the regression $Y_{it} = \sum_{-3}^{4} \beta_k FP_{j(it)} \mathbb{1}(t - Exp_{j(it)} = k) + \sum_{-3}^{4} \beta_{0k} \mathbb{1}(t - Exp_{j(it)} = k) + \gamma X_{it} + \tau_t + \varepsilon_{it}$, where Y_i is either ex ante VA (panel a), years of experience (panel b), or an indicator for having a postgraduate degree (panel c) for teacher i in year t; Exp_j is the year of expiration of district j's CBA; and τ_t is a vector of year fixed effects. The sample is restricted to teachers who exit public schools in each year. In panel A), X_{it} controls for interactions between age, experience, an indicator for having a postgraduate degree, and an indicator for years following 2011; in panel B) it controls for interactions between age, an indicator for having a postgraduate degree, and an indicator for years following 2011; and in panel C) it controls for interactions between age, experience, and an indicator for years following 2011. *Ex ante* VA is calculated using test scores for the years 2007–2011. Standard errors are clustered at the district level.

Figure 10: Entry Rates, by Year (Panel A) and by Time-to-CBA expiration (Panel B)

Panel A) By year

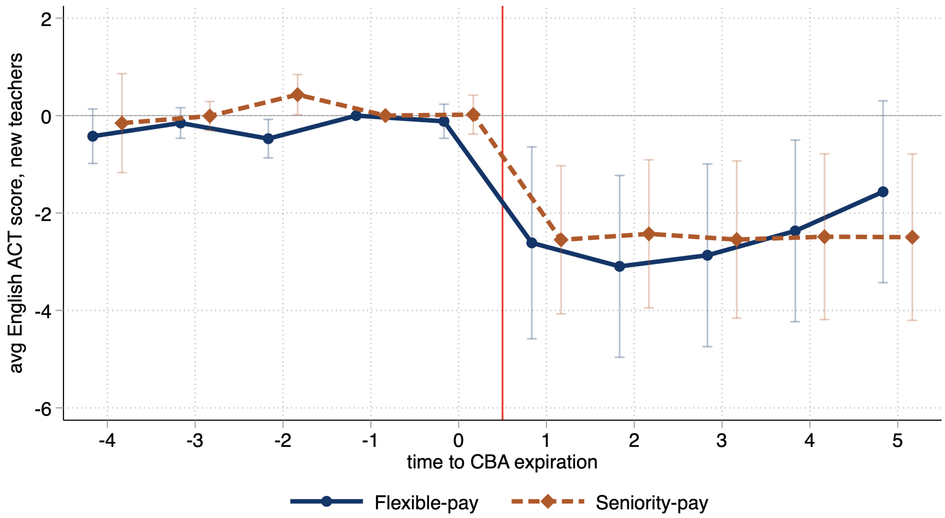
Panel B) By time-to-CBA expiration



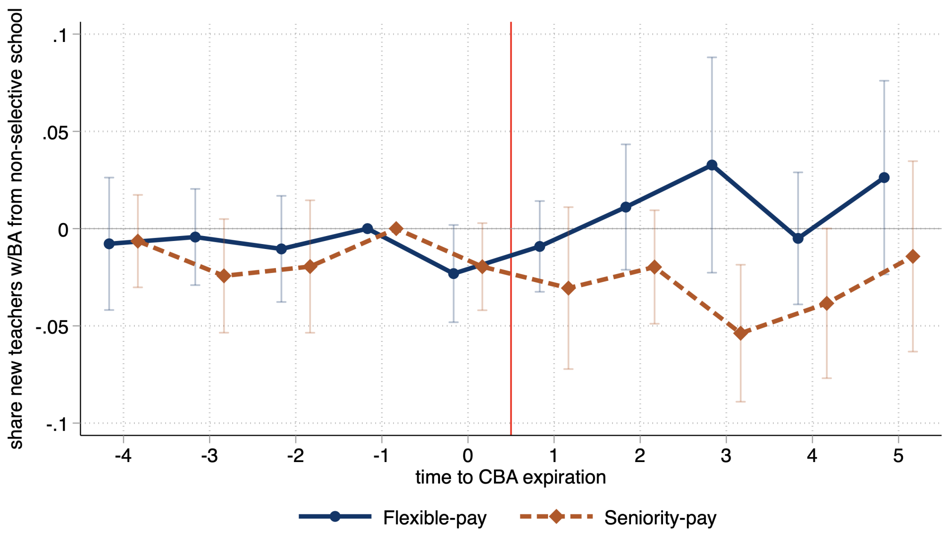
Notes: Shares of teachers entering Wisconsin public schools, by year (panel A) and by time elapsed from the expiration of each district's CBA (panel B). In the top panel, rates are normalized with respect to 2010; in the bottom panel, they are normalized with respect to the year before a CBA expiration, and obtained controlling for year fixed effects. Standard errors are clustered at the district level.

Figure 11: Changes in The Characteristics of New Teachers Around a CBA Expiration

Panel A) Dep. var is 25th pctile of English ACT score of BA institution

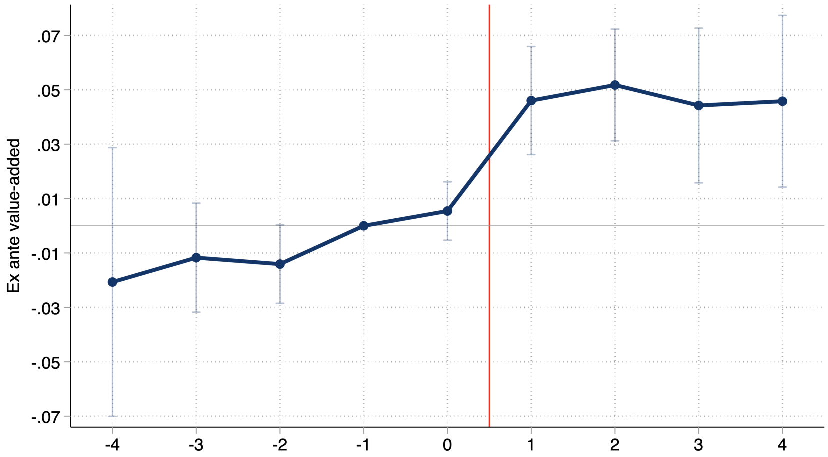


Panel B) Dep. var =1 if BA institution is non-selective



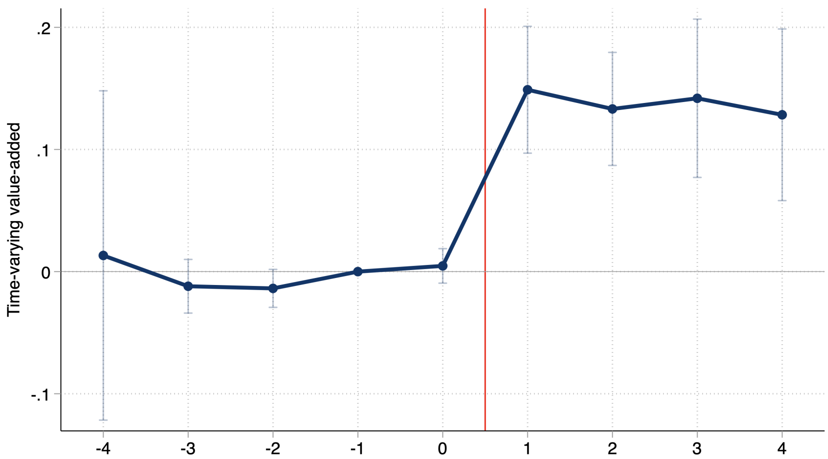
Notes: Estimates and 90 percent confidence intervals of β_k in the regression $Y_{it} = \sum_{-4}^{5} \beta_k FP_{j(it)} \mathbb{1}(t - Exp_{j(it)} = k) + \sum_{-4}^{5} \beta_{0k} \mathbb{1}(t - Exp_{j(it)} = k) + \delta Z_{j(it)t} + \tau_t + \varepsilon_{it}$, where Y_i is either the 25th percentile ACT score of the institution where teacher i obtained her BA (panel A) or an indicator for the BA institution of teacher i being non-selective (i.e., having a zero rejection rate). The variable Exp_j is the year of expiration of district j's CBA; $Z_{j(it)t}$ is a vector of district-year-level controls for the level of state aid as a share of total revenues, per-teacher expenditure on salaries, retirement, health, life, and other insurance, and other employee benefits, and indicators for whether the district had a union recertification election in year t and whether the election was successful. The vector τ_t contains year fixed effects. The sample is restricted to teachers who enter public schools in each year. Standard errors are clustered at the district level.

Figure 12: Changes in the Composition of the Teaching Workforce: Ex Ante Teacher Value-Added Around a CBA Expiration



Notes: Point estimates and confidence intervals of the parameters β_k in the equation $VA_i = \sum_{-4}^{4} \beta_k FP_{j(it)} * \mathbb{1}(t - Exp_{j(it)} = 4) + \sum_{-4}^{4} \beta_{0k} \mathbb{1}(t - Exp_{j(it)} = k) + \gamma X_{it} + \eta Z_{j(it)t} + \theta_{j(it)} + \tau_t + \varepsilon_{ijt}$, where VA_i is ex ante teacher VA, Exp_j is the year of expiration of district j's CBA, the vector X_{it} contains indicators for the year of experience and for whether the teacher has a postgraduate degree, the vector Z_{jt} contains interactions between *FP* and indicators for years following 2011, as well as district-year-level controls for the level of state aid as a share of total revenues, per-teacher expenditure on salaries, retirement, health, life, and other insurance, and other employee benefits, and indicators for whether the district had a union recertification election in year t and whether the election was successful. The vectors θ_j and τ_t contain district and year fixed effects, respectively. Ex ante VA is calculated using test score data for the years 2007–2011. Standard errors are clustered at the district level.

Figure 13: Changes in Teachers' Effort. Time-Varying Teacher Value-Added Around a CBA Expiration



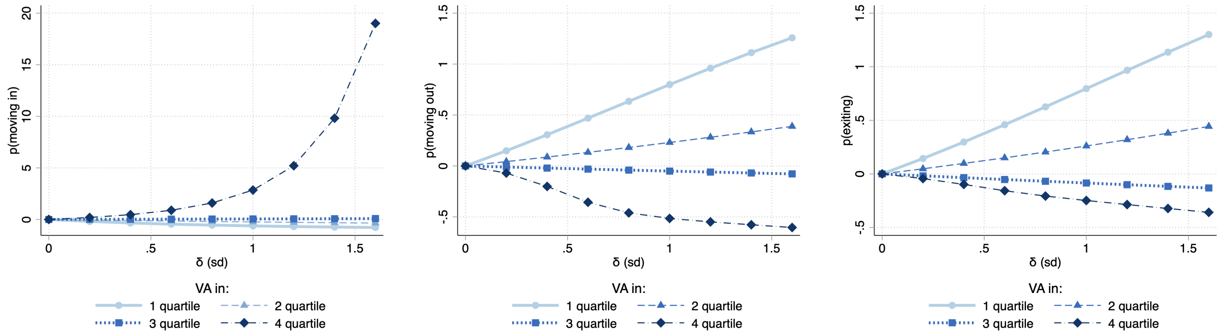
Notes: Point estimates and confidence intervals of the parameters β_k in the equation $VA_{it} = \sum_{-4}^{4} \beta_k FP_{j(it)} * \mathbb{1}(t - Exp_{j(it)} = 4) + \sum_{-4}^{4} \beta_{0k} \mathbb{1}(t - Exp_{j(it)} = k) + \gamma X_{it} + \eta Z_{j(it)t} + \theta_{j(it)} + \tau_t + \varepsilon_{ijt}$, where VA_i is teacher VA, allowed to vary before and after 2011; Exp_j is the year of expiration of district j's CBA; the vector X_{it} contains indicators for the year of experience and for whether the teacher has a postgraduate degree; the vector Z_{jt} contains interactions between *FP* and indicators for years following 2011, as well as district-year-level controls for the level of state aid as a share of total revenues, per-teacher expenditure on salaries, retirement, health, life, and other insurance, and other employee benefits, and indicators for whether the district had a union recertification election in year t and whether the election was successful. The vectors θ_j and τ_t contain district and year fixed effects, respectively. Time-varying VA is calculated separately for each teacher using using test score data for the years 2007–2011 and 2012–2016. Standard errors are clustered at the district level.

Figure 14: Counterfactual 1 - Teacher Responses to an Increase in δ in One District

Panel A: Movements to the district

Panel B: Movements out of the district

Panel C: Exits from the district

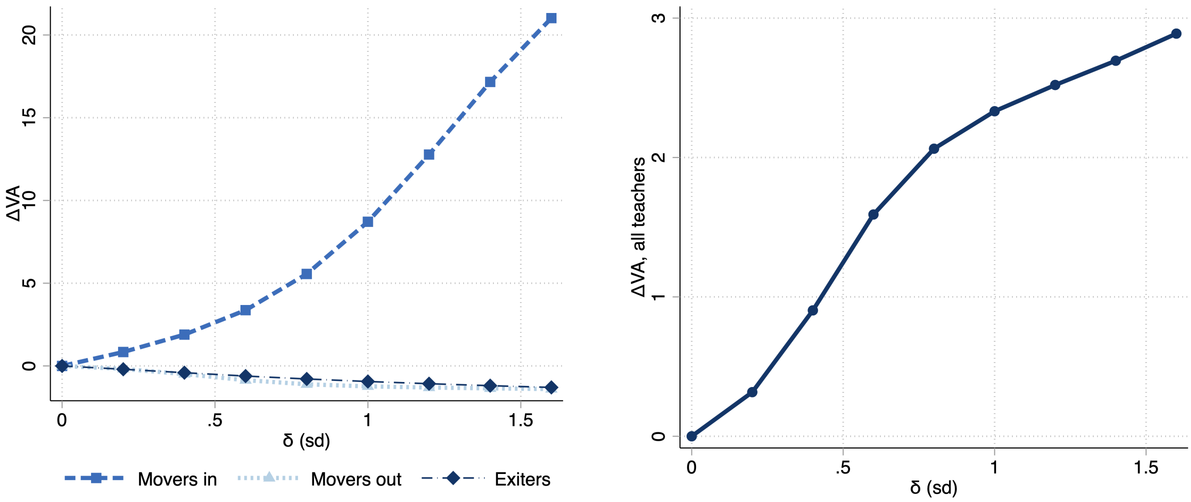


Notes: Percentage change in the probability that a teacher moves to the Ashland school district (panel A), out of the district (panel B), or exits from the district (panel C), by quartile of VA, and for different values of δ (as defined in Equation (30)), relative to $\delta = 0$, under the first counterfactual.

Figure 15: Counterfactual 1 - Compositional Changes

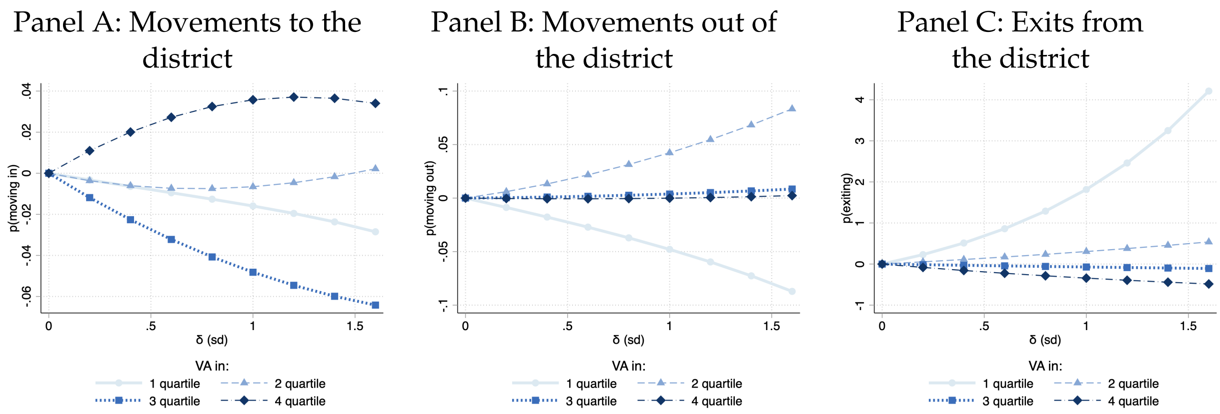
Panel A: VA of movers in, movers out, and exiters from the districts

Panel B: VA of all teachers in the districts



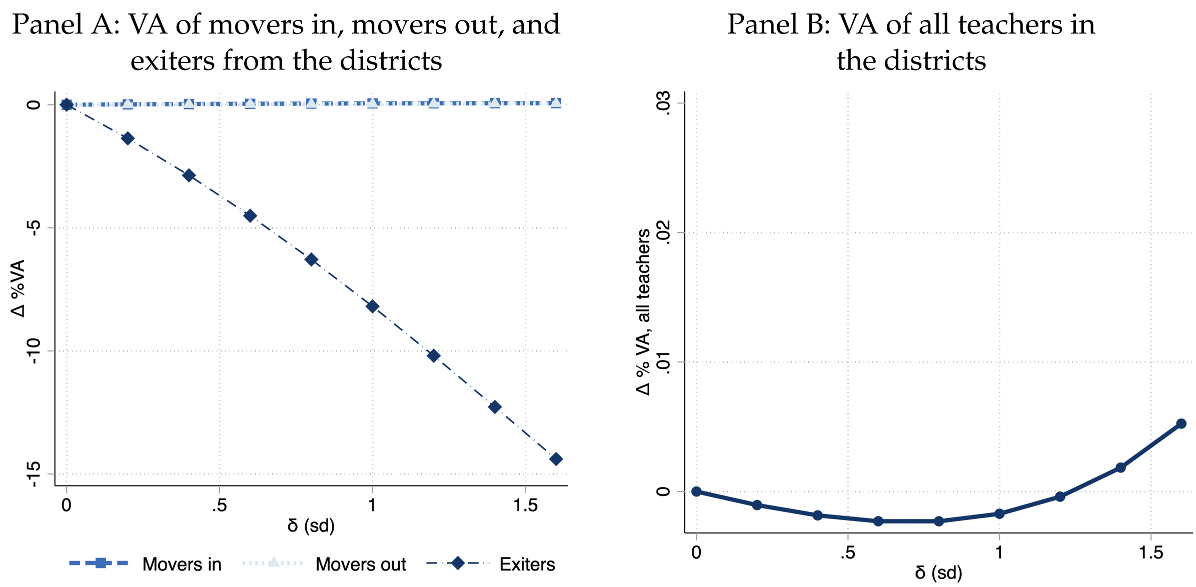
Notes: Percentage change in average VA of teachers moving to the Ashland school district, out of the district, and exiting public schools from the district (panel A), and average VA of teachers working in the district (panel B), for different values of δ (as defined in Equation (30)), relative to $\delta = 0$, under the first counterfactual.

Figure 16: Counterfactual 2 - Teacher Responses to an Increase in δ in All Districts



Notes: Percentage change in the probability that a teacher moves to the Ashland school district (panel A), out of the district (panel B), or exits from the district (panel C), by quartile of VA, and for different values of δ (as defined in Equation (30)), under the second counterfactual.

Figure 17: Counterfactual 2 - Compositional Changes



Notes: Percentage change in average VA of teachers moving to the Ashland school district, out of the district, and exiting public schools from the district (panel A), and average VA of teachers working in the district (panel B), for different values of δ (as defined in Equation (30)), relative to $\delta = 0$, under the second counterfactual.

Tables

Table 1: Teacher Salaries and Value-Added. OLS, Dependent Variable is log(Salary)

	All teachers			Middle-school teachers		
	(1)	(2)	(3)	(4)	(5)	(6)
	FP	SP	Diff	FP	SP	Diff
VA	-0.000	0.001	0.001	-0.002	0.001	0.001
	(0.001)	(0.001)	(0.001)	(0.002)	(0.001)	(0.001)
VA $\times$ post-CBA expiration	0.004**	-0.000	-0.000	0.007***	-0.001	-0.001
	(0.002)	(0.001)	(0.001)	(0.002)	(0.002)	(0.002)
VA $\times$ FP			-0.001			-0.003*
			(0.001)			(0.002)
VA $\times$ FP $\times$ after CBA exp			0.004**			0.008***
			(0.002)			(0.003)
District $\times$ year FE	Yes	Yes	Yes	Yes	Yes	Yes
Edu, exp $\times$ post-2011	Yes	Yes	Yes	Yes	Yes	Yes
N	40142	52761	92905	17592	24054	41641
# districts	74	90	164	74	90	164

Notes: The dependent variable is the natural logarithm of salaries. The variable *VA* is teacher VA, normalized to have mean 0 and standard deviation 1. The variable *post-CBA expiration* equals 1 for years after the expiration of each district's CBA. All the regressions include district-by-year fixed effects, as well interactions between indicators for years of experience interacted with indicators for the highest education degree interacted with an indicator for years after 2011. VA is calculated separately for the years 2007–2011 and 2012–2016. Bootstrapped standard errors in parentheses are clustered at the district level. *** $p < .01$, ** $p < .05$, * $p < .1$.

Table 2: Changes in The Characteristics of Movers After a CBA Expiration. OLS, Dependent Variables Are Teacher's Characteristics

	Movers to FP		Movers to SP		All movers	
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A) Dep. var is value-added						
post-CBA expiration	1.122***	1.002***	-0.114	-0.159	0.038	0.044
	(0.155)	(0.207)	(0.152)	(0.204)	(0.144)	(0.159)
FP × post-CBA expiration					0.942***	0.835***
					(0.166)	(0.183)
Panel B) Dep. var is experience (years)						
post-CBA expiration	-1.637**	-1.989**	-0.702	-0.650	-0.571	-0.623
	(0.811)	(0.904)	(0.682)	(0.822)	(0.549)	(0.638)
FP × post-CBA expiration					-1.112	-1.710*
					(0.888)	(0.892)
Mean of dep. var.	4.756	4.740	5.372	5.411	5.074	5.078
Panel C) Dep. var =1 if teacher has a Master's or PhD						
post-CBA expiration	-0.1532**	-0.1832**	0.0856**	0.0775*	0.0849***	0.0811*
	(0.0588)	(0.0815)	(0.0372)	(0.0422)	(0.0288)	(0.0413)
FP × post-CBA expiration					-0.2366***	-0.2734***
					(0.0491)	(0.0764)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Budget, CB controls	Yes	Yes	Yes	Yes	Yes	Yes
Past district	No	Yes	No	Yes	No	Yes
FP*post 2011	No	No	No	No	Yes	Yes
Mean of dep. var.	0.313	0.327	0.317	0.331	0.315	0.329
N	3298	2687	3065	2385	6363	5072
# districts	71	69	89	88	160	157

Notes: The dependent variable is *ex ante* teacher VA, expressed in standard deviations (panel A), years of experience (panel B), or an indicator for the teacher having a Master's or a PhD (Panel C). Columns 1-2, 3-4, and 5-6 are estimated on the subsample of movers to a FP district, mover to a SP district, and movers to any district respectively. The variable *FP* equals one for teachers in FP districts. The variable *post-CBA expiration* equals one for years following a CBA expiration. All the regressions include year fixed effects, as well as district-year-level controls for the level of state aid as a share of total revenues, per-teacher expenditure on salaries, retirement, health, life, and other insurance, and other employee benefits, and indicators for whether the district had a union recertification election in year t and whether the election was successful. Columns 2, 4, and 6 also control for the interaction between an indicator for the previous district where the teacher was working being FP and indicators for years before and after a CBA expiration. Columns 5 and 6 control for *FP* and *FP * post 2011*. *Ex ante* VA is calculated using test scores for the years 2007–2011. Standard errors in parentheses are clustered at the district level. *** p < .01, ** p < .05, * p < .1.

Table 3: Changes in The Characteristics of Exiters After a CBA Expiration. OLS, Dependent Variables Are Teacher's Characteristics

	Exiters from FP		Exiters from SP		All exiters	
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A) Dep. var is value-added						
post-CBA expiration	-0.5240	-0.5037	0.2633**	0.3238*	0.0868	0.1377
	(0.6892)	(0.4886)	(0.1154)	(0.1672)	(0.1212)	(0.1673)
FP $\times$ post-CBA expiration					-0.5844*	-0.5389*
					(0.3025)	(0.3137)
Panel B) Dep. var is experience (years)						
post-CBA expiration	-0.6247*	-0.4688	2.3009**	0.7089	1.9472**	0.7917
	(0.3733)	(0.7149)	(1.1445)	(0.7981)	(0.9710)	(0.6869)
FP $\times$ post-CBA expiration					-2.1052**	-1.9540**
					(0.9225)	(0.9347)
Mean of dep. var.	20.104	19.539	18.110	18.003	18.921	18.628
Panel C) Dep. var =1 if teacher has a Master's or PhD						
post-CBA expiration	-0.0682	0.0405	-0.0275	-0.0232	-0.0121	0.0675**
	(0.0566)	(0.0640)	(0.0246)	(0.0319)	(0.0249)	(0.0301)
FP $\times$ post-CBA expiration					-0.0888*	-0.0688
					(0.0512)	(0.0564)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Budget, CB controls	No	Yes	No	Yes	No	Yes
Teacher controls	Yes	Yes	Yes	Yes	Yes	Yes
FP*post 2011	No	No	No	No	Yes	Yes
Mean of dep. var.	0.536	0.535	0.485	0.483	0.513	0.513
N	7138	6291	12052	10752	21615	15586
# districts	73	71	89	89	162	160

Notes: The dependent variable is *ex ante* teacher VA, expressed in standard deviations (panel A), years of experience (panel B), or an indicator for the teacher having a Master's or a PhD (panel C). Columns 1-2, 3-4, and 5-6 are estimated on the subsample of teachers who left FP districts, teachers who left SP districts, and all teachers who left, respectively. The variable *FP* equals one for teachers in FP districts. The variable *post-CBA expiration* equals one for years following a CBA expiration. All the regressions include year fixed effects, as well as district-year-level controls for the level of state aid as a share of total revenues, per-teacher expenditure on salaries, retirement, health, life, and other insurance, and other employee benefits, and indicators for whether the district had a union recertification election in year t and whether the election was successful. Columns 5 and 6 control for *FP* and *FP * post 2011*. Panel A) controls for interactions between age, experience, an indicator for having a postgraduate degree, and an indicator for years following 2011; panel B) controls for interactions between age, an indicator for having a postgraduate degree, and an indicator for years following 2011; and panel C) controls for interactions between age, experience, and an indicator for years following 2011. *Ex ante* VA is calculated using test scores for the years 2007–2011. Standard errors in parentheses are clustered at the district level. *** p < .01, ** p < .05, * p < .1.

Table 4: Salaries and Exit. OLS, Dependent Variable is log(Salary)

	All Districts	FP	SP
	(1)	(2)	(3)
Exiter, does not reappear	-0.0103***	-0.0209***	-0.0044
	(0.0035)	(0.0062)	(0.0041)
exit * post-CBA expiration	-0.0029	-0.0001	-0.0024
	(0.0047)	(0.0096)	(0.0041)
VA	0.0008	0.0007	0.0009
	(0.0007)	(0.0013)	(0.0009)
VA * post-CBA expiration	0.0005	0.0013	-0.0002
	(0.0011)	(0.0019)	(0.0012)
VA * exit	-0.0072*	-0.0121**	-0.0029
	(0.0038)	(0.0060)	(0.0018)
VA * exit * post-CBA expiration	0.0086	0.0171*	0.0017
	(0.0059)	(0.0104)	(0.0030)
District × year FE	Yes	Yes	Yes
Edu, exp × post-2011	Yes	Yes	Yes
N	83750	36063	47630
# districts	164	74	90

Notes: The dependent variable is the natural logarithm of salaries. The variable *exit* equals one for teachers exiting from a district in the following year. The variable *post-CBA expiration* equals one for years following a CBA expiration (including the year of the expiration). The variable *VA* is teacher VA, normalized to have mean 0 and standard deviation 1. The sample is restricted to teachers who leave public schools at the end of each year; column 2 is further restricted to teachers in FP districts and column 3 is restricted to teachers in SP districts. All the regressions include district-by-year fixed effects, as well interactions between indicators for years of experience interacted with indicators for the highest education degree and with an indicator for years after 2011. VA is calculated separately for the years 2007–2011 and 2012–2016. Bootstrapped standard errors in parentheses are clustered at the district level. *** $p < .01$, ** $p < .05$, * $p < .1$.

Table 5: Changes in the Composition of the Teaching Workforce. OLS, Dependent Variable is Ex Ante Teacher Value-Added

	All Teachers				
	(1)	(2)	(3)	(4)	(5)
FP	-0.0280				
	(0.0174)				
FP $\times$ post-CBA expiration	0.0238**	0.0200*	0.0566***	0.0352***	0.0395***
	(0.0110)	(0.0113)	(0.0197)	(0.0127)	(0.0148)
post-CBA expiration	-0.0210	0.0005	-0.0006	0.0147	0.0145
	(0.0220)	(0.0176)	(0.0182)	(0.0112)	(0.0119)
FP $\times$ post-2011			-0.0367		-0.0043
			(0.0223)		(0.0149)
Year FE	Yes	Yes	Yes	Yes	Yes
District FE	No	Yes	Yes	Yes	Yes
Edu, exp FE	No	No	No	Yes	Yes
Budget, CB controls	No	No	No	Yes	Yes
N	89684	89684	89684	70690	70690
# districts	162	162	162	160	160

Notes: The dependent variable is *ex ante* teacher VA. The variable *FP* equals 1 for FP districts. The variable *post-CBA expiration* equals one for years following each district's CBA expiration, and the variable *post* equals one for years following 2011. All the regressions include year fixed effects. Columns 2-5 also include district fixed effects, and columns 4-5 control for indicators for years of experience and for whether a teacher has a Master's or a PhD. *CB controls* include an indicator for whether the district had a union recertification election in year t and whether the election was successful. *Budget controls* are district-year-level controls for the level of state aid as a share of total revenues, as well as per-teacher expenditure on salaries, retirement, health, life, and other insurance, and other employee benefits. Ex ante VA is calculated using test score data for the years 2007–2011. Standard errors in parentheses are clustered at the district level. *** $p < .01$, ** $p < .05$, * $p < .1$.

Table 6: Combined Changes in Teacher Composition and Effort. OLS, Dependent Variable is Teacher Value-Added

	All Teachers					
	(1)	(2)	(3)	(4)	(5)	(6)
FP	-0.0230					
	(0.0146)					
FP × post-CBA expiration	0.0773**	0.0761**	0.0910	0.0889*	0.0554	0.0847*
	(0.0362)	(0.0365)	(0.0628)	(0.0453)	(0.0428)	(0.0497)
post-CBA expiration	0.0995	0.0654	0.0649	0.1095***	0.1115***	0.0310
	(0.0750)	(0.0547)	(0.0567)	(0.0326)	(0.0334)	(0.0465)
FP × post-2011			-0.0150		0.0337	
			(0.0742)		(0.0472)	
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
District FE	No	Yes	Yes	Yes	Yes	Yes
Edu, exp FE	No	No	No	Yes	Yes	Yes
Budget, CB controls	No	No	No	Yes	Yes	Yes
Teacher FE	No	No	No	No	No	Yes
N	94020	94020	94020	74268	74268	92155
# districts	162	162	162	160	160	162

Notes: The dependent variable is teacher VA, allowed to vary before and after 2011. The variable *FP* equals 1 for FP districts. The variable *post-CBA expiration* equals one for years following each district's CBA expiration, and the variable *post* equals one for years following 2011. All the regressions include year fixed effects; columns 2-6 include district fixed effects, columns 4-6 control for indicators for years of experience, and for whether a teacher has a Master's or a PhD, and columns 5 and 6 controls for teacher fixed effects. *CB controls* include an indicator for whether the district had a union recertification election in year t and whether the election was successful. *Budget controls* are district-year-level controls for the level of state aid as a share of total revenues, as well as per-teacher expenditure on salaries, retirement, health, life, and other insurance, and other employee benefits. VA is calculated separately for the years 2007–2011 and 2012–2016. Standard errors in parentheses are clustered at the district level. *** $p < .01$, ** $p < .05$, * $p < .1$.

Table 7: Student Achievement. OLS, Dependent Variables Are Reading (panel A) and Math Test Scores (panel B)

	Panel A) Reading					
	FP		SP		Difference	
	(1)	(2)	(3)	(4)	(5)	(6)
post-CBA expiration	0.0580***	0.0401**	0.0142	0.0088	0.0142	0.0098
	(0.0190)	(0.0155)	(0.0152)	(0.0167)	(0.0151)	(0.0206)
FP * post-CBA expiration					0.0438*	0.0360*
					(0.0242)	(0.0217)
School × grade FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Dem controls	No	Yes	No	Yes	No	Yes
School controls	No	Yes	No	Yes	No	Yes
N	11350	8577	16909	10641	28259	19218
# districts	73	71	89	89	162	160
	Panel B) Math					
	FP		SP		Difference	
	(1)	(2)	(3)	(4)	(5)	(6)
post-CBA expiration	0.0476***	0.0289	-0.0146	-0.0142	-0.0146	-0.0175
	(0.0172)	(0.0269)	(0.0367)	(0.0387)	(0.0366)	(0.0471)
FP * post-CBA expiration					0.0622	0.0672
					(0.0404)	(0.0567)
School × grade FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Dem controls	No	Yes	No	Yes	No	Yes
School controls	No	Yes	No	Yes	No	Yes
N	11350	8578	16905	10636	28255	19214
# districts	73	71	89	89	162	160

Notes: The dependent variable is the average of student test scores for Reading and Math, measured at the school-by-grade-by-year level for students in grades 3 to 8. The variable *FP* equals 1 for FP districts. The variable *post-CBA expiration* equals one for years following each district's CBA expiration. All the regressions include school-by-grade and year fixed effects; columns 2, 4, and 6 also include controls for the share of students in each cell who are female, Black, Hispanic, economically disadvantaged, migrants, disabled, or English-language learners, as well as district-level controls such as an indicator for whether the district had a union recertification election in year t and whether the election was successful, the level of state aid as a share of total revenues, per-teacher expenditure on salaries, retirement, health, life, and other insurance, and other employee benefits. Observations are weighted by the number of students in each cell. Standard errors in parentheses are clustered at the district level. *** $p < .01$, ** $p < .05$, * $p < .1$.

Appendix

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Appendix A Additional Tables and Figures

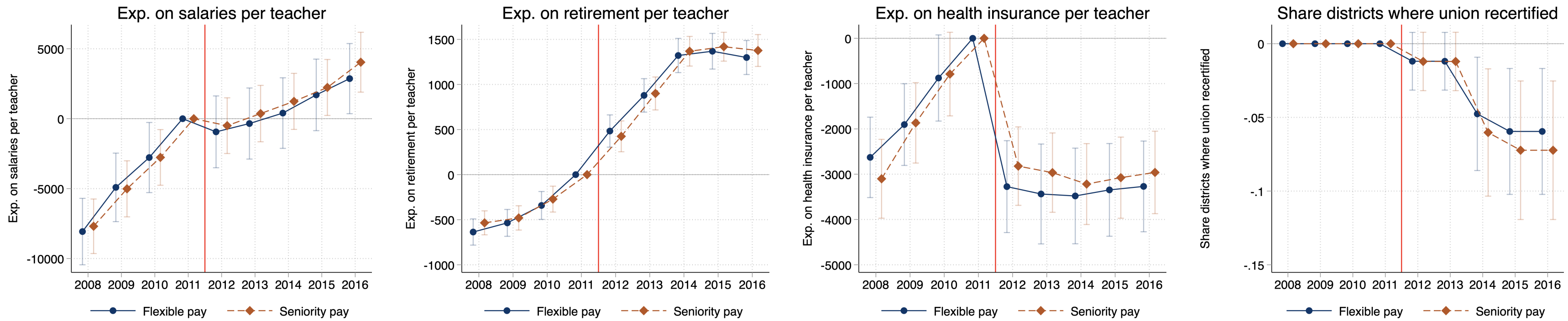
Figure A1: Salary Schedule - Racine School District, 2015

Step	BA	BA+12	BA+24	MA
1	40,593	42,784	44,976	47,169
2	41,526	43,717	45,909	48,516
3	42,459	44,651	46,842	49,864
4	43,392	45,584	47,775	51,211
5	44,325	46,517	48,709	52,560

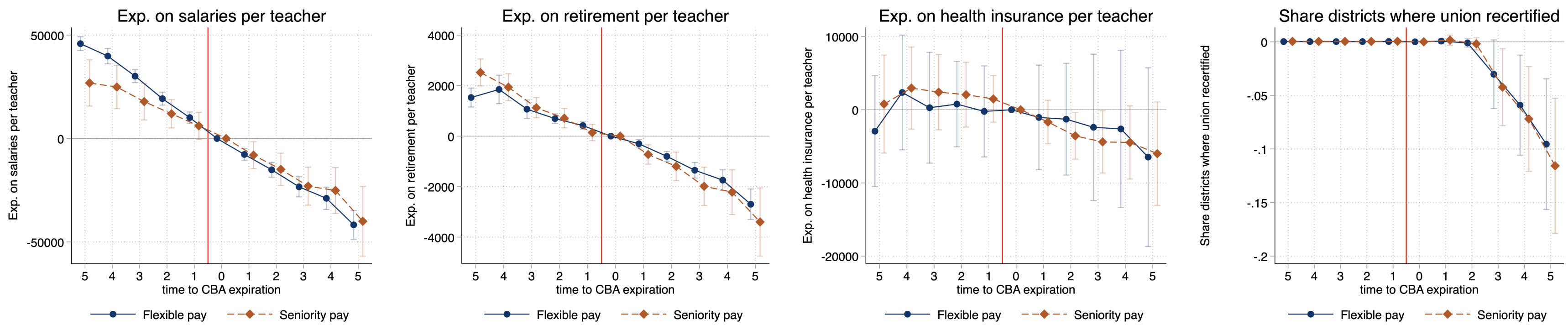
Notes: Subsection of the salary schedule used in the school district of Racine in 2015. Source: http://www.rusd.org.

Figure A2: Districts' Characteristics: By Year (top panel) and By Time-to-CBA (bottom panel)

Panel a) By year - FP and SP districts

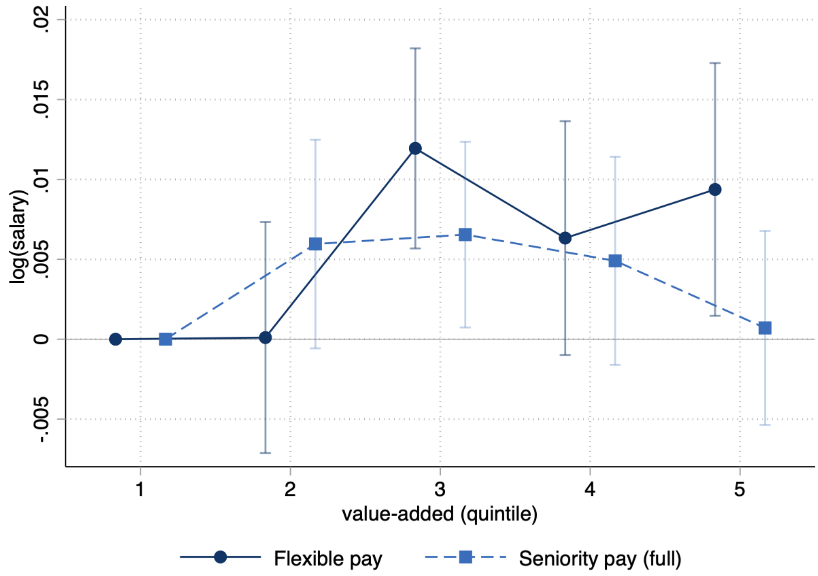


Panel b) By time-to-CBA, controlling for year fixed effects - FP and SP districts



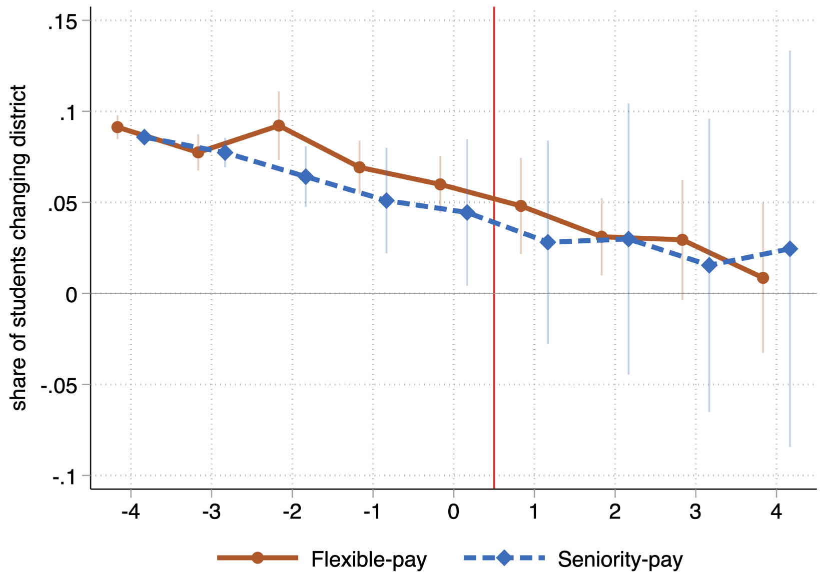
Notes: Panel a) shows trends in district characteristics between 2008 and 2016, relative to 2011, in FP and SP districts. Panel b) shows estimates of event studies of the same characteristics in a ten-years window around a CBA expiration, controlling for year fixed effects. Characteristics include, from left to right: Expenditure on salaries per teacher, expenditure on retirement benefits per teacher, expenditure on health insurance benefits per teacher, and an indicator for whether the union managed to recertify. Standard errors are clustered at the district level.

Figure A3: Salaries, by Quintile of Value-Added: FP and SP districts



Notes: OLS estimates and 90% confidence intervals of the coefficients δ_s in the regression $log(w_{it}) = \sum_{s=1}^{5} \delta_s^0 \mathbb{1}(D(VA_{it}) = s) + \sum_{s=1}^{10} \delta_s \mathbb{1}(D(VA_{it}) = s) * \mathbb{1}(t > Exp_{j(it)}) + \beta X_{it}^w + \theta_{j(jt)t} + \varepsilon_{it}$. The variable $log(w_{it})$ is the natural logarithm of salary for teacher i in year t. The variable VA_{it} is teacher VA. The function $D(VA_{it})$ denotes the decile in the distribution of value added, the variable Exp_j is the year of expiration of district j's CBA, and $\mathbb{1}(.)$ is an indicator function. The vector X_{it}^w includes a non-parametric function of years of experience, interacted with indicators for the highest education degree and with a dummy for years after 2011. The vector θ_{jt} contains district-by-year fixed effects. The coefficients δ_s are estimated separately for FP and SP districts. VA is calculated separately using test score data for the years 2007–2011 and 2012–20156. Bootstrapped standard errors are clustered at the district level.

Figure A4: Share of Students Changing District, by Time-to-CBA Expiration: FP and SP Districts



Notes: Fraction of students who change district in each year, by type of district and time-to-CBA expiration.

Table A1: Expiration Dates of CBAs and Districts' Observable Characteristics. OLS, Dependent Variables are Indicators for Years of Expiration

	CBA expires in		
	(1)	(2)	(3)
	2011	2012	2013
enrollment	-0.0000	0.0000	-0.0000
	(0.0000)	(0.0000)	(0.0000)
share econ. disadv. students	-0.0733	0.0119	0.0614
	(0.0981)	(0.0747)	(0.0644)
share Black students	-0.8952	0.8146	0.0806
	(0.7148)	(0.6748)	(0.2211)
share Hispanic students	0.0383	-0.0739	0.0356
	(0.2106)	(0.1656)	(0.1145)
teacher experience	-0.0017	0.0004	0.0013
	(0.0049)	(0.0036)	(0.0034)
share teachers w/ Master's	-0.0014	-0.0404	0.0418
	(0.0600)	(0.0427)	(0.0451)
teacher value-added	1.5704	-1.9782	0.4078
	(1.5721)	(1.5302)	(0.4169)
urban district	-0.0061	-0.1137***	0.1198
	(0.0905)	(0.0341)	(0.0933)
suburban district	0.0021	-0.0236	0.0216
	(0.0405)	(0.0272)	(0.0308)
N	208	208	208
R^2	0.22	0.23	0.09

Notes: The dependent variables are indicators for districts' CBAs agreements expiring in 2011, 2012, and 2013. The explanatory variables are measured in 2011 and averaged at the district level (one observation is a district). Robust standard errors in parentheses.

Table A2: Summary Statistics, Districts with and without Handbook Information

	without Handbook	with Handbook	Difference
enrollment	283.9	1093.1	-809.2***
			(142.3)
black students	0.063	0.028	0.034**
			(0.015)
hispanic students	0.047	0.056	-0.0091
			(0.0080)
disadvantaged students	0.43	0.34	0.086***
			(0.017)
math scores (sd)	-0.044	0.063	-0.11***
			(0.029)
teacher salary ($)	47753.8	51606.0	-3852.2***
			(500.2)
teacher experience (yrs)	15.8	15.4	0.40*
			(0.23)
teachers w/ BA	0.57	0.46	0.12***
			(0.015)
teachers w/ Master	0.42	0.54	-0.11***
			(0.015)
teachers w/ PhD	0.00096	0.0011	-0.00014
			(0.00042)
urban district	0.023	0.071	-0.048**
			(0.020)
suburban district	0.046	0.24	-0.19***
			(0.032)
value-added	-0.0021	-0.0020	-0.00011
			(0.0012)
expenditure p.p ($)	46546.6	45126.2	1420.3
			(1474.9)
state aid/expenditure (share)	0.32	0.33	-0.013
			(0.015)

Notes: Means and standard deviations (in parentheses) of district-level characteristics for 102 FP and 122 SP districts with non-missing handbook information, and 203 districts with missing handbook information, for the years 2009–2011.

Table A3: Summary Statistics, Wisconsin Teachers

	(1) Full sample		(2) FP/SP		(3) FP/SP with CBA exp. date	
	2007-11	2012-15	2007-11	2012-15	2007-11	2012-15
female	0.733	0.741	0.736	0.744	0.740	0.748
	(0.443)	(0.438)	(0.441)	(0.436)	(0.438)	(0.434)
experience (years)	14.46	13.94	14.31	13.78	14.20	13.74
	(9.769)	(9.184)	(9.647)	(9.048)	(9.575)	(8.999)
highest ed = BA	0.497	0.467	0.482	0.452	0.477	0.449
	(0.500)	(0.499)	(0.500)	(0.498)	(0.499)	(0.497)
highest ed = Master	0.496	0.525	0.510	0.539	0.514	0.542
	(0.500)	(0.499)	(0.500)	(0.498)	(0.500)	(0.498)
highest ed = PhD	0.00187	0.00205	0.00214	0.00239	0.00224	0.00251
	(0.0432)	(0.0452)	(0.0462)	(0.0488)	(0.0473)	(0.0500)
salary ($)	50341.1	53878.4	51179.3	54488.4	51522.5	54838.8
	(11545.0)	(12351.5)	(11692.2)	(12402.7)	(11728.8)	(12424.9)
mover	0.0151	0.0300	0.0141	0.0299	0.0135	0.0291
	(0.122)	(0.171)	(0.118)	(0.170)	(0.115)	(0.168)
value-added	-0.000392	-0.000311	-0.000475	-0.000372	-0.000192	-0.000592
	(0.0744)	(0.0487)	(0.0771)	(0.0507)	(0.0790)	(0.0515)

Notes: Means and standard deviations (in parentheses) of teachers' observable characteristics for the years 2007–2011 and 2012–2015, for all Wisconsin districts (columns 1), for FP and SP districts (columns 2), and for FP and SP districts with non-missing CBA expiration information (columns 3). The sample only includes teachers for whom VA estimates are available.

Table A4: Summary Statistics, Wisconsin Teachers, With and Without *ex ante* Value-Added

	Full sample			FP/SP		
	w/ *ex ante* VA	w/out *ex ante* VA	Difference	w/ *ex ante* VA	w/out *ex ante* VA	Difference
female	0.79	0.72	0.074***	0.80	0.72	0.078***
			(0.0013)			(0.0015)
experience (years)	14.8	14.1	0.71***	14.5	13.9	0.60***
			(0.029)			(0.031)
highest ed = BA	0.42	0.50	-0.076***	0.41	0.48	-0.071***
			(0.0015)			(0.0017)
highest ed = Master	0.57	0.49	0.076***	0.58	0.51	0.071***
			(0.0015)			(0.0017)
highest ed = PhD	0.0012	0.0022	-0.00095***	0.0014	0.0025	-0.0011***
			(0.00013)			(0.00016)
salary ($)	53090.5	51570.3	1520.2***	53771.9	52320.5	1451.4***
			(36.2)			(40.8)
mover	0.017	0.024	-0.0076***	0.016	0.023	-0.0070***
			(0.00048)			(0.00053)
value-added	-0.00040	-0.00012	-0.00029	-0.00050	-0.000084	-0.00042
			(0.00045)			(0.00052)

Notes: Means and standard deviations (in parentheses) of teachers' observable characteristics for the years 2007–2011 and 2012–2015, for all Wisconsin districts (columns 1) for FP and SP districts (columns 2), and for FP and SP districts with non-missing CBA expiration information (columns 3), and separately for teachers with and without *ex ante* VA, calculated as the average over the years 2007–2011. The sample includes teachers for whom overall VA estimates are available.

Table A5: Teacher Salaries and Value-Added. OLS, Dependent Variable is log(Salary). Sample of Tenured Teachers

	All Districts	FP	SP	Difference
	(1)	(2)	(3)	(4)
VA	0.0006	-0.0002	0.0012	0.0012
	(0.0008)	(0.0011)	(0.0010)	(0.0010)
VA $\times$ post-CBA expiration	0.0014	0.0044**	-0.0009	-0.0008
	(0.0013)	(0.0019)	(0.0015)	(0.0015)
VA $\times$ FP				-0.0014
				(0.0015)
VA $\times$ FP $\times$ after CBA exp				0.0052**
				(0.0024)
District $\times$ year FE	Yes	Yes	Yes	Yes
Edu, exp $\times$ post-2011	Yes	Yes	Yes	Yes
N	84072	36336	47680	84018
# districts	163	74	89	163

Notes: The dependent variable is the natural logarithm of salaries. The variable *VA* is teacher VA, normalized to have mean 0 and standard deviation 1. The variable *post-CBA expiration* equals 1 for years after the expiration of each district's CBA. All the regressions include district-by-year fixed effects, as well interactions between indicators for years of experience interacted with indicators for the highest education degree interacted with an indicator for years after 2011. VA is calculated separately for the years 2007–2011 and 2012–2016. Bootstrapped standard errors in parentheses are clustered at the district level. The sample is restricted to tenured teachers (with at least three years of experience). *** p < .01, ** p < .05, * p < .1.

Table A6: Teacher Salaries and Value-Added. OLS, Dependent Variable is log(Salary). Excluding Milwaukee and Madison

	All Districts	FP	SP	Difference
	(1)	(2)	(3)	(4)
VA	0.0006	-0.0002	0.0015*	0.0014*
	(0.0008)	(0.0011)	(0.0008)	(0.0008)
VA $\times$ post-CBA expiration	0.0015	0.0041**	-0.0010	-0.0009
	(0.0013)	(0.0017)	(0.0014)	(0.0014)
VA $\times$ FP				-0.0017
				(0.0014)
VA $\times$ FP $\times$ after CBA exp				0.0050**
				(0.0022)
District $\times$ year FE	Yes	Yes	Yes	Yes
Edu, exp $\times$ post-2011	Yes	Yes	Yes	Yes
N	82528	40142	42326	82470
# districts	163	74	89	163

Notes: The dependent variable is the natural logarithm of salaries. The variable *VA* is teacher VA, normalized to have mean 0 and standard deviation 1. The variable *post-CBA expiration* equals 1 for years after the expiration of each district's CBA. All the regressions include district-by-year fixed effects, as well interactions between indicators for years of experience interacted with indicators for the highest education degree interacted with an indicator for years after 2011. VA is calculated separately for the years 2007–2011 and 2012–2016. Bootstrapped standard errors in parentheses are clustered at the district level. The sample excludes teachers in the school districts of Milwaukee and Madison. *** $p < .01$, ** $p < .05$, * $p < .1$.

Table A7: Teacher Salaries and Value-Added. OLS, Dependent Variable is log(Salary)

	Schools w/ max 3 teachers/grade			Teachers whose VA is identified		
	FP	SP	Difference	FP	SP	Difference
	(1)	(2)	(3)	(4)	(5)	(6)
VA	-0.0006	0.0007	0.0007	-0.0008	0.0006	0.0006
	(0.0012)	(0.0013)	(0.0012)	(0.0012)	(0.0007)	(0.0007)
VA $\times$ post-CBA expiration	0.0063**	0.0006	0.0005	0.0031*	-0.0001	-0.0000
	(0.0029)	(0.0023)	(0.0022)	(0.0017)	(0.0012)	(0.0012)
VA $\times$ FP			-0.0013			-0.0012
			(0.0018)			(0.0014)
VA $\times$ FP $\times$ after CBA exp			0.0061*			0.0031
			(0.0037)			(0.0021)
District $\times$ year FE	Yes	Yes	Yes	Yes	Yes	Yes
Edu, exp $\times$ post-2011	Yes	Yes	Yes	Yes	Yes	Yes
Grade, subject $\times$ post-2011	Yes	Yes	Yes	Yes	Yes	Yes
N	18131	24078	42217	23699	33160	56880
# districts	73	89	162	74	89	163

Notes: The dependent variable is the natural logarithm of salaries. The variable *VA* is teacher VA, normalized to have mean 0 and standard deviation 1. The variable *post-CBA expiration* equals 1 for years after the expiration of each district's CBA. All the regressions include district-by-year fixed effects, as well interactions between indicators for years of experience interacted with indicators for the highest education degree interacted with an indicator for years after 2011. VA is calculated separately for the years 2007–2011 and 2012–2016. The sample is restricted to teachers in schools and grades with at most 3 teachers per subject (columns 1-3) and to teachers with identified VA (columns 4-6). Bootstrapped standard errors in parentheses are clustered at the district level. *** $p < .01$, ** $p < .05$, * $p < .1$.

Table A8: Teacher Salaries and Value-Added. OLS, Dependent Variable is log(Salary). Controlling for Teaching Assignment

	All Districts	FP	SP	Difference
	(1)	(2)	(3)	(4)
VA	0.0004	-0.0006	0.0008	0.0008
	(0.0006)	(0.0011)	(0.0008)	(0.0008)
VA $\times$ post-CBA expiration	0.0016	0.0042**	-0.0005	-0.0003
	(0.0011)	(0.0016)	(0.0013)	(0.0013)
VA $\times$ FP				-0.0012
				(0.0014)
VA $\times$ FP $\times$ after CBA exp				0.0043**
				(0.0021)
District $\times$ year FE	Yes	Yes	Yes	Yes
Edu, exp $\times$ post-2011	Yes	Yes	Yes	Yes
Grade, subject $\times$ post-2011	Yes	Yes	Yes	Yes
N	92943	40130	52745	92887
# districts	164	74	90	164

Notes: The dependent variable is the natural logarithm of salaries. The variable *VA* is teacher VA, normalized to have mean 0 and standard deviation 1. The variable *post-CBA expiration* equals 1 for years after the expiration of each district's CBA. All the regressions include district-by-year fixed effects, as well interactions between indicators for years of experience interacted with indicators for the highest education degree interacted with an indicator for years after 2011. VA is calculated separately for the years 2007–2011 and 2012–2016. Bootstrapped standard errors in parentheses are clustered at the district level. *** $p < .01$, ** $p < .05$, * $p < .1$.

Table A9: Changes in the Composition of the Teaching Workforce. OLS, Dependent Variable is Teacher Value-Added. Only Districts w/CBA Expirations After 2011

	Ex ante VA		Time-varying VA	
	(1)	(2)	(3)	(4)
FP × post-CBA expiration	0.0224	0.0496	0.0503	0.0733
	[1.9319]	[2.0650]	[0.7466]	[1.1687]
post-CBA expiration	0.0028	0.0197	0.1583	0.0930
	[0.1036]	[0.8806]	[2.0632]	[1.5703]
FP × post-2011	-0.0131	-0.0277	0.0164	-0.0077
	[-0.3433]	[-1.0148]	[0.1537]	[-0.0703]
Year FE	Yes	Yes	Yes	Yes
District FE	No	Yes	No	Yes
Edu, exp FE	Yes	Yes	Yes	Yes
N	18521	18521	19340	19340
# districts	7	7	7	7

Notes: The dependent variable is *ex ante* teacher VA (columns 1 and 2) or time-varying VA, allowed to vary before and after 2011 (columns 3 and 4). The variable *FP* equals 1 for FP districts. The variable *post-CBA expiration* equals one for years following each district's CBA expiration, and the variable *post* equals one for years following 2011. All the regressions include year fixed effects and indicators for years of experience and for whether a teacher has a Master's or a PhD. Columns 2 and 4 also include district fixed effects. Ex ante VA is calculated using test score data for the years 2007–2011. The sample is restricted to teachers in eight school districts with agreements expiring in 2012 and 2013. T-statistics obtained using a wild bootstrap and clustering at the district level are shown in brackets.

Table A10: Changes in the Composition of the Teaching Workforce. OLS, Dependent Variable is Ex Ante Teacher Value-Added. Excluding Milwaukee and Madison

	All Teachers				
	(1)	(2)	(3)	(4)	(5)
FP	-0.0235				
	(0.0230)				
FP $\times$ post-CBA expiration	0.0244**	0.0214*	0.0926***	0.0340**	0.0773**
	(0.0122)	(0.0127)	(0.0209)	(0.0138)	(0.0342)
post-CBA expiration	-0.0552**	-0.0262	-0.0380**	-0.0158	-0.0270
	(0.0213)	(0.0192)	(0.0176)	(0.0279)	(0.0339)
FP $\times$ post-2011			-0.0715***		-0.0436
			(0.0198)		(0.0327)
Year FE	Yes	Yes	Yes	Yes	Yes
District FE	No	Yes	Yes	Yes	Yes
Edu, exp FE	No	No	No	Yes	Yes
Budget, CB controls	No	No	No	Yes	Yes
N	74215	74215	74215	61562	61562
# districts	160	160	160	158	158

Notes: The dependent variable is *ex ante* teacher VA. The variable *FP* equals 1 for FP districts. The variable *post-CBA expiration* equals one for years following each district's CBA expiration, and the variable *post* equals one for years following 2011. All the regressions include year fixed effects. Columns 2-5 also include district fixed effects, and columns 4-5 control for indicators for years of experience and for whether a teacher has a Master's or a PhD. *CB controls* include an indicator for whether the district had a union recertification election in year t and whether the election was successful. *Budget controls* are district-year-level controls for the level of state aid as a share of total revenues, as well as per-teacher expenditure on salaries, retirement, health, life, and other insurance, and other employee benefits. Ex ante VA is calculated using test score data for the years 2007–2011. Standard errors in parentheses are clustered at the district level. The sample excludes teachers in the school districts of Milwaukee and Madison. *** $p < .01$, ** $p < .05$, * $p < .1$.

Table A11: Changes in the Composition of the Teaching Workforce. OLS, Dependent Variable is Ex Ante Teacher Value-Added (Columns 1-2) or Time-Varying Value-Added (Columns 3-4)

	Ex ante VA		Time-varying VA	
	(1) Schools-grades w/max 3 teachers	(2) Teachers w/identified VA	(3) Schools-grades w/max 3 teachers	(4) Teachers w/identified VA
FP × post-CBA exp	0.0672**	0.1339**	0.1702***	0.2241***
	(0.0295)	(0.0566)	(0.0355)	(0.0494)
post-CBA exp	-0.0452*	-0.0066	-0.0359	0.0257
	(0.0273)	(0.0270)	(0.0329)	(0.0289)
FP × post-2011	-0.0698**	-0.1070***	-0.1289***	-0.1544***
	(0.0311)	(0.0388)	(0.0296)	(0.0459)
Year FE	Yes	Yes	Yes	Yes
District FE	Yes	Yes	Yes	Yes
Edu, exp FE	Yes	Yes	Yes	Yes
N	39695	45964	42918	57681
# districts	162	162	162	162

Notes: The dependent variable is *ex ante* teacher VA. The variable *FP* equals 1 for FP districts. The variable *post-CBA expiration* equals one for years following each district's CBA expiration, and the variable *post* equals one for years following 2011. All the regressions include district and year fixed effects and indicators for years of experience and for whether a teacher has a Master's or a PhD. Ex ante VA is calculated using test score data for the years 2007–2011. Standard errors in parentheses are clustered at the district level. The sample is restricted to teachers in schools and grades with at most 3 teachers per subject (columns 1 and 3) and to teachers with identified VA (columns 2 and 4). *** $p < .01$, ** $p < .05$, * $p < .1$.

Table A12: Combined Changes in Teacher Composition and Effort. OLS, Dependent Variable is Teacher Value-Added. Excluding Milwaukee and Madison

	All Teachers				
	(1)	(2)	(3)	(4)	(5)
FP	-0.0198				
	(0.0191)				
FP × post-CBA expiration	0.0612	0.0578	0.2113***	0.0697	0.0820
	(0.0407)	(0.0401)	(0.0406)	(0.0468)	(0.0542)
post-CBA expiration	-0.0090	-0.0376	-0.0613***	-0.0279	-0.0486
	(0.0338)	(0.0353)	(0.0212)	(0.0594)	(0.0356)
FP × post-2011			-0.1542***		
			(0.0350)		
Year FE	Yes	Yes	Yes	Yes	Yes
District FE	No	Yes	Yes	Yes	Yes
Edu, exp FE	No	No	No	Yes	Yes
Budget, CB controls	No	No	No	Yes	Yes
Teacher FE	No	No	No	No	Yes
N	78034	78034	78034	64926	76400
# districts	160	160	160	158	160

Notes: The dependent variable is teacher VA, allowed to vary before and after 2011. The variable *FP* equals 1 for FP districts. The variable *post-CBA expiration* equals one for years following each district's CBA expiration, and the variable *post* equals one for years following 2011. All the regressions include year fixed effects; columns 2-6 include district fixed effects, columns 4-6 control for indicators for years of experience, and for whether a teacher has a Master's or a PhD, and columns 5 and 6 controls for teacher fixed effects. *CB controls* include an indicator for whether the district had a union recertification election in year t and whether the election was successful. *Budget controls* are district-year-level controls for the level of state aid as a share of total revenues, as well as per-teacher expenditure on salaries, retirement, health, life, and other insurance, and other employee benefits. VA is calculated separately for the years 2007–2011 and 2012–2016. Standard errors in parentheses are clustered at the district level. The sample excludes teachers in the school districts of Milwaukee and Madison. *** $p < .01$, ** $p < .05$, * $p < .1$.

Table A13: Changes in Student Characteristics, Movers to FP and SP

	Econ disadv	Female	Black	Hispanic	Disabled	
	(1)	(2)	(3)	(4)	(5)	(6)
FP	-0.059	-0.005**	-0.033	-0.003	-0.001	-0.001
	(0.040)	(0.002)	(0.026)	(0.019)	(0.006)	(0.006)
post-CBA expiration	-0.169***	-0.000	-0.101**	-0.107***	-0.009	-0.009
	(0.034)	(0.006)	(0.045)	(0.027)	(0.008)	(0.008)
FP * post-CBA expiration	0.016	0.005	0.001	0.017*	-0.008	-0.008
	(0.022)	(0.003)	(0.015)	(0.009)	(0.006)	(0.006)
Year FE	Yes	Yes	Yes	Yes	Yes	No
Mean of Dep. Var.	0.36	0.49	0.07	0.09	0.13	
N	4920	4920	4920	4920	4920	4920
# districts	162	162	162	162	162	162

Notes: The dependent variables are average characteristics of students of the teachers who move to FP and SP districts. The variable *FP* equals 1 for FP districts, the variable *post-CBA expiration* equals 1 for years after a CBA expiration. All specifications contain year fixed effects. Standard errors in parentheses are clustered at the district level.

Appendix B Estimating Teacher Value-Added With Grade-School Links

Teacher value-added (VA) is defined as the contribution of each teacher to achievement (or achievement growth), once all other determinants of student learning have been taken into account. The starting model is the following (Kane and Staiger, 2008):

$$A_{kt} = \beta X_{kt} + \nu_{kt} \tag{9}$$
$$\text{where } \nu_{kt} = \mu_{i(kt)} + \theta_{c(kt)} + \varepsilon_{kt}$$

and where A_{kt} is a standardized measure of test scores (or test score gains) for student k in year t, and X_{kt} is a vector of student, grade, and school observables which could affect achievement, including: school and grade-by-year fixed effects; cubic polynomials of past scores interacted with grade fixed effects; cubic polynomials of average past scores for the students in the same grade and school, interacted with grade fixed effects; student k's demographic characteristics, including gender, race and ethnicity, disability, English-language earner status, and socioeconomic status; the same demographic characteristics, averaged for all students in the same grade and school as student k in year t; and the student's socioeconomic status interacted with the share of low-socioeconomic status in her grade and school in t.[35] The residual ν_{kt} can be decomposed into three parts: The error term component $\mu_{i(kt)}$ is the individual effect of teacher i, teaching student k in year t; the component $\theta_{c(kt)}$ is an exogenous classroom shock; and ε_{kt} is an idiosyncratic student-specific component which varies over time. VA is an estimate of the teacher effect μ_i.

A range of techniques have been proposed to estimate μ_i, including fixed effects (Aaronson et al., 2007) and two-steps procedures based on the decomposition of test score residuals (Kane and Staiger, 2008; Chetty et al., 2014a). Here, I consider the two-steps estimator of Kane and Staiger (2008), a special case of the more general framework of Chetty et al. (2014a) which allows for the correction of noise in the estimates using a Bayes "shrinkage" approach. The estimation procedure can be summarized as follows:

1. Estimate β in equation (9) via OLS;
2. Construct residuals $\hat{\nu}_{kt} = A^*_{kt} - \hat{\beta} X_{kt}$, where $\hat{\beta}$ is the OLS estimate of β;
3. Estimate VA as $\bar{\nu}_i \left(\frac{\sigma_\mu}{Var(\bar{\nu}_i)} \right)$, where
   (a) $\bar{\nu}_i = \sum_t w_{it} \bar{\nu}_{it}$ is a weighted average of average test score residuals $\bar{\nu}_{it}$ for teacher i in year t;
   (b) $w_{it} = \frac{h_{it}}{\sum_t h_{it}}$, with $h_{it} = \frac{n_{it}}{n_{it}\sigma^2_\theta + \sigma^2_\varepsilon}$, are the weights, function of class size n_{it}, the variance of the classroom component σ^2_θ and of the residual component σ^2_ε;
   (c) the variance of the teacher effect is $\sigma^2_\mu = Cov(\bar{\nu}_{it}, \bar{\nu}_{it-1})$; the variance of the residual component is $\sigma^2_\varepsilon = Var(\nu_{kt} - \bar{\nu}_{it})$; the variance of the classroom component is $\sigma^2_\theta = Var(\nu_{kt}) - \sigma^2_\varepsilon - \sigma^2_\mu$.

Constructing an estimate of teacher VA thus requires correctly estimating $\bar{\nu}_{it}$, which in turn requires linking each teacher with the students she taught in each year. The WDPI started to record classroom identifiers, which allow to link students to teachers, only in 2017; data from previous years only contain identifiers for schools and grades. This means that, in a given year, a student can be linked to all the teachers in her school and grade, but not to the specific teacher who taught her (and conversely, a teacher can be linked to all students attending her grade in her school, but not to her own pupils). The lack of information on classroom identifiers is common to teacher-student datasets from several other states and/or districts (Rivkin et al., 2005, for example, face a similar issue with data from Texas).

How to identify teacher effects in the absence of classroom links? A simple approximation is given by grade-level average test score residuals. Rivkin et al. (2005), however, show that in the presence of

[35] This specification largely follows Chetty et al. (2014a).

teacher turnover across grades or schools one can obtain a more accurate measure of teacher effects than grade residuals. The intuition behind the identification of these effects is as follows. In the absence of teacher turnover, teachers in grade g and school s would have the same $\bar{\nu}_{it}$ for every t, and separately identifying their individual effects would be impossible. With data on test scores for multiple years and in the presence of turnover, teachers switches across schools or within schools and grades allow to isolate the effect of the individual teacher through the comparison of test score residuals before and after her arrival in a given grade and school. Importantly, teacher turnover allows a more precise identification of the effects not only of the teacher who switches school or grade, but also of the teachers teaching in her same grade and school at any point in time.

To incorporate this feature of the data, I proceed as follows.

a. I calculate the grade-school-year average residuals $\bar{\nu}_{gst}$ for each g, s, and t;

b. I construct the "teams" of teachers in each grade and school in each year;

c. Given these teams, I identify teachers or groups of teachers whose value added can be separately identified, either because they move or because other teachers in their team move. For these teachers I can identify a $\bar{\nu}_{it}$; in the Wisconsin data, these teachers represent 70 percent of the whole sample. For 10 percent of the sample, $\bar{\nu}_{it}$ will not be separately identifiable from that of another teacher, and for 20 percent of the sample $\bar{\nu}_{it}$ will not be separately identifiable from that of two or more teachers.

d. Given these $\bar{\nu}_{it}$, I can calculate VA from step 3 above. This strategy does not allow to separately identify θ_c; I therefore assume θ_c and σ_θ to be zero.

Two features of this identification strategy are worth highlighting:

1. While my VA estimates are more precise than grade-school residuals, they contain more noise relative to estimates obtained with teacher-student links: Even in the presence of turnover, teachers always teaching the same grade-school would have the same $\bar{\nu}_{it}$ for every t, and hence the same estimate.

2. The aggregation of teacher effects at the grade level overcomes a problematic form of selection, which occurs within schools and grades and across classrooms when some parents manage to have their children assigned to specific teachers. The (forced) use of grade-school estimates circumvents this form of selection, and is in practice equivalent to an instrumental variable estimator based on grade rather than on classroom assignment (Rivkin et al., 2005).

Identification of Teacher Value-Added With Turnover

To understand the identification argument, consider a simple example of 3 teachers (A, B, C) observed in 3 periods ($t = 1, 2, 3$) and in 2 possible grades ($g = 4, 5$). The teaching assignments are as follows.

period	grade	
1	A,B	C
2	B,C	A
3	A,C	B

The objective is to calculate VA of the three teachers in period 3. I define A_{kt} as the average test score residual for students of teacher k in period t, and $\bar{A}_t^g$ the average test score residuals of students in grade g in period t. Following Chetty et al. (2014a) I can write the VA estimate for each teacher as follows (I suppress the hats on the VA estimates for ease of notation and I consider 3 lags):

$$\mu_{A3} = \begin{bmatrix} A_{A1}^2 & A_{A1}A_{A2} \\ A_{A1}A_{A2} & A_{A2}^2 \end{bmatrix}^{-1} \begin{bmatrix} A_{A1}A_{A3} \\ A_{A2}A_{A3} \end{bmatrix} \quad (10)$$

$$\mu_{B3} = \begin{bmatrix} A_{B1}^2 & A_{B1}A_{B2} \\ A_{B1}A_{B2} & A_{B2}^2 \end{bmatrix}^{-1} \begin{bmatrix} A_{B1}A_{B3} \\ A_{B2}A_{B3} \end{bmatrix} \quad (11)$$

$$\mu_{C3} = \begin{bmatrix} A_{C1}^2 & A_{C1}A_{C2} \\ A_{C1}A_{C2} & A_{C2}^2 \end{bmatrix}^{-1} \begin{bmatrix} A_{C1}A_{C3} \\ A_{C2}A_{C3} \end{bmatrix} \quad (12)$$

Assuming a constant number of students in each classroom, one can write:

$$\bar{A}_1^4 = \frac{1}{2}(A_{A1} + A_{B1}) \quad (13)$$

$$\bar{A}_1^5 = A_{C2} \quad (14)$$

$$\bar{A}_2^4 = \frac{1}{2}(A_{B2} + A_{C2}) \quad (15)$$

$$\bar{A}_2^5 = A_{A2} \quad (16)$$

$$\bar{A}_3^4 = \frac{1}{2}(A_{A3} + A_{C3}) \quad (17)$$

$$\bar{A}_3^5 = A_{B3} \quad (18)$$

My VA estimator implies:

$$\mu_{A3} = \begin{bmatrix} (\bar{A}_1^4)^2 & \bar{A}_1^4\bar{A}_2^5 \\ \bar{A}_1^4\bar{A}_2^5 & (\bar{A}_2^5)^2 \end{bmatrix}^{-1} \begin{bmatrix} \bar{A}_1^4\bar{A}_3^4 \\ \bar{A}_2^5\bar{A}_3^4 \end{bmatrix} \quad (19)$$

$$\mu_{B3} = \begin{bmatrix} (\bar{A}_1^4)^2 & \bar{A}_1^4\bar{A}_2^4 \\ \bar{A}_1^4\bar{A}_2^4 & (\bar{A}_2^4)^2 \end{bmatrix}^{-1} \begin{bmatrix} \bar{A}_1^4\bar{A}_3^5 \\ \bar{A}_2^4\bar{A}_3^5 \end{bmatrix} \quad (20)$$

$$\mu_{C3} = \begin{bmatrix} (\bar{A}_1^5)^2 & \bar{A}_1^5\bar{A}_2^4 \\ \bar{A}_1^5\bar{A}_2^4 & (\bar{A}_2^4)^2 \end{bmatrix}^{-1} \begin{bmatrix} \bar{A}_1^5\bar{A}_3^4 \\ A_{C2}\bar{A}_3^4 \end{bmatrix} \quad (21)$$

Equations (10)-(21) represent a system of 12 equations in 12 unknowns: μ_{A3}, μ_{B3}, μ_{B3}, A_{A1}, A_{A2}, A_{A3}, A_{B1}, A_{B2}, A_{B3}, A_{C1}, A_{C2}, A_{C3}. In this case, VA can be perfectly identified for all teachers because at least one teacher switches grade each year.

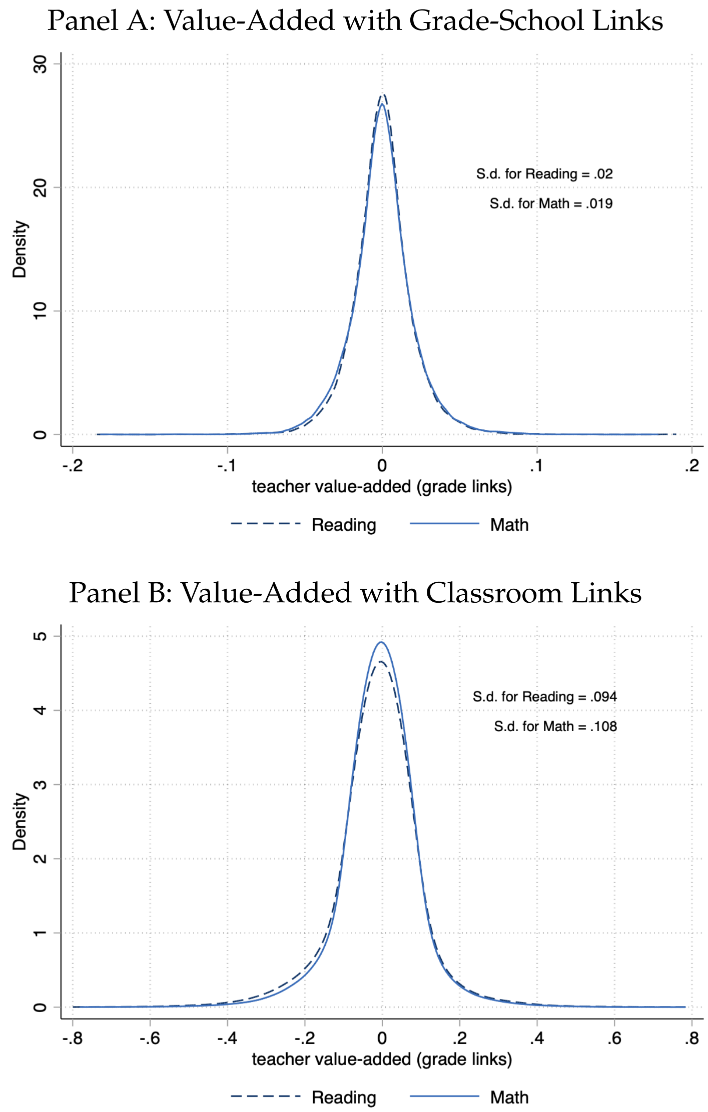
Validation Exercise: Value-Added with Classroom Links and with Grade-School Links in the NYC data

To validate the VA estimator with grade-school links described above (which I call GL) against the standard Kane and Staiger estimator with classroom links (CL), I use teacher and student data from the New York City Department of Education (NYCDOE) from the years 2006-07 to 2009-10. This dataset contains classroom, grade, and school identifiers, which allow me to estimate both CL and GL measures. I estimate teacher VA for 15,469 teachers of Math and English-Language-Arts (ELA) using the procedure of Kane and Staiger (2008).

Measurement Error The main limitation of GL relative to CL is measurement error. Since students are linked to teachers at the grade-school level, the VA of a teacher will also be a function of test scores of students she never taught.

Classic measurement error will push VA estimates towards zero. To quantify the extent of this problem, Figure B1 shows the kernel density of the distribution of GL (top panel) and CL (bottom panel). As expected, the distribution of GL is more concentrated around zero compared to CL. In spite of this, GL is able to explain a significant amount of variance in test scores. Its standard deviation (measured in test scores standard deviation units) is equal to 0.02 for Math teachers; by comparison, the standard deviation of CL is equal to 0.11. Figure B2 shows the density of GL for Wisconsin teachers. Its standard deviation is equal to 0.10 for Math teachers.

Figure B1: Empirical Distribution of Value-Added Estimates: New York City, 2007-2010

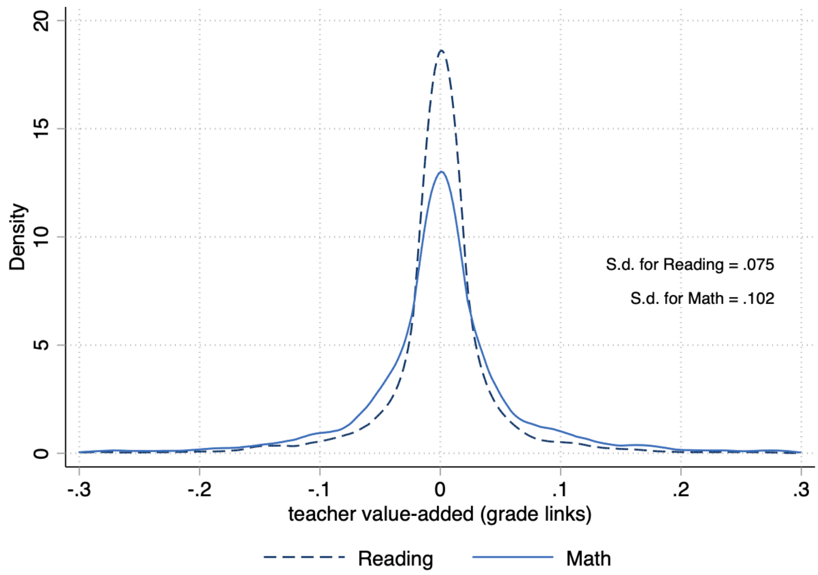


Notes: Kernel densities of the empirical distribution of VA estimates for NYC math and ELA teachers, for each subject. Estimates are averaged across years for each teacher. Each density is weighted by the number of student test scores observations used to estimate each teacher's VA, and estimated using a bandwidth of 0.05. The figure also reports the standard deviations of these empirical distributions.

Forecast Bias of GL as a Proxy for CL Next, I text whether GL is a forecast-unbiased estimate for CL. Figure B3 shows a binned scatterplot of the two estimates in the NYC data, averaged across the four years for each teacher. Their correlation is 0.62. The forecast bias of $\hat{\mu}_i^{GL}$ as a proxy for $\hat{\mu}_i^{CL}$ can be defined based on the best linear predictor of $\hat{\mu}_i^{CL}$ given $\hat{\mu}_i^{GL}$:

$$\hat{\mu}_i^{CL} = \alpha + \gamma \hat{\mu}_i^{GL} + \chi_i \tag{22}$$

Figure B2: Empirical Distribution of Value-Added Estimates: Wisconsin, 2007-2015



Notes: Kernel densities of the empirical distribution of VA estimates for Wisconsin math and reading teachers, for each subject. Estimates are averaged across years for each teacher, separately for years before and after Act 10. Each density is weighted by the number of student test scores observations used to estimate each teacher's VA, and estimated using a bandwidth of 0.05. The figure also reports the standard deviations of these empirical distributions.

Assuming χ_i to be uncorrelated with $\hat{\mu}_i^{GL}$, the forecast bias f is zero if $\gamma = 1$: $f = 1 - \gamma$. I can estimate the slope coefficient γ via OLS on equation (22). The 95% confidence interval for γ, whose point estimate is equal to 0.99, includes 1, which implies that the forecast bias f is equal to 0.01 and it is indistinguishable from zero (Figure B3).

Teacher Switches as a Quasi-Experiment As an additional test for the unbiasedness of GL estimates I exploit teacher switches across grades as a quasi-experiment, as in Chetty et al. (2014a). If VA is an unbiased measure of teacher quality, changes in average VA of teachers in a given school and grade (driven by teacher switches) should predict changes in average student test score residuals one-by-one. To understand the rationale behind this test suppose that, in a given school with three 4th-grade classrooms (and hence three 4th-grade math teachers), one of these teachers leaves and is replaced by a teacher with a 0.3 higher VA (measured in standard deviations of test scores). If VA is an unbiased measure of teacher effectiveness, test scores should raise by 0.3/3 = 0.1 standard deviations due to this switch (Chetty et al., 2014a).

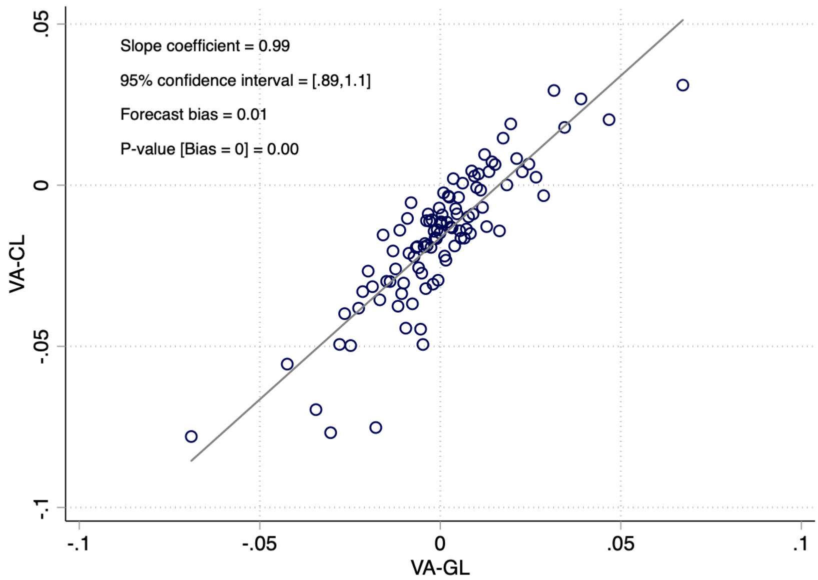
I estimate the degree of forecast bias for the Wisconsin GL measures by estimating the following first-differences equation (I restrict attention to the years 2007 to 2011 to parse out any changes in teacher effort, as done in the paper):

$$\Delta A^*_{gst} = a + b\Delta Q_{gst} + \Delta\chi_{gst} \tag{23}$$

where A^*_{gst} are test score residuals of students in grade g, school s, and year t, Q_{gst} is average teacher VA, and $\Delta W_{gst} = W_{gst} - W_{gst-1}$ for any variable W_{gst}. The forecast bias is defined as $\lambda = 1 - b$. Table B3 shows estimates of b and λ, obtained using either mean residual test scores or mean actual test scores, and controlling for school-by-year fixed effects (as in Chetty et al., 2014a).[36] Estimates of b are all close to

[36]The fact that using test scores as a regressor instead of test score residuals yields similar results further confirms

Figure B3: Binned scatterplot: $\hat{\mu}_i^{CL}$ and $\hat{\mu}_i^{GL}$



Notes: The figure shows the relationship between $\hat{\mu}_i^{CL}$, estimate of teacher VA obtained using the procedure of Kane and Staiger (2008) and teacher-student links, and $\hat{\mu}_{GL}$, its analogous obtained discarding these links. Estimates are obtained using data from New York City students and teachers of math and ELA for the years 2007-2010.

1 both over the full sample period and in the years after Act 10. While slightly larger than Chetty et al. (2014a), who estimate it to be between 0.003 and 0.026, estimates of b are small and indistinguishable from zero, both over the full sample period and in the years after Act 10.

Non-Classical Measurement Error A possible concern with the GL version of VA is non-classical measurement error, which occurs when the precision of the estimates is related to characteristics of the teachers or the students. This issue could arise, for example, if teachers who switch across schools or grades (and, analogously, the grades and schools employing these teachers) are selected on the basis of observable and/or unobservable characteristics.

In Table B2 I use the GL and CL estimates of VA from the NYC data to investigate the extent of measurement error. Specifically, I correlate the difference between GL and CL (a proxy for measurement error) with a range of student and teacher observable characteristics. These estimates reveal no discernible relationship between the error and these characteristics. Importantly, the measurement error does not appear to be systematically different between teachers who switch across grades (i.e., those with "switcher" equal to 1) and teachers who do not switch. While only suggestive of the lack of non-classical measurement error, this evidence reassuringly shows no systematic patterns of correlations between VA and student and teacher observables.

that selection of students across teachers is unlikely to generate substantial bias in the estimates (Chetty et al., 2014a).

Table B1: Forecast bias in teacher VA

	Δ test scores	Δ test score residuals
	(1)	(2)
ΔVA_{gst}	0.978	1.055
	(0.290)	(0.377)
School-by-year FE	Yes	Yes
Observations	13684	13684
# districts	414	414
λ	0.022	-0.055
p-value λ=0	0.94	0.88

Notes: The dependent variable is the first difference in grade-school average test score residuals (from a regression of test scores on student characteristics, school, and grade fixed effects, column 1) or in average test scores at the grade, school, and year level (column 2). The variable ΔVA_{gst} is the first difference in average teacher VA in school s and grade g. VA is calculated using data from Wisconsin for the years 2007-2011. All regressions include school-by-year fixed effects, and observations are weighted by the number of students. Standard errors in parentheses are clustered at the district level.

Table B2: Correlations Between the Difference [GL-CL] and Student and Teacher Observables

	(1)
experience	-0.0002
	(0.0003)
switcher	0.0005
	(0.0022)
Black	-0.0019
	(0.0025)
Hispanic	0.0027
	(0.0028)
% low SES students	-0.0049
	(0.0030)
% Black students	0.0002
	(0.0046)
% Hispanic students	-0.0044
	(0.0051)
Observations	7032

Notes: OLS regression of the difference between GL and CL and a range of student and teacher characteristics, averaged at the teacher-year level. VA is calculated using data from NYC. Robust standard errors in parentheses.

Appendix C Solving the And Estimating the Model

The framework is a two-sided static choice model in which job vacancies and salaries are exogenously determined. Matching between teachers and districts happens in two steps. First, each district decides whether to make an offer to each teacher. Each teacher then reviews her offers and either chooses the one that maximizes her utility, or leaves the market.

Districts' Problem

District j's payoff from hiring teacher i, u_{ij}, is a linear function of teacher i's characteristics x_i, such as experience, education, and VA:

$$u_{ij} = \beta x_i + \varepsilon_{ij} \tag{24}$$

where ε_{ij} is a independent, normally distributed idiosyncratic component, the vector x_i contains teacher i's years experience, an indicator for having a postgraduate degree, and VA, and β is a vector of parameters.[37] I assume that districts' utility is non-decreasing in x_i, i.e., $\beta \geq 0$. This assumption will be crucial for the estimation of teachers' labor demand.

The total district payoff is the sum of teacher-specific payoffs across all hired teachers. Each district j decides whether to make an offer to teacher i; this instance is denoted by $o_{ij} = 1$. The district's strategy is therefore a vector $\mathbf{o}_j = [o_{1j}, o_{2j}, ..., o_{N_j}]$, where N is the number of teachers. Lastly, district j can spend up to B_j in salaries and can hire up to H_j teachers; these quantities are exogenously determined. District j's problem is as follows (I omit the subscript j for ease of notation):

$$\max_{\mathbf{o}} \sum_{i=1}^{N} h_i o_i u_i \tag{25}$$

$$\text{s.t.} \qquad \sum_{i=1}^{N} h_i o_i w_i \leq B, \sum_{i=1}^{N} h_i o_i \leq H, o_i \in \{0,1\} \; \forall i = 1,..,N \tag{26}$$

where w_i is the salary paid to teacher i, and h_i is the probability that teacher i accepts the district's offer, if one is made. In other words, each district maximizes the *expected* payoff from making a set $\mathbf{o}$ of offers, with respect to the probability of acceptance. Intuitively, districts incorporate the fact that an offer made to a teacher i is only accepted with probability h_i. Since offers are made simultaneously, districts choose the offer set that maximizes their expected payoff and, in expectation, allows them to spend at most B and hire at most H teachers. I construct each district's budget limit B by multiplying the previous year's total salary bill by the pre-Act 10 growth rate of total salaries. Similarly, I construct the capacity limit H by multiplying the district's enrollment in the previous year by the average, district-specific number of teachers per student in the years until 2011.

Solving the District's Problem If h_{ij} is known, each district's problem is analogous to a two-constraints version of the knapsack problem (Dantzig, 1957), and it can be solved using linear programming techniques. I use the algorithm proposed by Martello and Toth (2003), based on the continuous relaxation of the original problem. The solution proceeds in the following steps:

1. I write the continuous relaxation (CR) of the problem, i.e. I substitute the third constraint with the milder $0 \leq o_i \leq 1 \; \forall i$. This allows me to assign a Lagrange multiplier λ to the second constraint.

[37] This framework can be reconciled with one in which districts maximize a function of student achievement, which is in turn a function of teacher characteristics.

2. I re-write the CR problem as a function of the multiplier λ on the second constraint (CR(λ)):

$$\begin{aligned} &\max_{\{\mathbf{o}\}_{i\in N}} \sum_{i=1}^{N} h_i o_i (u_i - \lambda) + \lambda H \\ \text{s.t.} \quad &\sum_{i=1}^{N} h_i o_i w_i \leq B \\ &0 \leq o_i \leq 1 \; \forall i = 1,..,N \end{aligned}$$

For each value of λ, this continuous relaxation is a one-constraint version of the unbounded knapsack problem (Dantzig, 1957), which can be solved using linear programming techniques. As in all linear programming problems, existence of a solution follows from the feasibility of the problem, i.e. the existence of a set of offers that satisfies both constraints, which is easily verifiable in this case.

   (a) I define a teacher's *relative payoff* as the payoff the district obtains from hiring her (net of the shadow price of relaxing the capacity constraint) per dollar of salary: $(u_i - \lambda)/w_i$. Intuitively, the relative payoff measures the "efficiency" of the hire from the standpoint of the district.

   (b) I then sort teachers in descending order of relative payoff, so that $(u_i - \lambda)/w_i \geq (u_{i+1} - \lambda)/w_{i+1}$. This ranking incorporates the fact that the payoff from a hire contains both a monetary cost, captured by the salary that must be paid, and a utility cost, which stems from the the capacity constraint becoming tighter.

   (c) I define the "critical" teacher as the one indexed by $s(\lambda) = \min\{i : \sum_{j=1}^{i} w_j h_j > B$ or $h_i(u_i - \lambda) < 0\}$. In words, the critical teacher is the first teacher whose hire is unworthy from the point of view of the district, either because it leads to a violation of the budget constraint, or because the payoff from the hire is smaller than the utility cost from tightening the capacity constraint. The position of the critical teacher in the ranking separates teachers whose hire is worthy ($i < s(\lambda)$) from teachers whose hire is unworthy ($i > s(\lambda)$).

3. Solve the CR(λ) problem as in Dantzig (1957). The solution to this problem, o^{c^*}, is as follows:

$$o^{c^*}(\lambda) = \begin{cases} 1 & \text{if } i < s(\lambda) \\ \frac{c - \sum_{j=1}^{i-1} w_j}{w_i} & \text{if } i = s(\lambda) \text{ and } h_i(u_i - \lambda) \geq 0 \\ 0 \text{ if } i = s(\lambda) & \text{and } h_i(u_i - \lambda) < 0 \text{ or } i > s(\lambda) \end{cases} \tag{27}$$

where teachers are sorted so that $(u_i - \lambda)/w_i \geq (u_{i+1} - \lambda)/w_{i+1}$, and $s(\lambda)$ represents the "critical" teacher, i.e. $s(\lambda = \min\{i : \sum_{j=1}^{i} w_j h_j > B$ or $h_i(u_i - \lambda) \leq 0\})$.

4. For a given λ, define the solution to the discrete choice model as $o^*(\lambda) = \lfloor o^{c^*}(\lambda) \rfloor$.[38]

5. Select the optimal λ^* as follows:

   (a) Construct a set S of admissible levels of λ. As shown by Martello and Toth (2003), this includes: a) $\lambda = 0$; b) $\lambda = u_i \; \forall i$; c) $\lambda = (u_j w_i - u_i w_j)/(w_j - w_i) \; \forall i < j$ and such that $\lambda > 0$.

   (b) For each of these admissible levels, compute the value of the relaxed capacity constraint: $R(\lambda) = \sum_{i=1}^{s(\lambda)-1} h_i + o^{c^*}_{s(\lambda)}(\lambda) h_{s(\lambda)}$

[38]This solution method corresponds to the graphical solution to the knapsack problem provided by Dantzig (1957). All teachers are represented as points in a plane having utility net of λ on the vertical dimension and salary on the horizontal dimension. Each teacher has coordinates $(u_i - \lambda, w_i)$. The solution consists in rotating clockwise a ray with the origin as pivot point and the vertical axis as starting point, and in setting $o^*_i(\lambda) = 0$ for all teachers swept out by the ray, until the point in which the sum of their salaries exceeds the budget.

(c) Select the median value of the elements of S, called λ^M.

(d) If $R(\lambda) = H$, then $\lambda^* = \lambda^m$.

(e) If $R(\lambda) > H$, then remove λ^m from S, and reiterate from (c).

The solution to the problem is then given by $\mathbf{o}^*(\lambda^*)$. It should be noted that this procedure selects only one value of λ^*, and therefore yields a unique solution to the problem. In principle all λ satisfying $R(\lambda) = H$ are optimal, which would give rise to multiple optimal solutions to the problem. Since, as shown by Martello and Toth (2003), $R(\lambda)$ is a non-increasing function of λ, the only case in which this can happen is if the function $R(\lambda)$ is flat and equal to H over an interval $[\underline{\lambda}, \overline{\lambda}]$. In this case, all λ in this interval would give rise to optimal solutions. It should be noted, however, that these λ will all be relatively close to each other, and virtually yield the same solution to the problem.

Teacher's Problem

Teachers have preferences over job characteristics z_{ij}, which include salary, an indicator for the district being in the same commuting zone as where teacher i is an incumbent, an indicator for teacher i being an incumbent in district j (which captures the cost of moving across districts), the share of disadvantaged students, and indicators for urban and suburban districts. In each period they receive a set of offers O_i from school districts and choose the one that maximizes their utility. I define the utility of teacher i from working in district j as

$$v_{ij} = \alpha z_{ij} + \xi_{ij} \tag{28}$$

where α is a vector of utility parameters and ξ_{ij} is an idiosyncratic utility component, independent across districts and identically distributed with an Extreme Value Type 1 distribution. Each teacher has an outside option, with associated utility $v_{i0} = \alpha_0 + \xi_{i0}$, where ξ_{i0} is independent across teachers, orthogonal to ξ_{ij}, and identically distributed with an Extreme Value Type 1 distribution. The teacher's problem can be expressed as follows:

$$\max_{k \in O_i \cup \{0\}} v_{ik} \tag{29}$$

Salaries

I assume that salaries are not competitive, i.e. they do not adjust to equate demand and supply in equilibrium; they are instead exogenously determined and district-specific. The advantage of this assumption is that it makes the model more tractable and realistic.[39] The drawback is that it rules out the possibility that each district's salary structure is dependent on other endogenous variables of the model, for example the pre-Act 10 composition of the teaching workforce.

Estimating teachers' preferences requires observing the characteristics of all the job alternatives available to a teacher, including salaries. In the data, however, I only observe salaries when a match is realized. To construct salary offers for unrealized matches, I back out each district's post-Act 10 salary structure by estimating a district-specific wage function:

$$w_{ijt} = \gamma_{0j} + \gamma_j f(X_{it}) + \delta_j VA_{it} + \omega_{ijt} \tag{30}$$

where X_{it} is a full set of interactions between indicators for two-year seniority classes and highest education degree, and VA_{it} is time-varying VA of teacher i. I estimate the salary parameters γ_{0j}, γ_j, and δ_j in equation (30) separately for each district, using OLS and data on post-reform teacher-district matches.

[39] If salaries were competitive, one could simply use the hedonic approach of Antos and Rosen (1975) to estimate teachers' preferences. Teacher salaries, however, are typically rigid and unable to fully adjust for differences in either workers' characteristics or the non-pecuniary attributes of their jobs. Hedonic models are hence not appropriate for this setting.

Equilibrium

The equilibrium of the model can be defined as a set of offers $\mathbf{o}^* = [\mathbf{o}_1^*, \mathbf{o}_2^*, ..., \mathbf{o}_J^*]$, where J is the number of districts, such that all agents in the market make the choice that is optimal for them given their beliefs on all other agents' optimal choices. The equilibrium can be formally defined as follows:

$$\begin{aligned}
\forall j, \mathbf{o}_j^* \quad &\in \quad \arg\max_{\mathbf{p}_j} \sum_{i=1}^{N} h_{ij} p_{ij} u_{ij} \text{ s.t. constraints} \\
h_{ij} \quad &= \quad \begin{cases} P(v_{ij} \geq \max_{k \in O_i \cup \{0\}} \{\{v_{ik}\}_{k \neq j}, v_{i0}\}) & \text{if } j \in O_i \\ 0 & \text{otherwise.} \end{cases}
\end{aligned}$$

Estimation Procedure

I estimate α, α_0, β, and γ in two steps, using data from 2014 and therefore exploiting the cross-district variation in pay schemes. I start by recognizing that, if each teacher's offer set O_i were known in advance, I could simply estimate α via conditional logit. Even if O_i is not observed, however, I can construct a subset $\tilde{O}_i \subseteq O_i$ exploiting the teacher-district matches observed in the data and the monotonicity of districts' preferences: for any teacher k matched with district j, all teachers with $x_i \geq x_k$ and $w_{ij} \leq w_{ik}$, and who are not employed in j, must have received an offer from j and declined it. Due to the irrelevance of independent alternatives axiom (Hausman and McFadden, 1984), I can then consistently estimate teachers' labor demand (i.e., the parameters α and α_0) using $\tilde{O}_i$ as a choice set instead of O_{it}.

Having estimated α and α_0, I then estimate β (districts' payoff) and σ^2 (variance of the district's shock) using maximum likelihood and data from 2014, with the procedure outlined below:

The estimation procedure develops in the following steps (t denotes year).

1. For each district, teacher, and year I compute the district's payoff as $u_{ijt} = \beta x_{it} + \sigma \varepsilon_{ijt}^z$, where ε_{ijt}^z is an independent and identically distributed Normal(0,1).

2. I assume that teachers have initial beliefs about their set of offers O_i^I, which coincides with the set of all district in teacher i's CESA.

3. I assume districts have full knowledge about teachers' preferences α, α_0, and beliefs O_i^I. Given preferences and beliefs, I solve each district's problem and obtain the optimal set of offers, o_{jt}^*, and the subsequent set of offers received by each teacher, O_{it}, which will be a function of β and σ.

4. I write the log-likelihood function as

$$l(\beta, \sigma^2 | \mathbf{z}, \mathbf{x}) = \sum_{i=1}^{N} \log h_{ij(it)t} = \sum_{i=1}^{N} \log \left[\frac{\exp\{\alpha z_{ijt} - \alpha_0\}}{1 + \sum_{k \in O_i(\beta,\sigma)} \exp\{\alpha z_{ijt} - \alpha_0\}} \right] \tag{31}$$

   where $j(it)$ denotes the district to which teacher i is matched in year t.

The log-likelihood is maximized using a Nelder-Mead simplex algorithm as described in Lagarias et al. (1998). I compute standard errors as the square root of the diagonal elements of the inverse of the information matrix, and I calculate the information matrix using numerical derivatives.[40]

For estimation, divide Wisconsin into 12 separate geographic labor markets, corresponding to the 12 Cooperative Educational Service Agencies (CESAs), and I assume that teachers can only move within CESAs and that districts can only make offers to teachers already working in their CESA.[41] The final sample contains 12,368 teachers working in 411 districts.

[40]Optimization is implemented using the package *fminsearch* in Matlab. In line with the assumptions for the estimation of α, the components of β are constrained to be non-negative.

[41]In 2014, about 60 percent of teacher movements happened within a CESA.

Identification

The model allows for a transparent identification of the parameters of teachers' utility. Identification relies on cross-district heterogeneity in district characteristics (such as location and student composition), and on the variation in salaries introduced by Act 10. Movements of teachers across districts and exits help identify the utility parameters α and α_0.[42]

Identification of the parameters of districts' payoff function is more subtle. The parameters β and σ are identified out of cross-district variation in optimal offer strategies. While I assume that districts have identical preferences, their optimal strategies might differ due to differences in their budget and capacity constraints. These differences, in turn, arise from the attrition of different types of teachers over time. To see this, consider the following example. Suppose that districts *A* and *B* are identical in terms of student and teacher composition, size, salary structure, and *ex-ante* budget. At a certain point in time they both lose one teacher and thus have one vacancy to fill. If district *A*'s exiting teacher has 30 years of experience (and was therefore being paid a high salary) but district *B*'s teacher only has 1 (and was being paid a lower salary), then district A has more money "freed up" (and therefore a larger budget) than district *B*. To the extent that the characteristics of leavers are random (which the reduced-form results show to be true before Act 10), the hiring choices of district *A*, compared with *B*, reveal how teacher attributes are valued and identify β and σ.[43]

Model Fit

To assess the in-sample fit of the model I compare a set of moments obtained simulating the model on data from 2014, used in estimation, with the same set of moments taken from the data. I use the share of teachers moving to a different district and the share of teachers exiting public schools, for all teachers and separately for teachers with positive and negative value-added. Columns 1 and 2 of Table C1 show the results of this exercise. The model predics movements fairly well but tends to underestimate exit. To assess out-of-sample fit I simulate the same moments using data from 2010 (not used in estimation), and compare them with moments from the data (Todd and Wolpin, 2006). Despite underpredicting exit overall, the model predicts moving rates fairly well, and it also predicts a higher moving rate in 2014 compared to 2010, a pattern observed in the data.

Parameter Estimates

Estimates of the parameters α are shown in Table C2. Teachers receive positive utility from salary and negative utility from moving and from changing commuting zone. Teachers also prefer urban districts to suburban and rural ones (Table C2, column 1). To interpret the magnitudes of these coefficients, one can compare the elasticities between the probability of matching with a district and various district characteristics, shown in column 2 of Table C2.[44] A 1 percent higher salary (equivalent to $590 at the mean)

[42]For example, suppose teacher *x* is an incumbent in district *A* where she earns a wage w_A. She receives an offer from district *B*, located 5 miles from *A* and offering a wage w_B, with $w_B > w_A$, and an offer from district *C*, located 7 miles from *A* and offering a wage w_C, with $w_C > w_B$. The choice of teacher *x* identifies the parameters her utility. For example, if she chooses *C*, this implies that the desire for higher salaries offsets the drawback of a longer commute, and translates into a higher utility parameter on salaries and a lower parameter on distance. Similarly, teachers' exit will identify the value of the outside option.

[43]Another useful example is the following. Suppose that, given teachers' preferences and districts' budgets, for given values of β and σ districts' optimal strategies are such that one district ends up hiring too many teachers and the other ends up hiring too few with respect to their capacity. To bring the market into equilibrium, β and σ need to adjust in order for each district to maximize its payoff and satisfy both constraints. In a specular way, if the optimal strategies given teachers' preferences, districts' capacity, and given parameter values are such that one or both districts violate the budget constraint, β and σ need to adjust to bring the market back into equilibrium.

[44]Defining p_{ij} as the probability that teacher i matches with district j, the elasticity of p_{ij} to a job characteristic z_{ij} implied by the logit assumption on the error term of teachers' utility is $\beta_z(1 - p_{ij})z_{ij}$. The elasticities shown in the table are calculated at the mean of p_{ij} and z_{ij}.

Table C1: Model fit

moment		2014 (estimation year) model (1)	data (2)	2010 (testing year) model (3)	data (4)
p(move)		0.1807	0.0717	0.0385	0.0380
	VA>0	0.1797	0.0718	0.0413	0.0330
	VA<0	0.1819	0.0716	0.0356	0.0435
p(exit)		0.0079	0.0551	0.0103	0.0433
	VA>0	0.0077	0.0534	0.0099	0.0447
	VA<0	0.0081	0.0569	0.0107	0.0418

Notes: Estimation year refers to 2014; testing year refers to 2010. Model estimates are obtained from the model and using the parameter estimates in Table C2.

is associated with a 0.06 percent increase in the match probability (Table C2, columns 1-2). Moving costs (which correspond to the opposite of the estimate of the incumbent dummy) are equal to approximately 14 percent of salary (0.8385/6.1210), or about $8,260. The cost of changing commuting zone is instead equal to 11 percent of salary (0.6489/6.1210), or $6,490.

Estimates of the parameters of districts' payoffs imply that districts prefer higher VA teachers and do not value experience or academic credentials (Table C2, column 3).

Table C2: Estimates of Model Parameters

Teacher: parameter	interpretation	estimate (1)	elasticity (2)	District: parameter	interpretation	estimate (3)
α	salary ($1,000)	0.1235	6.1210	β	VA	2.0592
		(0.0034)				(0.0124)
	same CZ	1.48045	0.6489		seniority	1.1719e-06
		(0.0783)				(0.1532)
	incumbent	6.3065	0.8385		master's degree	3.4281e-07
		(0.0853)				(0.1030)
	% disadvantaged	1.0101	32.24	σ	s.d. shock	0.0185
		(0.1761)				(0.0015)
	urban	0.1637	0.1268			
		(0.0938)				
	suburban	-0.1433	-0.1295			
		(0.0701)				
α_0	outside option	9.468				
		(0.1613)				

Notes: Estimates of the parameters of the structural model. Parameters are estimated by maximum likelihood. Defining p_{ij} as the probability that teacher i moves to district j, the elasticity of p_{ij} to a continuous job characteristic z_{ij} (implied by the logit assumption on the error term of teachers' utility) is $\alpha_z(1-p_{ij})z_{ij}$, where α_z is the parameter estimate on z_{ij}. The elasticities of *same CZ* , *incumbent*, *urban*, and *suburban* are defined as $(1-p_{ij})(1-\exp(-\alpha_z))$. Elasticities are evaluated at the median of each variable, equal to $59,000 for salary and 38 percent for the share of disadvantaged students. Standard errors in parentheses are calculated as the square root of the inverse of the information matrix using numerical derivatives.