Appendix I: Summary Statistics

Appendix A1 - Summary Statistics for Math

VARIABLES	N	Mean	SD
SEDA – School District Variables:			
Urban	14,060	0.101	0.302
Suburban	14,060	0.110	0.313
Town	14,060	0.236	0.425
Rural	14,060	0.553	0.497
% Indian / Native American	14,060	0.0223	0.113
% Asian	14,060	0.0124	0.0229
% Hispanic	14,060	0.295	0.274
% Black	14,060	0.143	0.191
% White	14,060	0.527	0.274
% English Language Learner	14,060	0.0699	0.0849
% Special Education	14,060	0.109	0.0320
Total Enrollment	14,060	3,324	7,430
Total Teachers	14,060	452.4	983.0
Total Instructional Aides	14,060	101.2	195.4
Per Pupil Revenue ($)	13,840	10,723	2,357
SEDA – Community Variables			
Poverty Rate (Ages 5-17)	13,470	0.202	0.113
% household receiving snap benefits	13,470	0.204	0.115
% of adults with BA and above	14,060	0.188	0.108
% household with female head	13,470	0.265	0.107
Unemployment Rate	14,100	0.0432	0.0218
Median Income ($)	13,470	51,626	19,059
Standardized SES composite index	13,470	-0.323	0.925
SEDA – Average Scores			
Math			
All	15,060	249.4	20.87
White	12,290	257.0	20.78
Black	6,670	238.6	18.86
Hispanic	8,480	245.4	19.61
Asian	1,790	274.2	26.24
SASS – Unionization Variables			
Meet and Confer	4,620	0.152	0.359
Union Density	4,310	0.525	0.296

Note: N is rounded to the nearest ten.
Source: 2008-2009 and 2012-2013 *Stanford Education Data Archive* (SEDA, v. 2.1) and 2007-2008 and 2011-2012 *School and Staffing Survey* (SASS). N's for SEDA variables reflect 2 years and 6 grades.

Appendix A2 - Summary Statistics for English

VARIABLES	N	Mean	SD
SEDA – School District Variables:			
Urban	16,780	0.102	0.302
Suburban	16,780	0.115	0.319
Town	16,780	0.233	0.422
Rural	16,780	0.551	0.497
% Indian / Native American	16,780	0.019	0.103
% Asian	16,780	0.012	0.023
% Hispanic	16,780	0.291	0.275
% Black	16,780	0.143	0.190
% White	16,780	0.534	0.275
% English Language Learner	16,780	0.069	0.084
% Special Education	16,780	0.109	0.033
Total Enrollment	16,780	3,316	7,482
Total Teachers	16,780	453.3	991.0
Total Instructional Aides	16,780	101.0	199.5
Per Pupil Revenue ($)	16,510	10,814	2,340
SEDA – Community Variables			
Poverty Rate (Ages 5-17)	16,060	0.197	0.112
% household receiving snap benefits	16,060	0.200	0.114
% of adults with BA and above	16,780	0.191	0.110
% household with female head	16,060	0.264	0.106
Unemployment Rate	16,780	0.042	0.021
Median Income ($)	16,060	52,346	19,403
Standardized SES composite index	16,060	-0.283	0.921
SEDA – Average Scores			
All	16,800	230.3	22.63
White	13,730	240.1	21.08
Black	6,840	219.2	21.32
Hispanic	9,430	221.8	22.42
Asian	1,900	249.8	24.53
SASS – Unionization Variables			
Meet and Confer	4,620	0.152	0.359
Union Density	5,220	0.527	0.291

Note: N is rounded to the nearest ten.
Source: 2008-2009 and 2012-2013 *Stanford Education Data Archive* (SEDA, v. 2.1) and 2007-2008 and 2011-2012 *School and Staffing Survey* (SASS). N's for SEDA variables reflect 2 years and 6 grades.

Appendix II: Multilevel (Hierarchical) Mixed-Effect Linear Model

To adjust for unobservable factors shared by districts in the same state, I use multi-level mixed-effect models that have both fixed effects and random effects. The mixed-effect model has the following form in matrix notation:

$$\mathbf{y} = \mathbf{X}\beta + \mathbf{Z}u + \varepsilon, \tag{B1}$$

where **y** is a n x 1 vector of outcomes, **X** is the n x p covariate matrix for the fixed effects β, the regression coefficient to be estimated. **Z** is the n x q covariate matrix for the random effects u. ε is the error terms of n x 1 vector, and is assumed to be $N\sim(0, \sigma_\varepsilon^2 R)$, where R is a n x n covariance matrix. **X**β is the linear predictor of the fixed portion in equation (B1). For the random portion of equation (B1), **Z**u + ε, u is assumed to have variance-covariance matrix K orthogonal to ε. The total variance matrix is:

$$Var\begin{pmatrix} u \\ \varepsilon \end{pmatrix} = \begin{pmatrix} K & 0 \\ 0 & \sigma_\varepsilon^2 R \end{pmatrix} \tag{B2}$$

The random effects u are not directly estimated but instead are characterized by the variance components of K, and they are estimated along with the overall residual variance (σ_ε^2) and the residual-variance parameters.

When districts are clustered within states, we can rewrite (B1) as:

$$y_j = X_j\beta + Z_j u_j + \varepsilon_j, \tag{B3}$$

where j = 1, 2, ..., M indicates clusters (states) and the j^{th} cluster has n_j observations. These clusters can be considered as M independent groups, so the random effect u_j can be seen as M realizations of a q x 1 vector that is normally distributed with mean zero and $Var(u_j) = \Sigma$, a q x q variance matrix. In a two-level model, the individuals comprise the first level, where the observation y_{ij} is for individual i within cluster j, and the clusters comprise the second level of the model.

In a random intercept model, the random effect only works through the intercept

and not through the coefficient, so there is only one random effect at state level. The only possible covariance structure is the identity matrix (I) so that $\Sigma = \sigma_u^2 I$. $\hat{\sigma}_\varepsilon^2$ is called within-state estimated variance component and $\hat{\sigma}_u^2$ is called between-state estimated variance component. I use these values to estimate intra-class correlation (ρ), a summary of the proportion of the outcome variability that is attributable to differences across states. The ρ is calculated as:

$$\hat{\rho} = \frac{\hat{\sigma}_u^2}{\hat{\sigma}_u^2 + \hat{\sigma}_\varepsilon^2}, \tag{B4}$$

which ranges between 0 and 1. When the intra-class correlation is large (close to 1), the within-state variation among districts is so small that districts in the same state behave almost identically. When the intra-class correlation is small (close to 0), then the districts in the same state are almost independent from each other, and simple OLS regression could suffice for the analysis. In our models, the estimated intra-class correlation (ρ) is sizable, ranging between 0.3 and 0.4 depending on subgroups. This implies that districts within the same state do not behave independently of one another, and that there are unobservable omitted factors in the error term. Thus, the estimates from the standard OLS regressions will be biased, and the multilevel models are preferred.

In a standard modeling with weights, the sampling weight for district i in state j in the two-level sample is $wij = 1/\pi_{ij}$, where π_{ij} is the probability that district i in state j is selected. However, multilevel modeling of survey data is different from standard modeling in that weighted sampling occurs at multiple levels in the model, resulting in multiple sampling weights. Therefore, it is not enough to use the single sampling weight (w_{ij}) because weights enter into the log likelihood at both the state level and the district level. we need w_j, the inverse of the probability that state j is selected in the first stage, and $w_{i|j}$, the inverse of the probability that district i from state j is selected at the second stage, conditional on state j already being selected. Thus, we specify two types of weights, district's final weight and state's final weight, in both data levels. Because w_{ij} is unique to state j, the state-to-state magnitudes of these weights need to be normalized so that they are constant across groups. I rescale w_{ij} to sum to the cluster size n_j.

We also try other rescaling methods, but the estimates are robust to these rescaling methods. As the statistical strategy for estimating variance components and fitting the multilevel model, I use maximum likelihood estimation (MLE).

In our multilevel dataset, districts comprise the first level and states the second level of the model. The equation for the multilevel model to measure the effect of teachers unions on student test score is:

$$W_{ij} = \beta_0 + \beta_1 Union_{ij} + \beta_2 X_{ij} + (u_{0j} + u_{1j}\ Unionr_{ij}) + \varepsilon_{ij}$$
$$= (\beta_0 + u_{0j}) + (\beta_1 + u_{1j}) Union_{ij} + \beta_2 X_{ij} + \varepsilon_{ij}, \quad \text{(B5)}$$

where $Union_{ij}$ represents if district i at state j is a union member, and X is the vector of district characteristics. There are two levels of error terms for each district: one is at the individual district level (ε_{ij}), and the other at the state level (u_{0j}). The first error term ε_{ij} is unique to district i in state j and assumed to be i.i.d. for all districts with $\varepsilon_{ij} \sim N(0, \sigma_\varepsilon^2)$. The other error term u_j is unique to state j, and its value is identical for all districts in state j to represent the common experience that all districts in that state share. u_j is also assumed to be i.i.d. across states with $u_j \sim N(0, \sigma_u^2)$. Since all districts in the same state have the same value of u_j, the total error terms ($\varepsilon_{ij} + u_j$) in the model are associated across districts within the same state.

The model (B5) allows random effects through both random slope (u_{1j}) and random intercepts (u_{0j}). The random coefficient assumes that the effect of districts unions on district salary may vary from one state to the other. Since fixed intercept models are nested in random intercept models, we perform a likelihood ratio test to check if adding random intercept of each state improves the fit of the model. The model with random intercepts was favored over the model with fixed intercepts. Thus, we decide to add a state-specific intercept into the model.

After this, we perform another likelihood ratio test to see if adding random slope to the random intercept model can make a significant improvement in the fit of the model, as the random intercept models are nested in random slope combined with the random intercept models. The model that has only random intercept is favored to the model that has both random slope and random intercept. This implies that random slope is unnecessary, and we can treat the effect of teachers unions the same for all five states. Thus, model (B5) becomes simpler as there is now a single coefficient for unionism:

$$W_{ij} = (\beta_0 + u_j) + \beta_1 Member_{ij} + \beta_2 X_{ij} + \varepsilon_{ij}. \quad \text{(B6)}$$

The model now has both fixed effects and random effects component, called mixed-effect. The model estimates a state-specific intercept for each state but a single coefficient for each independent variable. The fixed portion of the model, $\beta_0 + \beta_1 Member_{ij} + \beta_2 X_{ij}$, produces a single regression line representing the population average whereas the random effect, u_j, is a shifting factor of this regression line up or down, depending on states.

Appendix III: Mean Comparison between MC and non-MC Districts

Table B1: District Characteristics by MC Status

	MC Districts	Non-MC Districts
Union density (%)	51.9 (27.6)	53.1 (30.1)
Test Scores		
Math	247.9 (21.6)	250.1 (19.9)
English	228.9 (23.6)	229.4 (22.6)
Districts Characteristics		
Student composition (%)		
White	42.5 (28.1)	51.2 (27.1)
Black	14.1 (18.5)	19.0 (22.7)
Hispanic	32.7 (30.4)	25.5 (25.7)
Asian	2.6 (3.3)	1.8 (2.9)
Native American	7.8 (21.2)	2.3 (11.9)
% English language learners	9.9 (11.5)	7.2 (8.7)
% Special education	12.1 (2.4)	11.0 (3.2)
Total enrollment (grade 3-8)	10,531.8 (15459.8)	6105.9 (9206.4)
Total teachers	1,246.7 (2125.4)	849.3 (1,229.7)
Total instructional aides	293.0 (435.3)	182.3 (239.4)
Revenue per pupil ($)	10,084.8 (2,667.7)	10,494. (1,980.8)
Neighborhood Characteristics		
Location (%)		
Urban	38.3 (48.5)	17.4 (37.4)
Suburban	22.7 (41.7)	19.2 (39.6)
Town	17.7 (38.5)	18.5 (39.0)
Rural	21.2 (41.2)	44.8 (49.7)
% Female-headed household	28.7 (9.9)	27.7 (10.6)
Poverty rate (age 5-17) (%)	20.2 (11.5)	20.3 (10.4)
% household receiving SNAP benefits	19.8 (11.8)	20.1 (11.2)
Unemployment rate (%)	4.8 (2.3)	4.6 (2.0)
Median household income ($)	54,718.6 (23,544.8)	52,399.6 (18,829.0)
% adults with BA and above	24.9 (15.1)	21.1 (11.6)
Observations (N)	860	5,440

Note: Standard deviations are reported in parentheses. N is rounded to the nearest ten.
Source: Education Data Archive (SEDA, v. 2.1) combined with 2007-2008 and 2011-2012 School and Staffing Survey (SASS).

Table B2: Teacher Characteristics by MC Status of Districts

	MC Districts	Non-MC Districts	Difference (SE)
Experience	12.9	12.1	0.80***(0.226)
MA and above (%)	50	37.7	12.3***(1.135)
Regular certification (%)	90.3	87.7	2.60***(0.745)
Alternative certification (%)	15.1	21.8	-6.7***(0.925)
Teacher voluntary quit (%)	2.1	3	-0.90*(0.481)
Charter school teachers (%)	0.5	9.4	8.9***(0.623)
Base salary ($)	43,480	43,820	340 (245)
Number of contract days	190.4	194.3	-3.79***(0.79)
Teaching hours	29.1	29.8	-0.58***(0.15)

Note: Standard errors are reported in parentheses. *** p<0.01, ** p<0.05, * p<0.1.
Source: School and Staffing Survey (SASS), pooled across 2003-2004, 2007-2008, and 2011-2012 waves.

Appendix IV: Sensitivity Test

Table C1: Results from Multilevel Linear Model for Union Density Effects, by Student Race/Ethnicity and by District SES status

Eight States without Collective Bargaining (AL, AZ, GA, MS, NC, SC, TX, and VA)

	Math	English
Panel A: By student Race/Ethnicity		
All students	0.277	0.071
	(0.272)	(0.151)
White students	-0.830	-0.818
	(0.710)	(0.762)
Black students	0.123	0.335
	(0.271)	(0.289)
Hispanic students	1.315***	1.701***
	(0.305)	(0.364)
Asian students	2.485	2.876
	(2.004)	(2.910)
Panel B: By District's SES Status		
High SES District	0.435	0.077
	(0.282)	(0.640)
Mid SES District	0.142	0.314*
	(0.405)	(0.171)
Low SES District	0.414	-0.320
	(0.383)	(0.226)

Note: Standard errors are clustered within states (presented in parentheses). *** p<0.01, ** p<0.05, * p<0.1. N is rounded to the nearest ten. The covariates included in the models are student race and ethnicity composition in %, % English language learners, % Special education, total enrollment (grade 3-8), total teachers, total instructional aides, revenue per pupil, % Female-headed household, poverty rate (age 5-17), % household receiving SNAP benefits, unemployment rate, median household income, % adults with BA and above, city/urban locale, suburban locale, town locale, student grades 4-8, and 2013 year dummy.
Source: Education Data Archive (SEDA, v. 2.1) combined with 2007-2008 and 2011-2012 School and Staffing Survey (SASS).

Table C2: Results from Multilevel Linear Model for MC effects, by Student Race/Ethnicity and by District SES Status

Eight States without Collective Bargaining (AL, AZ, GA, MS, NC, SC, TX, and VA)

	Math	English
Panel A: By race ethnicity		
All	1.049**	1.012*
	(0.490)	(0.600)
white	-0.052	0.610*
	(0.500)	(0.340)
black	0.451	0.853*
	(0.652)	(0.454)
Hispanic	1.484**	1.050**
	(0.811)	(0.491)
Asian	-0.410	0.780
	(1.205)	(1.565)
Panel B: By SES status		
High SES	-0.286	1.984***
	(0.902)	(0.366)
Mid SES	1.261**	1.103**
	(0.531)	(0.559)
Low SES	0.964	-0.140
	(1.259)	(0.586)

Note: Standard errors are reported in parentheses. *** p<0.01, ** p<0.05, * p<0.1. N is rounded to the nearest ten. The covariates included in the models are student race and ethnicity composition in %, % English language learners, % Special education, total enrollment (grade 3-8), total teachers, total instructional aides, revenue per pupil, % Female-headed household, poverty rate (age 5-17), % household receiving SNAP benefits, unemployment rate, median household income, % adults with BA and above, city/urban locale, suburban locale, town locale, student grades 4-8, and 2013 year dummy.

Source: Education Data Archive (SEDA, v. 2.1) combined with 2007-2008 and 2011-2012 School and Staffing Survey (SASS).