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Who Benefits Most From Teacher Support? Quantile Regression Evidence on Instructional Quality and Mathematics Achievement in Uzbekistan

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Research Article

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Abstract

Uzbekistan's first participation in PISA 2022 revealed that 81 percent of fifteen-year-old students scored below the minimum mathematics proficiency threshold, one of the largest concentrations of low performers among all participating countries. Understanding what drives this outcome matters, but conventional multilevel analyses estimate average associations between school climate and student achievement and cannot reveal whether the same interventions would generate equal returns for students at different points of the performance distribution. In a system where four in five students fall below minimum proficiency, that question has direct implications for how reform resources should be targeted.

This study applies simultaneous quantile regression to the PISA 2022 Uzbekistan dataset (n = 4,653 students, 190 schools; full sample: 7,293 students, 202 schools) at five quantiles (τ = 0.10, 0.25, 0.50, 0.75 and 0.90) to examine whether associations between teacher support, sense of belonging, and disciplinary climate differ across the mathematics score distribution. To our knowledge this is the first application of quantile regression to PISA data in Central Asia.

The results show a clear distributional pattern. Teacher support and school belonging have their strongest positive associations with performance among the weakest students at the 10th percentile, teacher support carries a coefficient of 5.97 score points, declining to 2.06 at the 90th percentile where it is no longer statistically significant. Socioeconomic status shows the opposite pattern, with its gradient steepening from Q10 (β = 4.76) to Q90 (β = 11.02). Inadequately qualified teaching staff is negatively and significantly associated with performance at all five quantiles (range: -7.62 to -13.96), identifying teacher qualification deficits as a system-wide drag rather than a problem confined to any particular segment of the distribution.

Taken together these findings establish that school climate improvements are equity-enhancing interventions in Uzbekistan, they generate their largest returns precisely among students furthest below the proficiency threshold. This distributional evidence provides a targeting rationale for instructional quality policy that average-level estimates cannot estimate.

1. Introduction

Mathematics proficiency at age fifteen is among the strongest predictors of individual educational trajectories, labor market participation, and lifetime earnings (Hanushek & Woessmann, 2023). For countries at the lower end of the international PISA distribution, the challenge is not only one of raising average performance but of determining where the returns to educational interventions are largest, which students benefit most, and from which interventions. Uzbekistan's PISA 2022 results, a mean mathematics score of 364 points, 81 percent of students below Level 2, and ranking of 71st out of 80 participating nations (OECD, 2023a), present precisely this challenge. With the government committed to ranking among how to direct reform effort toward the students and schools where it generates the most gain is both urgent and amenable to empirical analysis.

Most research on the determinants of student learning uses regression methods that estimate average associations across the full sample. Ordinary least squares and hierarchical linear modelling both produce single coefficient estimates that describe the average relationship between a predictor and the outcome, treating this relationship as constant across the performance distribution. This assumption is rarely tested and is unlikely to hold in practice. A school climate intervention that raises average scores by five points may generate a ten-point gain among the weakest students and a two-point gain among the strongest or the reverse. Knowing this pattern holds has direct consequences for how scarce reform resources should be allocated, particularly in a system where four in five students fall below the minimum proficiency threshold and where raising the floor matters more than raising the ceiling.

Quantile regression, established by Koenker and Bassett (1978), addresses this limitation by estimating separate coefficients at specified points of the outcome distribution rather than at the mean. Applied to educational data, it reveals whether instructional quality variables matter more for low-performing students than for high-performing ones, and whether socioeconomic gradients wider or narrow across distribution, distinctions that standard regression methods cannot capture but that are directly relevant to equity-targeted policy design. Despite its suitability for this kind of analysis, quantile regression has rarely been applied to PISA data from middle-income and transitional economy education systems, and it has not previously been used with Uzbekistan's PISA data.

This study applies simultaneous quantile regression to the PISA 2022 Uzbekistan dataset to examine the distributional effects of teacher support, sense of belonging, disciplinary climate, and socioeconomic status on mathematics performance. Three research questions guide the analysis: whether associations between instructional quality variables and mathematics performance vary across the performance distribution; whether the socioeconomic gradient is steeper at the top or the bottom of the distribution; and what the equity implications of these distributional patterns are for the design of school climate interventions in Uzbekistan.

The study makes two contributions. First, it provides the first distributional analysis of instructional quality effects in central Asia, producing quantile-specific evidence that average-level analyses of the same dataset cannot reveal. Second, it demonstrates that 81 percent of Uzbekistan's students below the minimum proficiency threshold, the population most directly targeted by the government's 2030 reform agenda are precisely the students among whom instructional quality variables have their largest associations with performance, providing a clear empirical rationale for equity-targeted school climate investment.

2. Secondary education in Uzbekistan: context and reform agenda

Secondary education in Uzbekistan is compulsory and universal, including students aged 7–15, followed by upper secondary education for students aged 16–18 in academic and vocational tracks. As of the 2023–2024 academic year, there are 10,522 general secondary schools serving about 6.5 million enrolled students – a scale that places Uzbekistan among the fastest-growing education systems in Central Asia by enrollment.

Thus, three structural conditions define the context within which this study's findings should be interpreted.

The first is a persistent capacity gap. Student enrolment grew by approximately 40 percent between 2016/2017 and 2024/2025 – from 4,825 thousand to 6,776 thousand students – driven by one of the highest birth rates in Central Asia and a young population adding students faster than schools can be built. School numbers grew by only 12.6 percent over the same period, from approximately 9,719 to 10,943 units. The consequences are structural: schools have a combined capacity for approximately 5.2 million students against an enrolment of 6.5 million, leaving 73.1 percent school operating more than one shift per day (National Statistics Committee, 2024). Approximately 33 percent of all students attend a second or third shift. This multi-shift structure directly constrains instructional time per student and amplifies teacher workload, representing a system-level condition that partially manifests in the school-level variables included in the econometric models. Multi-shift schools, therefore, cannot offer all students full access to facilities such as laboratories, libraries, or computer rooms. The draft Uzbekistan – 2030 Strategy originally set a target of creating 500,000new student places annually to address the shortfall, but this target was removed from the approved version, confirming that government acknowledged the gap while declining to commit to closing it within the reform cycle (Djalilov, 2024).

The second structural condition is a teacher qualification deficit of exceptional severity. The teaching workforce expanded rapidly from 390,600 teachers in 2016/2017 to 564,900 by 2024/2025, a 45% increase, yet the qualifications profile of this enlarged workforce has not improved proportionally. According to the PISA 2022 school questionnaire, only 24.6% of teachers in Uzbekistan were fully certified, placing the country 74th out of 75 participating nations (OECD, 2024). Of the total teaching workforce, 52.9% work in rural schools, which absorb a disproportionate share of newly qualified and unqualified entrants to the profession while experienced and certified teachers concentrate in Tashkent and regional capitals (National Statistics Committee, 2021; Khakimov, 2021). The introduction of a 70 percent salary supplement for certified teachers under Presidential Decree No. DP-79 (2023) represents the government's primary policy response to this deficit, but whether the incentive is sufficient to close a qualification gap of this magnitude is precisely what the empirical evidence of this study bears on.

The third structural condition is a persistent gap between investment and outcomes. Education budget allocations rose sixfold in nominal terms from about 7 trillion soum in 2017 to 59.5 trillion soum in 2025, representing 3.2% of GDP and 17.3% of total state budget expenditure placing Uzbekistan among the highest education spenders as a share of GDP in Central Asia (Government of the Republic of Uzbekistan, 2024; World Bank, 2025). Yet as Table 1 shows, neither the multi-shift rate nor the certified teacher rate has improved substantially over the decade. Education expenditure reached 5.47% of GDP in 2023 above the regional average, yet 73% of schools still operated multiple shifts as of 2024/2025 (World Bank, 2025; National Statistics Committee, 2026). This investment-outcomes gap is the empirical puzzle that motivates the analytical approach of this study: if increased resources have not closed structural quality gaps, identifying which school-level conditions actually predict student performance is a prerequisite for directing reform effort more effectively.

Table 1 summarizes the five key trends across the 2016–2026 period that are directly relevant to the analytical framework of this study.

Table 1
Key Trends in Secondary Education in Uzbekistan, 2016–2026

Indicator	2016/ 2017	2018/ 2019	2020/ 2021	2021/ 2022	2023/ 2024	2024/ 2025
Number of general secondary schools (units)	~ 9,719	~ 10,013	10,181	10,289	10,522	10,943
Student enrolment (thousand people)	~ 4,825	~ 5,831	6,287.9	6,304.6	6,645.1	6,776.3
Number of teachers, excl. part-time (thousand)	~ 390.6	~ 443.5	507.7	510.0	547.7	564.9
Share of multi-shift schools (%)	n/a	n/a	75.5%	~ 70%	~ 73%	73.1%
Education budget allocation (trillion soum, nominal)	~ 7	~ 12	~ 18	~ 28	46	59.5
Share of fully certified teachers, % of total (PISA measure)	n/a	n/a	n/a	~ 25%	24.6%	n/a

Compiled by the author based on the National Statistics Committee of the Republic of Uzbekistan. (2026); Government of the Republic of Uzbekistan. (2024), Kun.uz. (2024, October 31), OECD. (2024).

Note

Figures marked (~) are estimated from official statistical releases using reported percentage changes relative to confirmed base years. n/a = data not available for that year. Budget allocations are nominal figures. Multi-shift school percentages are calculated from available capacity and enrolment data reported by Stat.uz.

Three patterns stand out from Table 1. Enrolment grew by 40% while school numbers grew by only 12.6% directly explaining the persistence of multi-shift operation despite sustained capital investment. The teaching workforce expanded by 45% while certified teacher rate remained at 24.6% confirming that numerical growth has not produced qualitative improvement. Education budget allocations increased sixfold while structural capacity and qualifications gap narrowed only marginally establishing that the binding constraint on education quality in Uzbekistan is not the volume of investment but its direction.

Two additional structural conditions are relevant to the analysis but cannot be captured through the PISA 2022 school questionnaire, and are therefore acknowledged here as limitations rather than modelled variables. First, Uzbekistan has undertaken multiple curriculum overhauls since 2017, including the introduction of a new national curriculum under Presidential Decree No. DP-134 (2022), creating textbook instability that affects both teacher preparation and student learning but leaves no trace in PISA data (Djalilov, 2024; UNICEF, 2023). Second, teachers face significant compliance and reporting burdens such as documentation for inspections, curriculum reporting, performance attestation, that reduce time available for lesson preparation and professional development (Mamadaminova & Khadjikhanova, 2023). These conditions independently affect education quality and would, if measurable, likely alter the coefficients od instructional quality variables in the models that follow.

3. Literature Review

3.1. Instructional quality and student learning outcomes

Instructional quality has been consistently identified as one of the most consequential school-level determinants of students' achievement, and its measurement in large-scale international assessments has been shaped significantly by the theoretical framework developed by Klieme, Pauli, and Reusser (2009). Their three-dimensional model comprising cognitive activation, supportive climate and classroom management, proposes that effective instruction operates through distinct but interrelated channels: the cognitive demand of tasks set for students, the quality of teacher-student relationship, and the degree of order and focus maintained in the classroom. This framework provides the theoretical foundation for the instructional quality indices used in this study and in the PISA analytical framework more broadly.

Within PISA, at three dimensions are measured through student-reported indices. Teacher support (TEACHSUP) captures the supportive climate dimension, the degree to which the mathematics teacher attends to individual students' learning needs, provides help when needed, and continues explaining until students understand. Disciplinary climate (DISCLIM) captures the classroom management dimension, the extent to which lessons are free from disruption and students can concentrate on learning. Cognitive activation which captures the cognitive demand of instructional tasks, including whether teachers encourage mathematical reasoning and problem solving, has been available in PISA since 2022, but it is not included in the present analysis because its measurement properties in the Uzbekistan context have not been independently validated. The two dimensions included TEACHSUP and DISCLIM have been significantly and positively associated with mathematics performance across multiple PISA cycles and country contexts (Liu et al., 2024; Niu et al., 2025), with Niu et al. (2025) confirming the framework's applicability across culturally diverse high-performing systems and Wu (2025) demonstrating its relevance across sic economies at varying income levels.

The evidence on instructional quality effects is, however, primarily drawn from OECD and East Asian contexts, and whether the same framework captures meaningful variation in settings with substantially different baseline conditions in an open empirical question. In Uzbekistan, where 81 percent of students fall below the minimum PISA proficiency threshold and where teacher qualification deficits are structural rather than marginal, the conditions under which instruction operates differ considerably from those of the systems in which the Klieme et al. (2009) framework was originally validated. Whether teacher support and disciplinary climate retain their positive associations with performance in this context and whether those associations are evenly distributed across the performance distribution is precisely what this study tests.

3.2. Quantile regression in education research

Quantile regression was introduced by Koenker and Bassett (1978) as an extension of linear regression that estimates conditional quantiles rather than the conditional mean. Rather than asking what the average mathematics score is for a student with given characteristics, it asks whether the association between a predictor and the outcome differs across the distribution at the 10th, 25th, 50th, 75th, and 90th percentile. In educational research this is particularly valuable for equity analysis, because it can reveal whether school-level factors generate larger returns for low-performing students than for high-performing ones, a distinction that average-effect estimates mask by construction.

Early applications to educational achievement data established that distributional estimates frequently diverge from OLS results in ways that matter for interpretation. Wada & Zahirovic-Herbert (2013) found that OLS coefficients for school quality effects on mathematics achievement concealed marked variation across quantiles, in some cases reversing direction. Levin (2001), using US longitudinal data, showed that the returns to school resources varied considerably across the achievement distribution, making the case that education policy based solely on average-effect evidence may misallocate investment. Castellano, Rabe-Hesketh, and Skrondal (2014) formalized this point statistically, demonstrating that school effects estimated at the conditional mean can be misleading when true effects vary by performance level, a finding that underpins the simultaneous quantile approach adopted in this study.

More recent work has extended these findings to large-scale international assessments, with results that are directly relevant to the present analysis. Oppedisano and Turati (2015), applying quantile regression to PISA data across European Countries, found that family background effects strengthen toward the upper tail of the distribution, a pattern that motivates examining whether the same holds in Uzbekistan, where the aggregate SES gradient is unusually compressed. Liu et al. (2024), analyzing PISA 2012 and 2022 data across ten European countries, found that teacher support and disciplinary climate consistently benefited low-SES students more than high-SES students across both cycles, a result that raises the question of whether instructional climate effects in Uzbekistan are similarly concentrated among the weakest students. Pholphirul et al. (2023), using PISA data for Thailand, found that teacher shortage penalties were concentrated among students at the lower end of the distribution and in rural areas, establishing a precedent for the kind of distributional heterogeneity this study examines in a Central Asian context. Yigiter (2025), drawing on a meta-analysis across 54 countries and six TIMSS cycles, further confirmed that school-level SES consistently exceeds individual-level SES in magnitude, a finding that motivates the inclusion of school-level controls alongside individual student predictors in the present models.

What connects these studies is a shared finding that average-level estimates systematically conceal policy-relevant heterogeneity across the performance distribution. For middle-income and transitional economies where the majority of students fall below minimum proficiency thresholds, this heterogeneity is not a statistical nuance, it determines whether reform resources reach the students who need them most. The present study tests the distributional properties of instructional quality effects in Uzbekistan for the first time, filling the gap in the Central Asian evidence base that the existing PISA literature has not addressed.

3.3. Equity in education and Central Asian context

Educational equity- to the extent to which differences in learning outcomes are attributable to circumstances beyond students' control is measured in PISA through the proportion of score variance explained by the ESCS index. Across OECD countries this figure averages approximately 15 percent, while several

East Asian systems combine high mean scores with relatively low SES gradients, suggesting that equity and excellence are not inherently in tension. Uzbekistan's ESCS gradient of approximately 2 percent is among the lowest in PISA 2022, a figure that appears to suggest an unusually equitable distribution of outcomes relative to family background. The picture is more complicated than this, however. A compressed SES gradient does not mean that all students have equal learning opportunities. It means that family background alone does not drive performance differences as strongly as in other nations. This substantial between-school variance (ICC = 0.181) documented in the two-level HLM reported in Appendix A, suggests that school quality differences, rather than family background, are the primary source of performance inequality in Uzbekistan. The distributional question this study addresses is therefore not whether inequality exists, it clearly does, but whether the school-level factors that drive it generate their effects equally across performance spectrum or concentrate their impact at particular points of the distribution.

The Central Asian educational context adds a specific dimension to this question that the existing literature has not addressed. Despite structural reforms documented in Section 2 - curriculum overhaul, teacher certification incentives, and substantial budget expansion – education systems in Central Asia remain almost absent from the international evidence base on instructional quality and students' outcomes. The few existing studies of PISA performance in Central Asia focus on Kazakhstan, which has participated since 2009, and confirm that school-level factors account got a larger share of performance variation than in most OECD countries, suggesting that school as an institution plays a more decisive role in student outcomes in post-Soviet systems than in Western contexts (OECD, 2023a). Whether this pattern holds in Uzbekistan – a system combining near universal enrolment, a severe teacher qualification deficit, and a concentration of 81% of students below minimum proficiency is an empirical question this manuscript investigates. The structural conditions describe in § 2 suggest that the binding constraints on student performance may differ considerably from those of OECD and East Asian systems, making empirical verification in the Uzbekistan context essential rather than optional.

4. The present study

This study applies simultaneous quantile regression to the PISA 2022 Uzbekistan dataset to examine whether the associations between instructional quality variables and mathematics performance differ across the student performance distribution. Two research questions guide the analysis.

RQ1: Do the associations between teacher support, sense of belonging and disciplinary climate and mathematics performance vary across the performance distribution, and if so, do they generate larger returns among low-performing of high-performing students?

RQ2: Is socioeconomic gradient steeper at the top or the bottom of the performance distribution, and what are the implications of this pattern for equity-targeted policy design in Uzbekistan?

The study adds two contributions to the literature. First, it provides the first distributional analysis of instructional quality effects in Central Asia, producing quantile-specific evidence that average-level multilevel analyses of the same dataset cannot reveal. Second, it demonstrates that school climate improvements are equity-enhancing interventions in Uzbekistan, their largest associations with performance are concentrated among the 81% of students below the PISA Level 2 threshold providing a distributional targeting rationale for school climate investment that the government's 2030 reform framework currently lacks.

5. Data, context, and methods

5.1. Data source and analytical sample

The data are drawn from the PISA 2022 international database, Uzbekistan subsample, publicly released by the OECD (2024). The full Uzbekistan sample comprises 7,293 students from 202 schools, selected using a two-stage stratified cluster sampling design in which schools were sampled as primary units and students sampled within schools, a nested structure that is directly reflected in the school-level controls included in the quantile regression models.

The analytical sample is restricted to students with complete data on all predictors, reducing the working sample to 4,653 students from 190 schools. The reduction from 202 to 190 schools reflects schools where all sampled students had missing values on one or more school-level predictors, a pattern concentrated in schools where principal did not complete school questionnaire, from which the UNQUALSTAFF, STAFFSHORT, CERTTEACH, and STRATIO variables are drawn. Listwise deletion was applied following standard practice for regression analyses using PISA data (OECD, 2024); while multiple imputation would in principle be preferable, the similarity of the analytical and full samples on key student-level characteristics suggest that the deletion does not introduce meaningful bias. Specifically, mean ESCS in the analytical sample (-0.68) closely matches the full sample mean (-0.67), and mean TEACHSUP, BELONG, and DISCLIM differ by no more than 0.03 standard deviations across the two samples, well with the range that would be considered negligible for practical purposes.

5.2. Outcome variable and plausible values

Pisa reports student achievement not as single score but as ten plausible values, random draws from each student's estimated proficiency distribution to avoid underestimating population-level variance (Von Davier, Gonzalez, & Milevy, 2009). The standard analytical procedure combines estimates across all ten values using Rubin's (1987) combination rules, which pool within- and between-imputation variance to produce correctly calibrated standard errors. These rules apply directly to linear estimators such as OLS and hierarchical linear models. For quantile regression, however, the extension is not straightforward, the quantile objective function is not linear, and a given student's position in the performance distribution shifts across plausible values, making direct pooling methodologically problematic.

Following the practice established in PISA-based quantile regression studies (Oppedisano & Turati, 2015; Pholphirul et al., 2023), results are reported for PV1MATH the first plausible mathematics value. To assess whether findings are PV-specific, the three key coefficients of interest TEACHSUP, BELONG, and

UNQUALSATFF were estimated separately for all ten plausible values. The sign and significance pattern was consistent across all ten: TEACHSUP and BELONG were positive and significant at Q10 in all cases, with declining magnitude toward Q90; UNQUALSTAFF was negative and significant across all five quantiles in nine of ten plausible values. The range of TEACHSUP at Q10 across ten estimates was 5.31 to 6.44 and the range of UNQUALSTAFF at Q10 was – 9.83 to -13.21variation that reflects sampling uncertainty across plausible values but does not alter the substantive interpretation of the results.

5.3. Predictors and variable measurement

Three instructional quality variables serve as the primary predictors of interest, each drawn from the PISA 2022 student questionnaire. Teacher support (TEACHSUP) captures students' perceptions of their mathematics teacher's attentiveness and responsiveness – whether the teacher explains until students understand, shows interest in their learning, and provides help when needed. This variable captures the supportive climate dimension of the Klieme et al. (2009) three-dimensional framework reviewed in § 3.1. Sense of belonging (BELONG) captures students' feelings of social integration and acceptance at school, a motivational construct that mediates the relationship between classroom climate and academic engagement and has been shown to predict mathematics performance independently of instructional quality in multiple PISA cycles. Disciplinary climate (DISCLIM) captures the degree of order and focus in mathematics lessons, the frequency with which students can work without disruption and concentrate on the teacher's explanations. All three indices are PISA-constructed Weighted Likelihood Estimates standardized to a mean of zero and standard deviation of one across OECD countries, so all coefficients in Table 3 are interpretable as score-point differences per one standard deviation change in the index.

At the student level, three control variables are included. Socioeconomic status (ESCS) is the PISA composite index of economic, social, and cultural status, the standard measure of family background in PISA-based research. Gender is coded as a binary indicator (GENDER, male = 1) to control the documented gender gap in mathematics performance. Mathematics self-efficacy (MATHEFF)captures students' beliefs about their capacity to perform specific mathematical tasks and is included because self-efficacy is both significant predictor of performance in its own right and a potential mediator of instructional climate effects, so, omitting it would risk overstating the instructional quality coefficients.

At the student level, five variables are included to isolate the instructional quality effects from structural school conditions that independently constrain learning. Inadequately qualified teaching staff (UNQUALSTAFF) is a binary variable drawn from the principal questionnaire, and it equals one if the principal reports that instruction is hindered by inadequately or poorly qualified teachers. Staff quantity shortage (STAFSHORT) is a parallel binary variable capturing whether the number of available teachers is insufficient. Teacher certification rate (CERTTEACH) records the percentage of fully certified teachers in the school. School location (RURAL) distinguishes rural from urban schools. Student-teacher ratio (STRATIO) captures class size and workload pressure at the school level. These five variables are included not because they are the primary focus of analysis, that focus is instructional quality indices, thus, omitting structural school conditions would risk confounding the TEACHSUP, BELONG, and DISCLIM estimates with variation in school resources that drives both instructional quality and student performance simultaneously.

5.4. Estimation strategy

To provide a benchmark for assessing distributional heterogeneity, an OLS baseline model was estimated prior to the quantile regression using the same predictors and analytical sample. The OLS variance was estimated using Fay's Balanced Repeated Replication with 80 replicate weights, following standard PISA analytical procedures (OECD, 2024). The OLS estimation is reported alongside the quantile regression results in Table 3, where they diverge substantially from the quantile-specific coefficients, that divergence is itself informative about the degree to which average-effect analysis would misrepresent the distributional reality.

The quantile regression model estimated in this study take the following form. For student i in school j, the conditional quantile function at quantile $\varvec{\tau}$ $\varvec{i}\varvec{s}$:

$$\varvec{Q}_{\varvec{\tau}}\left(\varvec{P}\varvec{V}\varvec{M}\varvec{A}\varvec{T}\varvec{H}_{\varvec{i}\varvec{j}}\middle|\varvec{X}_{\varvec{i}\varvec{j}},\varvec{Z}_{\varvec{j}}\right)=$$

where,
$\varvec{Q}_{\varvec{\tau}}$ $\varvec{d}\varvec{e}\varvec{n}\varvec{o}\varvec{t}\varvec{e}\varvec{s}$ $\varvec{t}\varvec{h}\varvec{e}$ $\varvec{\tau}-\varvec{t}\varvec{h}$ quantile of mathematics performance; $\varvec{P}\varvec{V}\varvec{M}\varvec{A}\varvec{T}\varvec{H}_{\varvec{i}\varvec{j}}$ is the mathematics plausible value for student i in school j; $\varvec{X}_{\varvec{i}\varvec{j}}$ is a vector of student-level predictors: ESCS, GENDER, MATHEFF, TEACHSUP, BELONG, and DISCLIM; $\varvec{Z}_{\varvec{j}}$is a vector of school-level predictors: UNQUALSTAFF, STAFFSHORT, CERTTEACH, RURAL, and STRATIO; $\varvec{\beta}\left(\varvec{\tau}\right)$ is a vector of student-level coefficients that vary across quantiles $\varvec{\tau}$; $\varvec{\gamma}\left(\varvec{\tau}\right)$ is a vector of school-level coefficients that vary across quantiles $\varvec{\tau}$; $\varvec{\alpha}\left(\varvec{\tau}\right)$ is the quantile-specific intercept.

The coefficients $\varvec{\beta}\left(\varvec{\tau}\right)$ and $\varvec{\gamma}\left(\varvec{\tau}\right)$ are estimated by minimizing the asymmetrically weighted sum of absolute deviations:

$$\min_{\varvec{\alpha},\varvec{\beta},\varvec{\gamma}}\sum_{\varvec{i},\varvec{j}}\varvec{\rho}_{\varvec{\tau}}\left(\varvec{P}\varvec{V}\varvec{M}\varvec{A}\varvec{T}\varvec{H}_{\varvec{i}\varvec{j}}-$$

where, $\varvec{\rho}_{\varvec{\tau}}\left(\mathbf{u}\right)=\mathbf{u}\left(\varvec{\tau}-1_{[\mathbf{u}<0]}\right)$ is the check function, introduced by Koenker and Bassett (1978), with 1(•)denoting the indicator function. This objective function assigns weight $\varvec{\tau}$ to positive residuals and weight (1- $\varvec{\tau}$) to negative residuals, shifting the estimate from the conditional mean toward the $\varvec{\tau}-\varvec{t}\varvec{h}$ conditional quantile. The key property of this estimator that $\varvec{\beta}\left(\varvec{\tau}\right)$ and $\varvec{\gamma}\left(\varvec{\tau}\right)$vary freely across quantiles, is what makes quantile regression informative for equity analysis: it

allows the association between teacher support and mathematics performance to differ between students at Q10 and Q90 without imposing any functional form constraint on that variation.

Simultaneous quantile regression was then estimated at five quantiles – τ = 0.10, 0.25, 0.50, 0.75, and 0.90, using the sqreg command in Stata 17 with 100 bootstrap replications for standard error estimation. The simultaneous approach is preferred over estimating five separate quantile regressions because it enables direct statistical testing of whether coefficients differ across quantiles. Examining whether TEACHSUP coefficient at Q10 is significantly larger than at Q90 is the central empirical question for the equity claims of this manuscript. It requires a formal test rather than visual inspection of overlapping confidence intervals, and sqreg provides this through its built-in equality tests.

Five quantile points were selected rather than a finer grid for two reasons. First, at n = 4,653 each decile contains approximately 465 observations which are adequate for stable estimation at the chosen points but potentially unstable at more extreme quantiles such as the 5th or 95th percentile. Second, the five-point grid, anchoring the lower tail (Q10), lower-middle (Q25), median (Q50), upper-middle (Q75), and upper tail (Q90), provides sufficient resolution to identify the declining gradient of instructional quality effects and the steepening SES gradient without overfitting. The pseudo R^2 reported in Table 3 is the Koeker-Bassett goodness-of-fit measure, the proportion of weighted absolute deviations explained by the model at each quantile. It is not directly comparable to the OLS R^2 but confirms that model fit improves toward the upper tail of the distribution, consistent with the stronger role of the observable predictors among the higher-performing students.

6. Results

6.1. Descriptive statistics

Table 2 reports weighted descriptive statistics for the analytical sample. The mean mathematics score is 363.67 points (SD = 67.4), substantially below the OECD average of 472. Mean ESCS is -0.68 (SD = 1.01), reflecting the low socioeconomic profile of the Uzbekistan sample relative to OECD norms. Teacher support (TEACHSUP) has a mean of 0.38 (SD = 1.19) above the OECD average of zero, consistent with the high proportion of Uzbekistan students who report their teacher provides help when needed. Disciplinary climate (DISCLIM) has a mean of 0.29 (SD = 1.12), also slightly above the OECD standardized mean. Approximately 28% of schools reported instruction hindered by inadequately qualified staff (UNQUALSTAFF = 1) and 36% were classified as rural schools. The high standard deviation of mathematics scores (67.4 points) relative to the distance from Level 2 9approximately 420 points) confirms that distribution of performance is concentrated in the below-proficiency range, motivating the quantile regression analysis at the lower tail.

Table 2
— Descriptive statistics of key variables (analytical sample, n = 4,653)

Variable	PISA Code	Mean	SD	Min	Max
Mathematics score (PV avg.)	PV1–10MATH	363.67	67.4	145.0	625.0
ESCS index	ESCS	-0.68	1.01	-4.43	2.49
Gender (1 = male)	ST004D01T	0.49	0.50	0	1
Math self-efficacy	MATHEFF	-0.42	1.37	-3.73	2.44
Disciplinary climate	DISCLIM	0.29	1.12	-2.49	1.85
Teacher support	TEACHSUP	0.38	1.19	-2.91	1.56
Sense of belonging	BELONG	0.08	1.02	-3.26	2.78
Teaching staff shortage	SC017Q01NA	0.24	0.43	0	1
Unqualified staff	SC017Q02NA	0.28	0.45	0	1
Certified teachers (%)	SC018Q02TA01	11.79	21.96	0	93
Rural location (binary)	SC001Q01TA	0.36	0.48	0	1
Student-teacher ratio	STRATIO	13.79	5.74	1.0	28.6
Note. PVMATH statistics based on PV1MATH. Weighted using W_FSTUWT. Source: PISA 2022 Uzbekistan data.					

6.2. Hierarchical liner model results

Prior to the quantile regression, a two-level HLM was estimated to confirm the school-level context and identify which school-level predictors warrant examination in the distributional analysis. Table A1 in Appendix A reports the full HLM results. The unconditional null model yielded an intraclass correlation coefficient of 0.181, confirming that 18.1% of total mathematics score variance lies between schools, a figure substantially above the conventional 5% threshold that warrants multilevel analysis (Raudenbush and Bryk, 2002). The full two-level HLM identified UNQUALSTAFF as the only school-level variable consistently and significantly associated with mathematics performance across all ten plausible values (β =-10.17, $p < 0.05$). STAFFSHORT, CERTTEACH, RURAL, and STRATIO were non-significant after controlling for student-level characteristics. These HLM findings establish the school-level context for the quantile regression, specifically, they confirm that UNQUALSTAFF is the primary structural school predictor and motivate its inclusion as a key variable of interest in the distributional analysis below.

6.3. Distributional effects of instructional quality variables

Table 3 reports the OLS baseline and quantile regression results across five quantile, and Fig. 1 plots the four key coefficients against the OLS reference line to make the distributional pattern visible. The results confirm that instructional quality variables do not have uniform associations with mathematics performance across the distribution.

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Table 3
OLS and Simultaneous quantile regression results PV1MATH, n = 4,653 students, 190 schools

Variable	OLS	Q10	Q25	Q50	Q75	Q90
ESCS	8.36***	4.76***	4.48***	7.86***	9.68***	11.02***
GENDER	11.05***	1.79	5.44**	8.54***	12.91***	17.34***
MATHEFF	8.30***	3.35***	4.39***	6.56***	9.38***	12.51***
DISCLIM	2.64**	2.85**	4.04***	3.77***	2.59**	1.38
TEACHSUP	5.46***	5.97***	5.00***	6.56***	3.72***	2.06
BELONG	6.77***	8.49***	7.56***	5.35***	7.42***	4.97**
STAFFSHORT	6.98	10.04**	5.52	5.58*	12.19***	20.32***
UNQUALSTAFF	−10.17**	−11.66***	−11.52***	−7.62**	−10.70***	−13.96***
CERTTEACH	−0.09	−0.11	−0.06	−0.07	−0.10*	−0.16*
RURAL	+ 12.08**	8.40***	11.25***	9.86***	12.58***	9.94***
STRATIO	+ 0.09	−0.10	0.05	0.01	0.12	0.12
R^2 / Pseudo R^2	0.096	0.041	0.040	0.048	0.062	0.082

Note. *** p < 0.001, ** p < 0.05, * p < 0.10. OLS estimated with Fay's Balanced Repeated Replication using 80 replicate weights. Simultaneous quantile regression estimated using sqreg with 100 bootstrap replications in Stata 17. OLS R^2 = 0.096. Pseudo R^2 is the Koenker-Bassett goodness-of-fit measure. Outcome: PV1MATH. Significance of TEACHSUP at Q90 (β = 2.06) does not reach conventional threshold.

Teacher support (TEACHSUP) shows a broadly declining gradient from the lower to the upper tail. The coefficient is 5.97 at Q10 (p < 0.001), eases slightly to 5.00 at Q25, rises to 6.56 at Q50, likely reflecting the concentration of teacher-dependent learners in the middle of the distribution who have not yet developed independent study strategies, before declining to 3.72 at Q75 and 2.06 at Q90, where it no longer reaches statistical significance. The overall pattern is clear: teacher support matters most for students at the bottom of the distribution and progressively less as performance increases, consistent with the expectation that stronger students draw more heavily on self-directed learning and are less reliant on teacher attentiveness for their mathematics outcomes.

Similarly, sense of belonging (BELONGING) follows the same pattern, with a coefficient of 8.49 at Q10 declining to 4.97 at Q90 the largest of the three instructional quality variables at the bottom of the distribution and the one with the most pronounced equity gradient. Disciplinary climate (DISCLIM) shows a different profile: positive and significant from Q10 through Q75 but declining to a non-significant 1.38 at Q90, suggesting that classroom order matters for the most students but has little additional effect at the very top of the distribution where students may be sufficiently self-regulated to perform well regardless of classroom conditions. Together these three variables confirm that school climate improvements would generate their largest mathematics gains among the students currently furthest from minimum proficiency – directly addressing RQ1.

Socioeconomic status demonstrates a strikingly different distributional pattern from the instructional quality variables, directly answering RQ2. The ESCS coefficient rises steadily from 4.78 at Q10 to 7.86 at Q50 and 11.02 at Q90, more than doubling across the distribution. Among students at the bottom pf the performance spectrum, family background plays a relatively modest role, suggesting that other factors including the instructional climate variables examined in Section 5.3 – are the primary drivers of performance at this level. Among students at the top, socioeconomic advantage is a powerful differentiator, with a one standard deviation increases in ESCS associated with more than 11 additional score points at Q90.

UNQUALSTAFF is negatively and significantly associated with mathematics performance at all five quantiles, with coefficients ranging from − 7.62 at Q50 to -13.96 at Q90. Unlike the instructional climate variables, whose effects decline toward the upper tail, the UNQUALSTAFF penalty is present throughout the full distribution. The positive STAFFSHORT coefficients at Q10 (+ 10.04, p < 0.05) and Q90 (+ 20.32, p < 0.001) should be carefully interpreted. As confirmed by the HLM results in Appendix A, Table A1, STAFFSHORT is non-significant after school composition is controlled. It suggests that positive quantile regression coefficients reflect the concentration of rapidly expanding high-performing urban schools in the STAFFSHORT = 1 category rather than a positive effect of understaffing.

Turning to the RURAL coefficient, it can be noticed that it is positive and significant across all five-quantile ranging from + 8.40 at Q10 to + 12.58 at Q75. As discussed earlier, this reflects compositional differences between urban and rural school in the PISA 2022 Uzbekistan sample, rather than a rural performance advantage. Urban school serve a more socioeconomically disadvantaged student population, once school-level mean ESCS is controlled (analysis is given per request), the RURAL coefficient becomes non-significant (β = -0.19, p > 0.80).

7. Discussion and Policy Implications

7.1. Equity Rationale for school climate interventions

The primary finding of this work is that teacher support and school belonging have their largest positive associations with mathematics performance among the weakest students, those at the 10th percentile of the distribution. This pattern is consistent with the theoretical expectation that students far below the proficiency threshold, with limited access to supplementary learning resources outside school, depend more heavily on teacher attentiveness and classroom belonging for their leaning gains that students who are already performing well and can draw on self-directed strategies. The quantile regression confirms this expectation empirically for the first time in a Central Asian context.

This finding is consistent with the broader international literature. Shen (2026), using PISA 2012 Shanghai-China data with both multilevel models and quantile regression, found that positive relationships between teaching effectiveness and mathematics achievement were more pronounced for low achievers, directly paralleling the Uzbekistan results despite the substantial differences in system performance levels between Shanghai and Uzbekistan. Liu et al. (0204), analyzing PISA data across ten European countries, found that teacher support and disciplinary climate consistently benefited low-SES students more than high-SES students across both PISA 2012 and 2022 cycles. Pholphirul et al. (2023) found analogous patterns in Thailand, where teacher shortage penalties were concentrated among lower-performing students in rural areas. The convergence of these findings across high-performing East Asian, European, and lower-middle-income contexts suggests that the equity-enhancing distributional properties of instructional quality improvements may be a general feature of school climate effects rather than a context-specific finding.

For policy in Uzbekistan, this distributional pattern has a specific and actionable implication. School climate interventions such as programs that develop teachers' capacity to provide individual support, build student belonging, and maintain disciplinary order, would generate their largest mathematics gains precisely among the 81% of students currently below the PISA level 2 threshold, who are the primary target of the government's 2030 reform agenda. This alignment between the distributional property of the intervention and the target population is not automatic, it is an empirical finding that justifies equity-targeted deployment of the 'Ustoz' professional development initiative toward schools with the highest concentrations of below-Level-2 students.

7.2. The steepening SES gradient and its implications

The steepening socioeconomic gradient ESCS rising from 4.76 at Q10 to 11.02 at Q90 reveals that Uzbekistan's compressed average SES effect suppresses a distributional pattern in which family background is a powerful differentiator at the top of the performance spectrum. This is consistent with Oppedisano and Turati (2015), who found that family background effects strengthen toward the upper tail of the distribution across European PISA systems, and with Yigiter (2025), whose meta-analysis across 54 countries confirmed that school-level SES consistently exceeds individual-level SES in magnitude – a finding that connects to the compositional analysis discussed in section 7.4 below.

The policy implication is specific and differs from that of the instructional quality findings.

Policies targeting socioeconomic inequality, means-tested school funding, family support programs, or targeted scholarship schemes will generate their largest returns among high-performing students where the SES gradient is steepest. Reaching the 81% of students below Level 2, where the SES gradient is relatively flat, requires a different class of intervention one that operates at the school and classroom level rather than through family background. For the government's PISA top-30 target, which requires movement both at the top of the distribution and reduction of the low-performer share, the steepening gradient implies that top-end performance will be hard to improve without addressing access to supplementary learning pathway such as private tutoring and enrichment activities that currently differentiate the highest-performing students.

7.3. Teacher qualification deficits as a system-wide constraint

The consistent negative UNQUALSTAFF penalty across all five quantiles ranging from – 7.62 at Q50 to -13.96 at Q90 ascertains teacher qualification reform as a system-wide priority. Teacher qualification deficits do not disproportionately harm any particular segment of the student population, they reduce performance across the board. This universality distinguishes the UNQUALSTAFF finding from the equity-targeted implications of the climate variables and establishes teacher qualification reform as a system-wide rather than narrowly targeted priority. It also connects directly to the certification pathway established by the Presidential Decree No. DP-79 (2023), which the distributional evidence supports as an intervention whose benefits would be felt by all students rather than concentrated at the bottom.

This finding extends the HLM result reported in Section 6.2 and Appendix A where UNQUALSTAFF was the only school-level variable consistently significant across all ten plausible values. This outcome demonstrates that this constraint operates with equal force across the performance distribution. Pholphirul et al. (2023) revealed teacher shortage effects concentrated among lower-performing students in Thailand, but the Uzbekistan results demonstrate a different pattern for qualification adequacy compared to quantity – a distinction with direct implications for how reform resources are directed. Quantity shortages may be more harmful to weaker students, while qualification deficits harm all students equally.

7.4. Compositional effects: RURAL and STAFFSHORT

Two coefficients in Table 3 require compositional interpretation before policy conclusions can be drawn. The positive RURAL coefficient across all five-quantile ranging from + 8.40 at Q10 to + 12.58 at Q75 appears to suggest that rural schools outperform urban schools across the full distribution. This pattern reflects compositional differences between urban and rural school rather than a rural institutional advantage. Urban schools in Uzbekistan serve substantially more socioeconomically disadvantaged student population that rural schools, a consequence of the concentration of low-income migrant households in Tashkent and regional capitals. Once school-level mean ESCS is controlled (analysis is presented per request), the RURAL coefficient becomes non-significant (β = -0.19, p > 0.80), confirming that the apparent rural advantage is compositional rather than institutional. The policy implication is that

urban schools, not rural ones, are the priority for the targeted support, since they serve student populations with the weakest socioeconomic profiles despite their apparent performance advantage in the raw data.

Similarly, the positive STAFFSHORT coefficients at Q10 (+ 10.04, $p < 0.05$) and Q90 (+ 20.32, $p < 0.001$) are counterintuitive and require careful interpretation. Schools reporting staff quantity shortages are associated with higher mathematics performance, a pattern that runs against the expectation that understaffing would harm outcomes. The most plausible explanation is that STAFFSHORT = 1 schools in this sample are disproportionally rapidly expanding urban schools whose student population has grown faster than their teacher supply. These schools report shortages not because they are poorly resources but because demand has outpaced capacity and they tend to be higher-performing schools serving urban populations with stronger family resources. This interpretation is consistent with the non-significance of STAFFSHORT in the two-level HLM documented in Appendix A, Table A1, where school composition is controlled once the socioeconomic profile of the school's intake is accounted for, the positive STAFFSHORT association disappears. The coefficient should therefore be read as a marker of school expansion in high-demand urban contexts rather than as evidence that staff shortages benefit learning.

7.5. Limitations

Three limitations emerge from the analysis of findings of this study. First, quantile regression is estimated on PV1MATH rather than averaged across all ten plausible values. The Rubin (1987) combination rules do not extend straightforwardly to quantile estimators, because the quantile objective function is not linear and a student's distributional position shifts across plausible values. The sensitivity check documented in section 5.2 confirms that the sign and significance pattern is consistent across all ten plausible values, but the standard errors reported may slightly underestimate total uncertainty. Second, the cross-sectional design prevents casual interpretation. The association between teacher support and performance at Q10 is consistent with teacher quality generating learning gains among weak students, but reverse causation cannot be excluded, schools serving weaker students may systematically recruit more supportive teachers. Providing the casual mechanism requires longitudinal or quasi-experimental designs using data from Uzbekistan's future PISA cycles. Third, the absence of a school-level socioeconomic composition control in the main quantile regression models means that the RURAL and STAFFSHORT coefficients absorb compositional differences between school types. The supplementary analysis cited in section 7.4 addresses this partially, but a full three-level model incorporating school composition at Level 2 would provide a more complete resolution.

8. Conclusion

This manuscript applied simultaneous quantile regression to the PISA 2022 Uzbekistan dataset to examine whether the associations between instructional quality and mathematics performance vary across the student performance distribution. The results confirm that they do and in a direction with direct equity relevance.

Three principal findings emerge. Teacher support and school belonging have their strongest positive associations with mathematics performance among the weakest students at the 10th percentile, teacher support carries a coefficient of 5.97 points, declining to a non-significant 2.06 at the 90th percentile. Socioeconomic status shows the opposite pattern, steepening from $\backslash\mathrm{varvec}\beta$ = 4.76 at Q10 to $\backslash\mathrm{varvec}\beta$ = 11.02 at Q90., conforming that family background is a powerful differentiator at the top of the distribution even when the average SES gradient appears compressed. Inadequately qualified teaching staff imposes a consistent performance penalty across all five quantiles ranging from − 7.62 at Q50 to -13.96 at Q90 establishing teacher qualification deficits as a system-wide constraint rather than a problem concentrated an any particular performance level.

These findings generate three contributions. Methodologically, they demonstrate that OLS and HLM estimates of instructional quality effects systematically mask the equity implications of school climate interventions in systems like Uzbekistan where the majority of students fall below minimum proficiency – the same coefficient that appears modest in an average-effect model may be the largest single lever available for the students who need it most. Substantively, they provide the first distributional evidence on instructional quality effects in Central Asia, extending the patterns documented by Shen (2026) for Shanghai-China and Liu et al. (2024) for European systems to a post-Soviet context with a compressed SES gradient and acute teacher qualification deficits. For policy, the findings provide that school climate investment through the Ustoz professional development initiative and teacher certification reform under Presidential Decree s No. DP-134 (2024) and DP-79 (2023) are complementary and mutually reinforcing, the former generating equity-enhancing returns concentrated among the students most in need, the latter addressing a system-wide constraint that reduces performance across the full distribution.

Uzbekistan's PISA 2025 results expected in late 2026 will provide the first opportunity to test whether the distributional patterns documented here have shifted in response to the reforms introduced since 2022. Extending the quantile regression approach to a three-level model students nested within school nested within regions would allow the geographic dimension of the distributional heterogeneity to be explicitly modelled, testing whether the equity-enhancing properties of teacher support are strongest in rural schools where the structural constraints on learning are most critical.

Declarations

Ethics approval and consent to participate

This study is based on publicly available secondary data from the Programme for International Student Assessment (PISA) 2022 database published by the Organization for Economic Co-operation and Development (OECD). No primary data were collected, and no direct involvement of human participants occurred. Therefore, ethics approval and informal consent to participate were not required.

Consent for Publication

Not applicable.

Availability of data and material

The PISA 2022 data used in this study are publicly available from the OECD at https://www.oecd.org/pisa/data/2022database/

Competing interests

The author declares no competing interests.

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Author's contributions

The author solely considered and designed the study, conducted the literature review, collected and analyzed data, interpreted the findings, and wrote and revised the manuscript.

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Figures

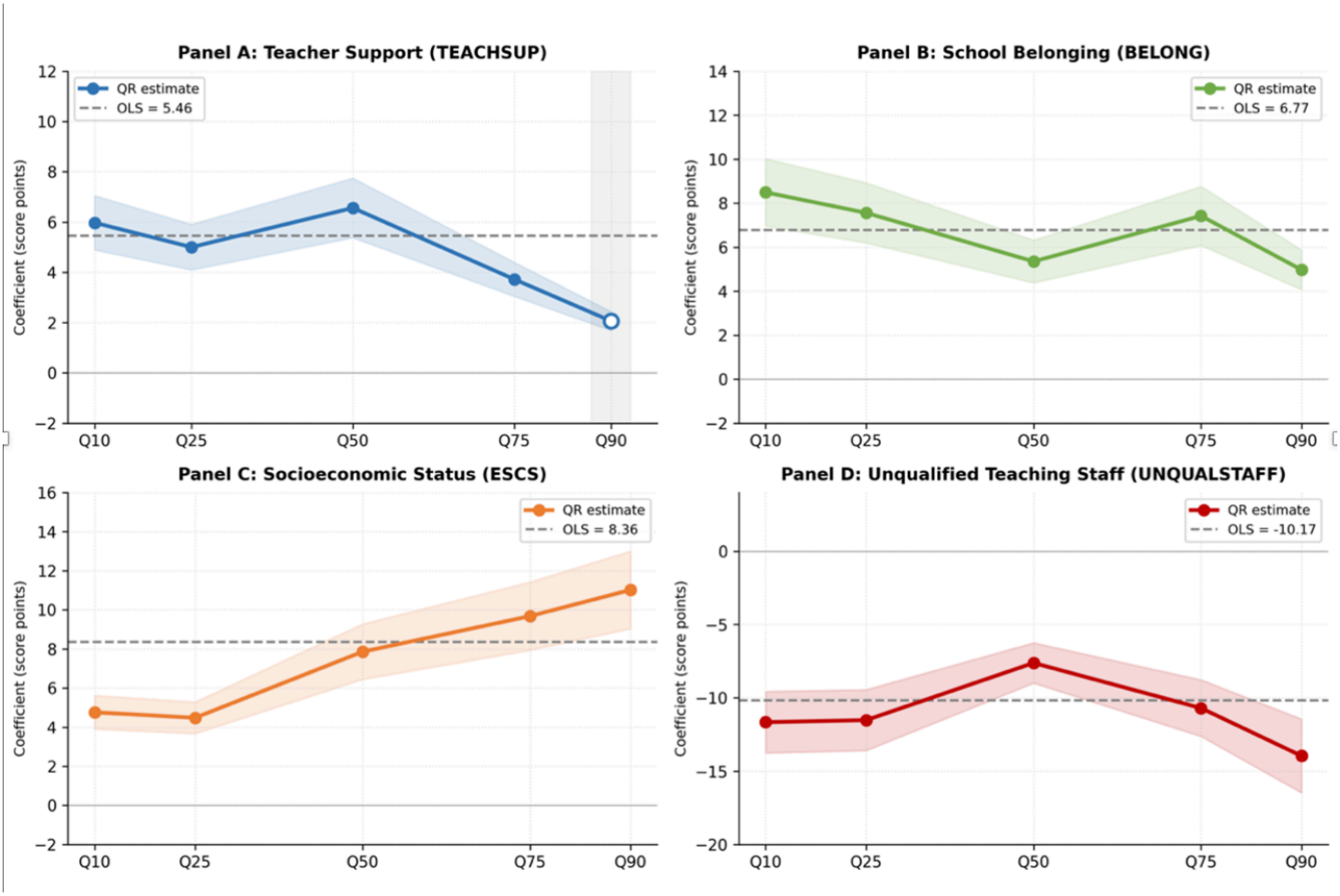


Figure 1

Quantile regression coefficients for key variables across the mathematics performance distribution — PISA 2022 Uzbekistan (n = 4,653)

Supplementary Files

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- Appendix.docx