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Comparative data analysis on the effect of socioeconomic factors on math proficiency

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SUMMARY

Our study addresses the socioeconomic factors that affect academic achievement and how they differ between various nations. We aim to identify which socioeconomic factors influence academic achievement most heavily and how such achievement is affected by social and economic development factors. We hypothesize that affluent economic backgrounds have a positive correlation with student achievement and the social and economic development level of nations has a positive correlation with how much socioeconomic status (SES) impacts student achievement. Using the Trends in International Mathematics and Science Study (TIMSS) 2019 dataset on mathematics achievement, we conducted multiple regression and statistical testing of the associated regression parameters to analyze the relationship between three socioeconomic status variables. We used Huber regression to analyze the expected marginal utility of each predictor. Overall, we found that inequality in educational achievement increased with the development level. The findings and analyses outlined above suggest key considerations for education policies in both developed and developing nations. For developed nations grappling with education inequality, high priority to correct this inequality should be the mitigation of the impact of SES disparities on academic outcomes. On the other hand, in developing nations, while education is widely recognized as a driver of economic and social progress, policymakers must also be mindful of the risk of exacerbating inequality.

INTRODUCTION

With technological advancements, mathematics education is increasingly prioritized for its role in fostering innovation and driving economic growth (1, 2). While math skills are critical for individual career success and national progress, leading many nations to prioritize STEM (Science, Technology, Engineering, Mathematics) funding, improved education quality does not automatically reduce inequality (3). Research indicates that socioeconomic status (SES) creates significant achievement gaps; wealthier parents invest more in educational resources, creating a feedback loop that reinforces inequality and limits social mobility (4, 5). These disparities are further complicated by racial factors and historical discrimination within educational systems (5-8).

Although cross-cultural research is limited, existing studies in nations like Pakistan and Australia confirm that household income, parental education, and school-level SES are strong predictors of academic success (9, 10). Conversely, students from low-SES backgrounds often face slower skill development and attend resource-poor schools, leading to higher dropout rates (11, 12). Researchers typically rely on two major datasets to analyze these trends: PISA, which measures real-world application, and TIMSS, which focuses on curriculum-based mathematics achievement (13, 14). Notably, Eriksson's analysis of PISA data revealed that the impact of factors like material wealth and books at home varies significantly depending on a nation's overall level of development (15).

Building upon prior literature, this study established two primary hypotheses: 1) that a more affluent economic background positively influences academic achievement, and 2) that a nation's level of social and economic development positively correlates with the magnitude of the impact of socioeconomic status (SES) on student performance. We identified a distinct gap in the field, noting a lack of global studies utilizing TIMSS data to compare SES indicators. Furthermore, existing research has largely focused on general academic achievement rather than specific performance in mathematics.

To address this void, the study utilized 2019 TIMSS data to examine the relationship between SES factors and mathematics performance across eleven diverse nations. The findings revealed that SES variables, specifically parental education, books at home, and school economic background, were consistently and positively associated with mathematics achievement. Crucially, these effects were observed to be stronger in more economically developed nations. These results imply that as nations continue to develop, early interventions addressing SES-linked disparities become increasingly critical to preventing the widening of educational inequities.

RESULTS

We conducted the following analyses to investigate which socioeconomic factors, if any, affect academic achievement and how such academic achievement is affected by social and economic development factors on a per-nation basis. We conducted the analysis using the TIMSS 2019 dataset, which includes data for mathematics questions, each student's answers, the student's characteristics, and the school's characteristics. We divided the data analysis into two major sections: multiple regression analysis and marginal utility comparisons. In both sections, the variables we examined included parental education level, the number of books at home, and the economic composition of the school.

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Regression analysis

We investigated eleven nations based on TIMSS data availability and multiple region representation: South Korea, Japan, and Hong Kong (East Asia); Turkey (Middle East); Jordan (West Asia); Morocco and Egypt (North Africa); US (North America); Chile (South America); and England and France (Europe). For each nation, we conducted regression analysis on three SES variables (parents' education level, number of books at home, schools' economic advantage) and aggregate mathematics scores calculated by summing student test scores for the assessment. We used robust least squares analysis to generate regression lines and tests for statistical significance of relationships between variables. We obtained 27 regression models. For every model, the correlation between SES predictors and aggregate mathematical achievement was positive. Each model's slope parameter was non-zero ($p<0.05$), indicating a statistically significant correlation between socioeconomic factors and mathematics achievement. Therefore, our hypothesis that a more affluent economic background positively affects mathematics achievement was conclusively supported by the 2019 data.

Our second investigation related to predicted effectiveness of each covariate. While significance testing showed the *existence* of a relationship between socioeconomic status and mathematics achievement, the regression parameters offered insights into the correlative *effectiveness* of each SES indicator. We defined the marginal utility score of each covariate as the expected value of improvement in aggregate score per unit of each dependent variable. For example, for parental education level, the slope of the regression model was the expected increase in aggregate score per increase in parental education category. Therefore, the regression intercepts proxied baseline performance, whereas the regressor slopes proxied the marginal utility of each covariate. By comparing regression data nation by nation, we quantitatively compared the relationship between a nation's level of inequality and how mathematical achievement was affected by SES factors (**Figure 1**). Additionally, by plotting the confidence regions of the regression parameters, we quantitatively clustered the nations by academic performance and covariate utility, taking into account the differences in the data collected for each nation. More data resulted in tighter confidence regions, whereas less data resulted in larger uncertainty regions. Overlapping confidence regions indicated that ranking nations was impossible within dataset uncertainties, whereas non-overlapping regions indicated a statistically indicative ranking. Examples (**Figure 1**) include Hong Kong and South Korea for books at home, France and England for parental education status, and Jordan and Egypt for school composition; here, data uncertainties prevent definitively ranking either country above the other.

We categorized overall scores into three groups based on y-intercept: high, middle, and low-scoring nations. The high-scoring nations included South Korea, Japan, and Hong Kong (with intercept scores of 499.0, 466.5, and 539.0, respectively), all of which are prominent East Asian nations. In contrast, Morocco and Jordan had lower overall scores. Other nations, such as England, France, and the United States, were positioned in the middle range.

Categorization based on regression model slopes indicated the relative utility of each covariate on aggregate mathematical performance; higher slopes indicated stronger SES impact. Notably, Hong Kong and Japan provided examples of high aggregate achievement with low SES impact, indicating success minimally contingent on wealth-based factors. Both demonstrated high aggregate scores (567.16, 558.43, respectively, **Table 4**) with marginal utilities under a 30-point increase per unit in school composition rating (13.04 and 29.26, respectively, **Figure 1c**). Interestingly, Japanese data indicated a strong impact of parental education on performance, revealing outsized family influence. Conversely, the United States, Turkey, and Chile showed the largest influence of wealth-based indicators, signifying strong educational inequality. These nations exhibited average mathematical performance largely affected by student and

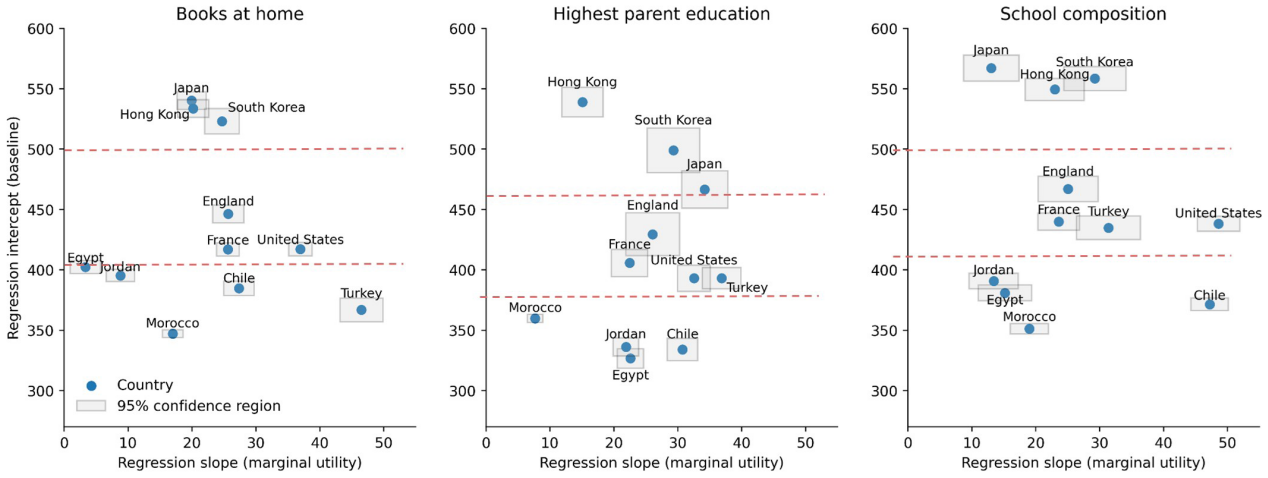

Figure 1: Aggregate slope/intercept plots for the effect of books at home (A), highest parent education(B), and school composition(C) on mathematics scores with uncertainties. The slopes of the linear regression models of the aggregate mathematics score (y-axis) and variables (education level of parents, number of books at home, and economic status of the school) (x-axis). Uncertainty regions (plotted in grey) indicate 95% confidence regions around each regression parameter. The threshold used to divide the eleven nations into three major groups are shown as red dotted lines. Note that the threshold is based on the order from least to greatest, not a consistent, specific value of the regression intercept.

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school wealth. Similarly, Jordanian, Egyptian, and Moroccan data demonstrated weak overall mathematical performance and weak wealth-based impact, suggesting a relatively weak educational system but low socio-economic disparity.

Analysis of marginal utility as a function of nation wealth

Our data supported the hypothesis that a more affluent economic background would positively affect achievement for every nation analyzed. We performed additional complementary comparisons of each covariate marginal utility against overall development and wealth at the nation level, as measured by Human Development Index (HDI) and Gross Domestic Product (GDP), respectively. We did not assess confidence regions for these analyses, as HDI and GDP are presumed to be deterministic and reliably measured values rather than empirically derived ones with an uncertainty distribution, implying a zero chance of confidence region overlap between nations. We plotted the results of a meta-regression between GDP/HDI original marginal utility of each covariate, nation by nation (**Figure 2, Figure 3)**. For all analyses, robust regression approaches such as Huber regression do not have an equivalent notion of r-values, as they are designed to allow the model to capture a trend in the presence of outliers. Plotting both regression approaches together also illustrates the sensitivity of these regression models to the outliers in each case, providing additional justification to the robust regression approach taken in this study.

Overall, our data comparing marginal utility with nation GDP or HDI demonstrated a strong, statistically significant ($p<0.01$) positive correlation (meta-regression values not tabulated). However, both the r-squared values as well as the differences between the OLS and Huber meta-regressions revealed the presence of outliers.

GDP and the marginal utility of the education level of parents had a positive relationship (Huber regression slope 0.196, **Figure 2**). However, Hong Kong, France, and Morocco were notable outliers. Morocco represented a true outlier with the only marginal utility of less than 10 points per unit increase, perhaps due to the prevalence of private education for the wealthy. Hong Kong and France, to a lesser extent,

Nation	Slope			Intercept		
	Value	z	95% Conf.	Value	z	95% Conf.
England	48.6	28.6	[45.3, 51.9]	438.25	139.4	[432.1, 444.4]
South Korea	25.07	10.4	[20.4, 29.8]	467.04	87.6	[456.6, 477.5]
Japan	29.26	11.8	[24.4, 34.1]	558.43	109.2	[548.4, 568.5]
Hong Kong	13.04	5.9	[8.7, 17.4]	567.16	103.3	[556.4, 577.9]
Egypt	22.99	9.8	[18.4, 27.6]	549.48	118.2	[540.4, 558.6]
Jordan	15.19	7.1	[11.0, 19.4]	380.96	114.5	[374.4, 387.5]
France	13.42	6.8	[9.6, 17.3]	390.78	119.6	[384.4, 397.2]
Turkey	23.61	14.2	[20.3, 26.9]	439.97	120.8	[432.8, 447.1]
Morocco	31.39	12.3	[26.4, 36.4]	434.82	87.2	[425.1, 444.6]
Chile	19.0	12.4	[16.0, 22.0]	351.21	163.0	[347.0, 355.4]

Table 4: Statistics of regression of the variable "economic composition of the school" and academic achievement score (n=58545 in total). The regression value, z-score (standard deviation), and 95% confidence interval are shown for the slope and intercept.

both had unusually high GDP per capita but low marginal utility of parental education, indicating a positive outcome in terms of educational equality. Turkey can also be considered an exception, with a lower GDP but high inequality, indicating a disproportionate advantage conferred by parental education. Meanwhile, when compared with HDI, the marginal utility pattern seemed more consistent, showing a general positive pattern, albeit with more variation among the nations with a higher GDP range of over 85 (**Figure 3**).

GDP and the marginal utility of the number of books at home were also positively correlated, with Turkey deviating from the trend (**Figure 2**). Comparison with HDI showed a similar result, with Turkey having a significantly higher marginal utility compared to other nations used in this analysis, indicating an abnormally high influence of family wealth on educational outcome when coupled with the parental education meta-regressions discussed above (**Figure 3**).

When comparing the GDP with the marginal utility of the economic composition of the school, the plots were seemingly more consistent with slightly more variation at the lower GDP

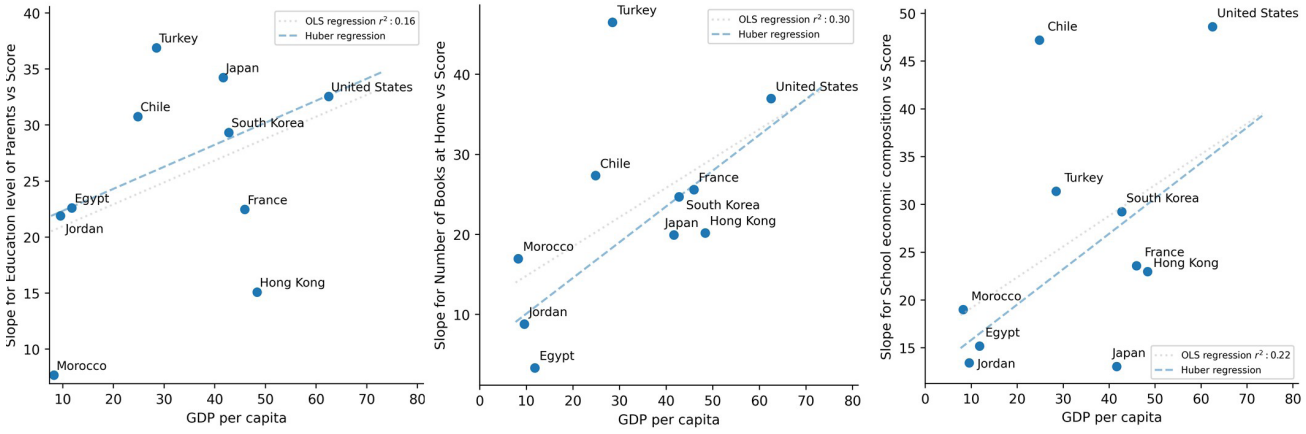

Figure 2: Scatter plot of regression slope of the education level of parents (A), books at home (B), or economic composition of school(C) and score with GDP per capita. Panel A shows the regression slope of the educational level of parents, panel B shows the regression slope of the number of books at home, and panel C shows the regression slope of the economic composition of the school. These variables are compared with gross domestic product (GDP_ per capita for an insight into their relationship with economic development.

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per capita range (**Figure 2**). The positive relationship likely supports the notion that the more economically developed the nation is, the stronger the influence is of the school's economic composition on student achievement. When compared with HDI, Japan was shown to be lower, whereas the US and Chile were shown to be higher than the general trend, respectively. While the two nations of US and Japan have a similar value of HDI, both in the 90-95 range, they have drastically different marginal utility compared to the other data points, indicating a higher degree of educational equality in Japan and abnormally high levels of inequality in the US and Chile (**Figure 3**).

DISCUSSION

Both hypotheses 1) that a more affluent economic background positively influences academic achievement, and 2) that a nation's level of social and economic development positively correlates with the magnitude of the impact of socioeconomic status (SES) on student performance were supported by the data, as all regressions were statistically significant. This supports the idea that relationships exist between SES factors and student achievement in addition to suggesting that a nation's level of social and economic development may influence the extent of education inequality based on SES.

In the initial regression analyses, student achievement scores for each nation clustered into three groups: highest-scoring East Asian nations, middle-range Western nations, and lower-range developing nations. This implied that scores may vary by region, not just development status, as developed middle-range Western nations did not score as high as East Asian nations. This widely observed pattern was attributed by Leung to East Asia's Confucian Heritage Culture, while Jerrim found Australian students of East Asian descent mirrored their origin nations' performance (17, 18). Jerrim's study suggested contributing factors like a strong cultural emphasis on education, tutoring, and rigorous work ethics (18).

Deviating nations included Hong Kong and Jordan, which displayed differing relationships between parental education and student achievement. Parental education affected scores less in Hong Kong but had a greater influence in Jordan compared to other SES factors. This is notable because both nations share similar Gini index values measuring economic inequality. Possible explanations include varying parental involvement and policies; Hong Kong's standardized curricula and government-funded programs promote equal opportunities, potentially mitigating parental education impacts (19).

As for marginal utility, the relationship between parental education, GDP, and student achievement appeared scattered, with only a slight indication of positive correlation. The HDI plot showed a similar pattern with greater variation at higher levels. While no clear trends were identified, a notable marginal utility contrast between Turkey and Hong Kong was evident.

We further analyzed the marginal utility, defined as the regression slope value, for each variable regarding development indicators. Notably, we observed a stronger correlation between the marginal utility of the number of books at home and indicators such as GDP and HDI. This positive trend implies that as nations advance economically and socially, disparities in book ownership exert a greater impact on student achievement. This finding aligns with prior research utilizing books at home as a proxy for SES, reflecting both economic resources and a household's emphasis on literacy and education (15). Such environments foster cognitive development and literacy skills, which are critical for academic success (20). We suggest that in developed nations where basic education resources are established, additional assets like books become key differentiators in performance, though this relationship warrants further specific study.

Turkey stood out in our study with a high marginal utility for books despite a middle-range development level, potentially linked to literacy gaps between SES groups (21). Furthermore, we contrasted the US and Japan regarding the marginal utility of a school's economic composition. The US, with its decentralized system funded by local property taxes, exhibits significant funding disparities (22), a pattern clearly

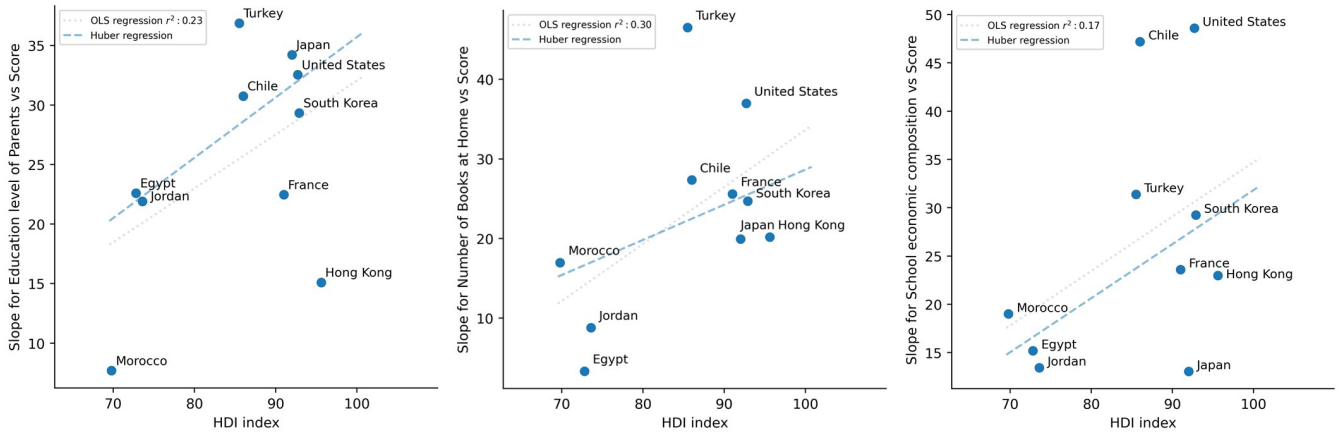

Figure 3: Scatter plot of regression slope of the education level of parents (A), books at home (B), or economic composition of school (C) and score with Human Development Index (HDI). Panel A shows the regression slope of the educational level of parents, panel B shows the regression slope of the number of books at home, and panel C shows the regression slope of the economic composition of the school. All of these variables are derived from the previously shown regression with aggregate score and compared with HDI of the nation for an insight into their relationship with social development.

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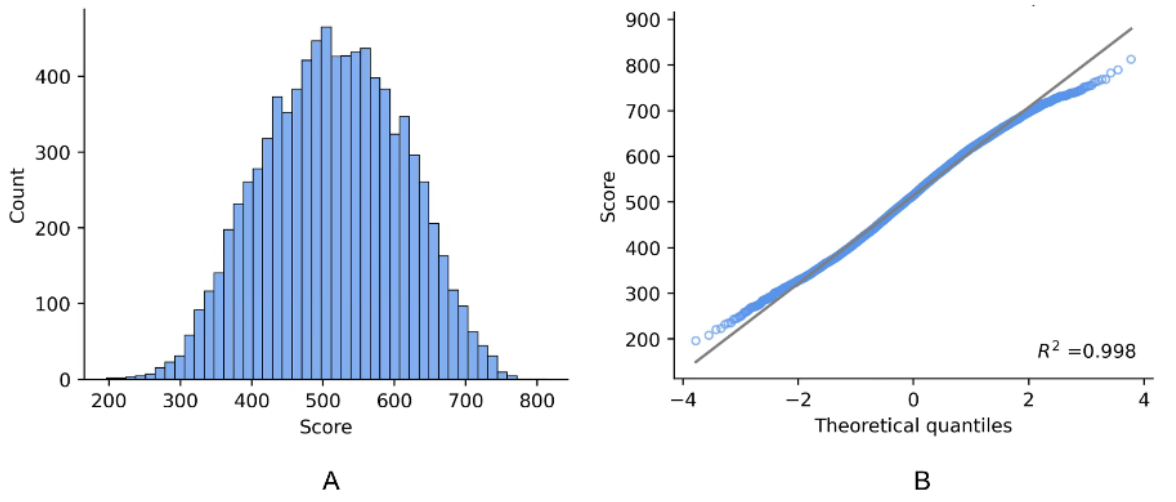

Figure 4: Distribution (A) and normal distribution of quartile-quartile plot (B) of the aggregate test scores of US students in 2019 (n=8698). The normal distribution plot on panel A shows the grade distribution of US students, which forms a normal distribution pattern. The quartile-quartile plot on panel B shows an R2 value of 0.998. The distribution of scores range from 0 to 1000.

reflected in our data (**Figure 3c**, **Figure 4c**). In contrast, Japan's centralized approach mitigates regional differences, resulting in a weaker correlation between school economic composition and achievement (23). Overall, the analysis of the "number of books at home" remains consistent with results showing a generally strong relationship that weakens in less developed nations (15).

This study has several strengths. The use of the TIMSS dataset allowed for an in-depth analysis of mathematics achievement alongside multiple socioeconomic predictors. Aggregating student scores with SES factors at the individual level provided a nuanced understanding of achievement disparities. Additionally, analyzing the marginal utility of SES factors offered insights into how a nation's level of development influences education inequality. These findings align with trends observed in other datasets, such as PISA, reinforcing the validity of the results (16). However, this study also has limitations. The small sample size of eleven nations and the limited number of analyzed variables constrains the scope of the findings; expanding the dataset could provide a more comprehensive understanding of these broader trends. Moreover, this study only investigated eighth-grade students, whereas analyzing multiple grade levels could potentially lead to deeper insights and reveal previously unseen patterns. Finally, using data only from 2019 is a major limitation, as the findings may not accurately reflect current achievement levels due to subsequent education disruptions caused by the COVID-19 pandemic.

The findings and analyses outlined above suggest key considerations for education policies in both developed and developing nations. For developed nations grappling with education inequality, the priority should be ensuring adequate resources for disadvantaged schools and students to help mitigate the impact of SES disparities. These resources include early child education for low-income families and affirmative action, as suggested by Alves (3). In developing nations, while education is widely recognized as a driver of economic and social progress, policymakers must also be mindful of the risk of exacerbating inequality. Without institutional measures to address disparities, the influence of SES on education outcomes may intensify. Research from Leila and Kimpo supports the idea that systemic, targeted interventions such as scholarships and funding for underprivileged schools are integral to lessening inequality (24). Future research should expand the scope of analysis by including a greater number of nations and variables. Additionally, exploring alternative analytical methodologies could provide more detailed insights and a broader understanding of global trends in education inequality.

MATERIALS AND METHODS

Dataset and Nation Selection

The data used in this study was accessed from the official website of TIMSS 2019 dataset for eighth-grade students. We focused only on math scores for this study, excluding science scores. The following eleven nations were selected for the analysis: South Korea, US, Japan, UK (United Kingdom), France, Hong Kong, Jordan, Morocco, Egypt, Chile, and Turkey. We intended to represent various continents, each being represented by 1–2 nations. Data from most nations in Southeast Asia and South America were not available. Among the selected nations, the US represents North America; South Korea, Japan, and Hong Kong represent East Asia; Jordan and Turkey represent Middle Eastern Asia; the UK and France represent Europe; Morocco and Egypt represent Africa; and Chile represents South America.

Relevant Variables

For the initial regression, the exogenous explanatory variables (covariates) are selected TIMSS categorical variables measuring inequality: the highest parental education level, number of books at home, and the school's socio-economic composition (**Table 1**). The endogenous response variable is the aggregate score for student mathematical ability. The TIMSS dataset provided question codes and student answers; to calculate points, each response was

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compared to a correct-answer codebook. We obtained an aggregate score by summing the binary correctness of each student's responses. All subsequent statistical analyses used this resultant score data, targeting general mathematical proficiency and avoiding overemphasizing any particular skill. Since the considered TIMSS variables were ordered categorical, applying regression models requires care. While regression approaches are common in TIMSS literature, we provide a clear exposition of modeling assumptions to justify our approach (15, 25, 27).

We assumed all explanatory variables to be deterministic and reliably measured, satisfying the common weak-exogeneity assumption, and we assumed homoscedasticity. Treating ordered categorical variables as continuous implicitly assumes linear spacing between categories, typical for TIMSS data analyses (25). The only variable where this assumption was unreasonable is the number of books at home. However, this non-linear spacing is unimportant in practice because we used the categories as a proxy metric for family wealth, rather than measuring the marginal utility per individual book. Similar wealth-proxy approaches exist in literature, with some deriving a home background index using a linear combination of parents' educational level and books at home (26-27). We did not combine books at home with other variables, as we aimed to investigate its marginal utility on a per-nation basis, accounting for differential levels of digitization and book ownership.

Finally, as our considered regressions are univariate, perfect multicollinearity was not an issue. We also assumed independence of observations, meaning a student's score cannot directly affect others (i.e., exams were proctored without significant cheating). This is reasonable as students receive individual test booklets with differing question subsets and orders. In light of these considerations, the regression modeling approach is justified.

Data Analysis

Datasets and regression analyses were divided by nation.
Python 3.11 (pandas, NumPy, Matplotlib, statsmodels, scikit-learn) was used for data processing, visualization, and statistical regression. Scores followed an approximately normal distribution per-nation, as expected for large student samples. The graphed aggregate US score distribution and quantile-quantile plot (**Figures 4-5**) showed minor tail deviations due to score truncation, but the normality assumption remained reasonable.
Other nations exhibited similar normal distributions with slight tail variations. To prevent response variable predictions from being exaggerated by tail effects or skewness, we applied a robust Huber regression instead of ordinary least squares (28-30).

To limit outlier influence, the Huber penalty matches the ordinary least squares penalty for residuals below a cutoff threshold M, but reverts to an l_1 like penalty outside $|r| < M$. Because outliers fall outside this region, we successfully reduced their effect on the estimated regression response. We believe this novel approach for TIMSS dataset analysis is completely justified.

For example, comparing non-robust and robust regressions on US school composition data (**Figure 4a**) revealed comparatively lower outlier scores in the quartile-quartile plot (**Figure 4b**). These outliers lowered the non-robust model's slope, exaggerating the effect of school composition. While both models had visually similar, significant non-zero slopes, they indicated differing average increases (22 vs 28 points) and a 21-point baseline difference, significantly altering the interpretation of empirical effectiveness.

Number	Meaning
Highest education level of parents	
1	Some <Primary education—ISCED Level 1 or Lower secondary education—ISCED Level 2> or did not go to school
2	<Lower secondary education—ISCED Level 2>
3	<Upper secondary education—ISCED Level 3>
4	< Post-secondary, non-tertiary education—ISCED Level 4>
5	<Short-cycle tertiary education—ISCED Level 5>
6	<Bachelor's or equivalent level—ISCED Level 6>
7	<Postgraduate degree: Master's—ISCED Level 7 or Doctor — ISCED Level 8>
Number of books at home	
1	None or very few (0–10 books)
2	Enough to fill one shelf (11–25 books)
3	Enough to fill one bookcase (26–100 books)
4	Enough to fill two bookcases (101–200 books)
5	Enough to fill three or more bookcases (more than 200)
School economic background	
1	More affluent
2	Neither more affluent nor more disadvantaged
3	More disadvantaged

Table 1: Original scales and meanings of each variable. Each row shows the number shown in the TIMSS data and their corresponding meaning taken from the data dictionary.

Consequently, we analyzed the score distributions using Huber regression and significance testing to obtain per-nation predictive indicators of mathematical achievement, providing a systematic analysis.

We analyzed score distributions using Huber regression and significance testing to obtain per-nation predictive indicators of mathematical achievement. This systematically analyzed correlations between sociological explanatory variables across nations. Using overall score as a measure of utility, we compared the empirical marginal utility, defined as the regression's x-variable coefficient, of explanatory variables across nations.

Following statistically significant results, a second analysis round focused on marginal utility derived from the robust regression. Adapted from economics (32), marginal utility here represents the change in academic achievement points per one-point increase in an individual's socioeconomic status variable. We plotted each nation's marginal utility points alongside its GDP per capita and HDI to investigate if social or economic development levels affect how strongly socioeconomic factors influence education inequality.

Nation Classifications

For the purposes of this investigation, the classification of developed nations and developing nations was based on their income level. The World Bank's nation classifications

by income level were the standard used to determine a nation's overall development. According to the World Bank Data Team, low to lower-middle income nations have a Gross National Income (GNI) per capita of $3,995 or lower, while upper-middle to high income nations have a GNI per capita of $3,996 or higher (32).

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APPENDIX

Google Drive link to code used in analysis:
https://drive.google.com/file/d/1BEXb2XjJpv4wniFhZdqGYqXFM5B2MQ-f/view?usp=drive_link