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Revolving Doors: Cross-Country Comparisons of the Relationship between Math and Science Teacher Staffing and Student Achievement

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ABSTRACT

Staffing classrooms with effective teachers remains a persistent policy challenge in the U.S. Teaching positions requiringSTEM expertise are particularly difficult to fill. Scholars have identified similar trends in other industrialized nations. Yet, limited research examines international comparisons of the causes and consequences of staffing challenges. We use the 2015 Trends in Mathematics and Science Study to track teacher staffing difficulties in 27 countries. We find substantial variation across countries in the proportion of principals reporting difficulties filling STEM positions, with U.S. schools mirroring international averages. We also find consistent relationships between lower math and science achievement and attending a hard-to-staff school.

Leaders of high-performing schools rely on qualified and effective teachers to support student learning (Leithwood et al., 2004). The staffing process is especially arduous at schools considered "hard to staff,"sites that experience high turnover as well as difficulty in recruiting and retaining qualified teachers (Opfer, 2011). Staffing difficulties are assumed to affect students in a variety of negative ways (Peske & Haycock, 2006; Ronfeldt et al., 2013). For instance, teacher turnover diverts financial and professional development resources away from schools and districts (Darling-Hammond, 2003; Watlington et al., 2010). Principals at schools with high teacher turnover must devote more time and money toward recruitment, interviewing, and supporting novice teachers often at the expense of other activities and expenditures (Grissom, 2011; Hughes et al., 2015).

Students at hard-to-staff schools must also readjust to the revolving door of new and/or underqualified teachers, making relationship building within the school more challenging. A growing literature area shows thata constantly changing faculty can have a toll on students' academic achievement and behaviors (Glazer, 2018).While much of this work is based on U.S. schools, scholars have identified similar trends in other industrialized nations (Allen et al., 2018; Sargent & Hannum, 2005). However, little prior research examines how the influence of teacher turnover on student achievement in U.S. schools compares to that of other countries.The purpose of our study is to examine the quantity of, and challenges facing, hard-to-staff schools in both the U.S. and international context.

Although a variety of social and demographic factors can contribute to school staffing issues, school funding and income inequality are often related to teacher quality and teacher shortages (Chiu & Khoo, 2005). Studies suggest school related effects such as inequitable access to qualified teachers are most pronounced and influential in countries with more inequality (Chudgar & Luschei, 2009). Moreover, decentralized educational systems, such as the U.S., often lead to a concentration of the lowest-income, lowest-achieving students into the most underfunded and underperforming schools and districts. For instance, some legislation, including the No Child Left Behind Act of 2002 in the

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U.S., may have further incentivized American teachersto leave challenging, underfunded environments for higher salaries and higher-performing students (Clotfelter et al., 2004; Darling-Hammond, 2007). Even in more economically diverse schools, or countries with a centralized educational system (and more equity of resources), the distribution of teacher quality often privileges more affluent students through tracking and informal gatekeeping (Chiu & Khoo, 2005).

This study examines hard-to-staff schools in the U.S. and around the world to understand how attendance at these schools is associated with individual studentmath and science achievement. Moreover, we consider how access to well-staffed schools relates to income inequality both between and within countries. Previous international studies examine the role of teacher quality measures such as experience (Akiba et al., 2007; Baker et al., 2002) and satisfaction (Mostafa & Pál, 2018), but to our knowledge, no previous studies have conducted a systematic comparative analysis linking school staffing to individual math and science achievement. The aim of this study is to provide a clear picture of teacher shortage trends in the U.S. and other countries and how they relate to *academic achievement* as well as the relationship between economic inequality, shortages, and achievement. Past research has investigated the factors contributing to high teacher turnover in both the U.S. and international context. However, analyses that examine student outcomes typically rely on either school orcountry-wide achievement data (R. Ingersoll, 2001; R. Ingersoll, 2011) or teacher perceptions of how teacher shortages affect academic progress (Micklewright et al., 2014; Osborne & Dillon, 2008) rather than using individual student-level data.

Our study utilizes Trends in Mathematics and Science Study (TIMSS, 2015) data onalmost188,0008th grade students from the United States and 26other countries, to examine the relationship between attendance at a hard-to-staff school and individual math and science achievement. One advantage of using TIMSS data is thatwe are able control for and compare the relationship with other measures of resource inequity such as physical resources and peer composition. Moreover, we can explore whether the U.S. differs from other countries on these measures or whether there are universal trends across countries. Specifically, we ask:

(1) To what extent is country-level income inequality associated with country-level math and science achievement?
(2) What percentage of students attend hard-to-staff schools and to what degree is attendance at a hard-to-staff school related to math and science achievement in the United States and other countries around the world?
(3) To what extent is student SES related to attendance at a hard-to-staff school in the United States and around the world?

Hard-to-staff schools

Wide disparities in school conditions in the U.S. have motivated inquiry into educator staffing and retention challenges. The majority of studies suggest an inverse relationship between high attrition schools and student achievement (Hanushek et al., 2016; Ronfeldt et al., 2013). Moreover, the most extreme teacher attrition in the U.S. usually occurs at the poorest and lowest-achieving schools, thus compounding disadvantage (Guin, 2004; Macdonald, 1999; Rice, 2010; Simon & Johnson, 2015). Even when schools with low-performing students attract high-quality teachers, they often have difficulty retaining them due to burnout, proximity to the teachers' home, and the allure of higher-paying, higher-achieving districts (Boyd et al., 2005; Reininger, 2012). Glazer (2018) points out that even effective teachers may leave the profession due to fatigue around constantly changing policies. As a result, lower-performing schools in the U.S. may experience a revolving door of inexperienced and under-qualified teachers (Peske & Haycock, 2006). The students, their teachers, and their principal at hard-to-staff schools thus find themselves at a significant disadvantage on a variety of inputs and outputs including academic performance.

Although the U.S. context illuminates many important factors and consequences of hard-to-staff schools, a comparative international approach affords researchers a means for further evaluating influences such as the role of inequality and occupational prestige of teachers. International studies of teacher staffing report wide variance between countries due to unique labor markets (Ladd, 2007), the social prestige of teachers (Zhan, 2015), job satisfaction (Mostafa & Pál, 2018) and other nuances of the educational system in each country. However, it is still quite difficult to pinpoint regional patterns in teacher shortages given the heterogeneity of conditions over time and between neighboring countries. For instance, a report on science, technology, engineering, and math (STEM) teachers in Europe found that Cyprus, Finland, and Portugal were identified as countries where teaching positions are extremely competitive, as contrasted with England, where there is a severe math and science teacher shortage despite heavy recruitment and favorable compensation (Allen et al., 2018). A study of 2000 PISA data explored which countries had high teacher shortages, teacher perceptions on if teacher shortages hindered academic progress, and which school level factors may be related to teacher turnover (White & Smith, 2005). Again, there was wide variance across Europe and North America, but Japan and South Korea reported lower levels of shortages and turnover.However, a more recent study using the Teaching and Learning International Survey (TALIS) 2013 data actually indicated that Japan had some of the highest levels of teacher shortages and inadequate teacher staffinglevels (Burns & Darling-Hammond, 2014). One possibility to explain inconsistencies over time suggests that cycles occur where systems allocate resources to recruitment and retention when shortages become severe and then shortages return.

In some cases, unique teacher labor market conditions contribute to school staffing challenges. Demographic conditions such as age and job stability contribute to these labor conditions in different ways. For example, we previously mentioned Portugal as a competitive labor market. In an analysis of 19 OECD nations, Mostafa and Pál (2018) identified Portugal as having older teachers on average, but also documented that teachers in that country experienced great stability in their jobs. Therefore, older teachers in countries such as Portugal may choose to retain these positions as long as they can. The recent labor market of Japan and many other European countries suggests staffing issues may be escalating due to a retiring teaching force (European Commission, 2012). Conversely, the U.S. produces more young teachers than ever, but shortages still exist in STEM fields and in many high-poverty schools (Cowan et al., 2016; Liu et al., 2008; Perrone & Eddy-Spicer, 2019). Even when countries have an ample supply of qualified teachers, teachers leave mid-career for a variety of reasons (Glazer, 2018; R. Ingersoll, 2002). Easy-to-staff schools, which often have greater resources and stable leadership (R. Ingersoll, 2011), are able to more easily support new teachers, preventing future turnover.

Although economic indicators and demographic trends can help explain shortages, cultural differences in the prestige of teachers is also important to consider (Hargreaves, 2009). Fwu and Wang (2003) highlight the relatively high status of teachers in Taiwan and find that the prestige results in quite high retention. Fwu and Wang (2003) trace this favored cultural status of teachers in Taiwan to historical influences of both China and Japan as well as governmental policies and selectivity of teacher preparation programs in the country. Policies in Finland promote the status of the teaching in many ways (Sahlberg, 2013). For instance, teacher education programs in Finland are selective and subsidized while all teachers must possess a master degree (Darling-Hammond, 2017). Prestige can be measured in both public perception as well as financial compensation awarded to teachers. In the case of East Asian countries such as Taiwan and Northern European countries such as Finland, teachers enjoy both forms of prestige (Hargreaves, 2009; Hwang et al., 2007). Scholars also find that teachers may be highly valued in less developed countries such as Cyprus or Dominican Republic, in part due to fewer professional jobs (Mostafa & Pál, 2018; Zembylas & Papanastasiou, 2004). Teachers in the U.S. and England have much lower prestige than some of these highlighted countries contributing to higher turnover (Hargreaves, 2009). In sum, a variety of diverse contextual factorsincluding demographics and teacher prestige can create hard-to-staff conditions.

Theoretical framework

As part of our theoretical framework, we examine why attending a hard-to-staff school is thought to be detrimental to students and why inequality is thought to be a driving force related to the prevalence of hard-to-staff schools. We theorize that attending a hard-to-staff school will indeed have adverse relationships, on average, with individual academic outcomes (Allensworth et al., 2009; Holme et al., 2018). Despite a general consensus on the adverse effects of staff shortages, it is possible that some teacher departures benefit schools and students (Grissom & Bartanen, 2019). Some researchers point out that lower-performing teachers are more likely to leave a school through termination, transfers, or resignations, giving school leaders an opportunity to select teachers that better fit the school culture (Guin, 2004; Perrone & Eddy-Spicer, 2019). Thus, there is evidence that teacher *attrition* can be positively associated with student achievement in some cases where a strong supply of replacement teachers exists (Adnot et al., 2017). However, researchers make a distinction between a high attrition or high turnover school and one that has chronic instability (Holme et al., 2018) or what some classify as hard to staff. Hard-to-staff schools often do not select which teachers leave and they do not have a large pool of high-quality applicants – especially in critical areas such as math and science (Berry, 2004; Hughes et al., 2015).

Scholars face several challenges in identifying the impact of staffing difficulties on student achievement. Do students perform worse academically because they attend a hard-to-staff school or do teachers want to leave the school in part because of lower performing students? Research suggests that the two casual directions are not mutually exclusive. We operate under the assumption that teachers are likely to leave lower-achieving schools for various reasons such as lower salary, challenging classroom environments, and principal turnover (Boyd et al., 2005; Johnson et al., 2012; Wang et al., 2019). In fact, Wang et al. (2019) analyzed international teacher data and found that low-academic performance was not significantly related to teacher satisfaction, though classroom disciplinary climate and principal satisfaction predicted teacher satisfaction. At the same time, the revolving door of new and/or lower-quality teachers adversely affects student learning. By the very nature of being defined a hard-to-staff school, that school is not able to pick and choose top teachers, especially in shortage areas such as STEM. The hard-to-staff status, which disproportionately affects poorer and heavily minority schools results in more hiring of novice teachers and teachers who are considered "out of field" – those who lack a college major or minor in the subject taught (Peske & Haycock, 2006).

A second aspect of our theoretical perspective addresses the role of macroeconomics on staffing issues. Although staffing trends are in part related to a country's educational values and policies, macroeconomic forces also play a notable role (Nagler et al., 2015). Both the overall size of the economy as well as the extent of income inequality have been found to be related to measures of teacher quality and staffing (Chiu & Khoo, 2005).For example, the U.S. has relatively high income inequality as well as weak unions in some Southern states making staffing of high-quality teachers more difficult(Han & Keefe, 2020).Conversely, the so-called social democracies of Northern Europe (including Sweden, Denmark, Finland, and Norway) are thought to have lower teacher turnover due to their relative wealth and low inequality combined with highly centralized educational systems/ compensation structures (Falch & Strøm, 2006). These social democracies traditionally have few private schools and strong collective bargaining that theoretically decreases the incentive to exit a particular school (Bonesrønning et al., 2005). Yet, researchers find that even in countries with *less* inequality, there is still stratification of both overall resources and the most qualified, experienced teachers (Chiu & Khoo, 2005).

Other macroeconomic conditions affect educational systems. For example, Chudgar and Luschei (2009) find that school resources have a stronger relationship with math and science achievement in countries with greater income inequality. Resource disparities affect teacher labor markets in several key ways. In the U.S., for instance, many poorer districts – which tend to be challenging settings for some teachers – simply offer lower salaries (Hanushek et al., 2004; U. S. Department of Education,

2018).In analyzing both U.S. and international samples, Zhang et al. (2008) found teacher salaries were related to job satisfaction, retention, and student achievement. Additionally, a lack of resources may discourage teachers from remaining at a particular school if they feel they cannot effectively teach or if they are constantly spending their own money on classroom materials. The U.S. is one of the few developed countries characterized by high inequality. Therefore, the U.S. fills harder-to-staff positions by relaxing credential requirements, establishing alternate certification programs such as Teach for America, and by offering free graduate training (Hargreaves, 2009). Countries in the "global South" with less wealth and more inequality may have more difficulty in seeking government interventions to fill these shortages. Still, overall, we hypothesize that countries with more inequality will have greater shares of hard-to-staff schools.

Data and methods

The study utilizes 8th gradedata fromTrends in Mathematics and Science 2015 (TIMSS). Overall, our sample of 8th graders included 187,751 students from 27 countries. TIMSS provides nationally representative data for each country capturing information on approximately 4,000 8th graders attending around 150–200 schools per country (Foy, 2017). Some countries in the sample had over 10,000 students. School principals were asked about the difficulty of filling math and science teacher positions with potential responses including "no vacancies"; "easy to fill vacancies"; "somewhat difficult"; and "very difficult".Countries were not included if they did not have respondents in all four staffing categories. The sample for science only included 25 countries as Korea did not have any teachers in the hard-to-staff category and Hungary did not administer that particular question.

Outcome variables include math and science achievement. The 8th grade math and science tests assess proficiency in different discipline domainsand use item response theory (IRT) to estimate performance around an international mean of 500 with each 100 points representing a one-unit standard deviation. The independent variable of interest is the difficulty in filling grade 8 math and science teacher positions. Since the questions on staffing refer to filling positions last year, it precedes the student tests given out during 8th grade. Although this temporal order does not translate to causal analysis, aligning students' exposure to staffing challenges with later exam results allows for predictive inferences. Control variables include gender, a continuous scale of family educational resources (as a proxy for SES), acategorical variable for percent disadvantaged studentsat school(0–10%; 11–25%; 26–50%; more than 50%), and a question for principals on whether resource shortages inhibited learning. Originally, higher values indicated resources were less of a problem, but we reverse-coded this variable to simplify interpretation so that negative values indicate a negative relationship between resource shortage and achievement.

As noted above, our three research questions examine: (a) whether inequality influences math and science achievement across countries; (b) how the relationship between staffing challenges and math and science achievement differs across countries; and (c) the extent to which student SES is related to the likelihood of attending a hard-to-staff school. We employed several descriptive and inferential statistical methods for this study. First, for research question 1, we analyze how much, in general, country level achievement was correlated with the Gini Coefficient, which measures inequality of wealth. Gini coefficients were obtained from the World Bank website. Using these data, we ran simple correlations, with countries graphed on scatterplots for math and science achievement by degree of inequality. For the second research question, we first ran tabulations to see the distribution of students attending each type of school (e.g., hard to staff, no vacancies) for the entire sample and for each country. Stacked bar graphs depict the distribution separately for both math and science teachers. We then ran a series of Ordinary Least Squares (OLS) regressions for each country. A baseline model examined the relationship between staffing category and math achievement, using "easy to fill" math teacher vacancies as the reference group. The second model added the various individual and school SES measures as well as a control for gender. Models 1 and 2 were then repeated using science achievement as an outcome. Finally, in order to better understand the relationship between student

SES and attending a hard-to-staff school, we ran a series of multinomial logistic regressions with easy to staff serving as the reference category. For each regression analysis, we user recommended weights (student weight in this case), calculate averages for the five plausible values for test scores and their corresponding standard errors, and run the jackknife replication technique (JRR) in order to obtain minimally biased standard errors and values.

Findings

Overall, we see that inequality has a moderate correlation with science and math achievement (Figure 1). On average, as country inequality increases, math and science achievement scores decrease. Table 1 provides more information on individual countries. These countries ranged in terms of income inequality with Western European and East Asian nations, largely, exhibiting less inequality. Scandinavian countries such as Sweden and Norway have extremely low Gini coefficients, suggesting low levels of inequality. The U.S. has the fourth highest level of inequality in the sample, only trailing Turkey, Saudi Arabia, and Chile. In general, countries in the global south (Africa, South America, the Middle East, and Southeast Asia) along with the U.S. have the highest inequality. Countries in the Middle East had large variation in inequality, with Egypt and Jordan having lower inequality while Saudi Arabia, Turkey, and Israel had quite high levels. The two countries with the starkest inequality – Chile and Saudi Arabia – have below average math and science achievement. Still, it appears that achievement mostly varies by geographic region with Middle Eastern countries and Southeast Asian countries having low levels of science and math scores. The U.S. and Israel represent an anomaly with high inequality and above average math and science performance. These regional patterns and outliers suggest that other curricular and economic factors (e.g., availability of STEM jobs) also contribute to math and science performance.

Next, we turn to the overall prevalence of staffing difficulties. Schools with reported hard-to-staff math teacher positions for 8th grade appear to be common across the world with particular countries having more extreme shortages (see Figure 2). The proportion of students in the U.S. who attended a school that was hard or somewhat difficult to staff with math teachers mirrored the international averages. For instance, about 5% and 16% of both U.S. students and the entire sample attended schools with principals reporting that it is very hard to staff or somewhat hard to staff math teachers. In terms of science teachers, the U.S. and the entire sample had similar rates of students attending schools

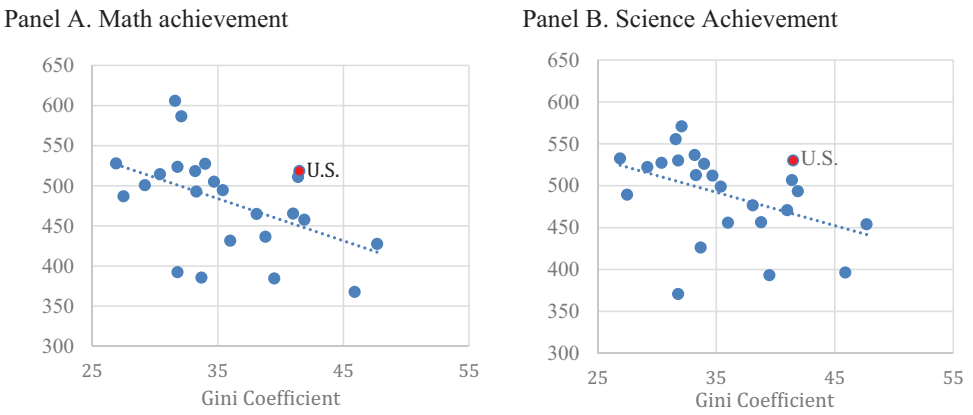

Figure 1. The relationship between income inequality and math and science achievement across countries, 2015. *Note*. r = 0.48 for math and 0.42 for science. Higher Gini coefficients imply greater income inequality.

Table 1. Income inequality and student achievement by county, 2015.

Country	Gini Coefficient	Math Achievement	Science Achievement
Kazakhstan	26.9	527.81	532.59
Norway	27.5	486.77	489.22
Sweden	29.2	500.72	522.27
Hungary	30.4	514.41	527.26
Korea, Rep.	31.6	605.74	555.60
Egypt	31.8	392.23	370.78
Ireland	31.8	523.49	530.10
Japan	32.1	586.47	570.90
England*	33.2	518.26	536.63
New Zealand	33.3	492.72	512.68
Jordan	33.7	385.55	426.16
Canada	34.0	527.28	526.17
Australia	34.7	504.96	511.99
Italy	35.4	494.39	498.93
Thailand	36.0	431.42	455.84
United Arab Emirates	38.1	464.78	476.65
Islamic Republic of Iran	38.8	436.35	456.42
Morocco	39.5	384.39	393.25
Malaysia	41.0	465.31	470.82
Israel	41.4	510.90	506.73
United States	41.5	518.30	530.00
Turkey	41.9	457.63	493.40
Saudi Arabia	45.9	367.72	396.42
Chile	47.7	427.43	453.97
Bahrain	NA	453.95	465.85
Oman	NA	403.16	454.56
Kuwait	NA	392.47	410.74
Sample Average	35.73	474.50	485.17

Source: Authors' calculations based on Trends in Mathematics and Science Study data, 2015data.

where it was somewhat difficult to fill positions (around 17%), but there were slightly more students in the U.S attending the hardest to staff schools (over 7% compared to about 6%).

England, a country with lower levels of inequality and relatively high math and science scores, had the most severe STEM teacher shortages with almost a quarter of students attending a school where it was very difficult-to-fill math positions and about the same amount attended schools where it was very difficult-to-fill science teacher positions. When the very difficult and somewhat difficult categories are combined, over two-thirds of English students attended a hard-to-staff science teacher school and almost two-thirds attend a hard-to-staff math teacher school. Students in Sweden and Thailand also had high levels of difficult (somewhat or very) tostaff schools – over 40% in both math and science. Canada, Korea, and Japan all had less than 10% of students attend schools where staffing was an issue (combined somewhat or very difficult to staff schools).

Next, we examine the second research question regarding the relationship between attending a hard-to-staff school and math and science achievement. It is helpful to remember here that 100 points is equal to one standard deviation. We first ran the baseline regression comparing the math averages by country and staffing category. Students at schools where it was easy to fill a math teacher positions scored higher than those at schools where it was hard to fill math teacher positions in 21 of 27 countries in the sample. The countries that had the largest math achievement disadvantages between easy to staff and hard-to-staff schools included the U.S., Egypt, Chile, Japan, England, and the United Arab Emirates. Somewhat surprisingly, Japan – a country with only moderate inequality – had the largest achievement disparity with the difference between an easy to staff and hard-to-staff school being associated with a 95-point difference on achievement (roughly one standard deviation).

We then ran the multivariate analysis for math achievement in model 2, highlighting the U.S. as well as Chile and Japan due to their statistically significant relationships between staffing and math achievement (Bahrain and United Arab Emirates also had statistically significant relationships). The

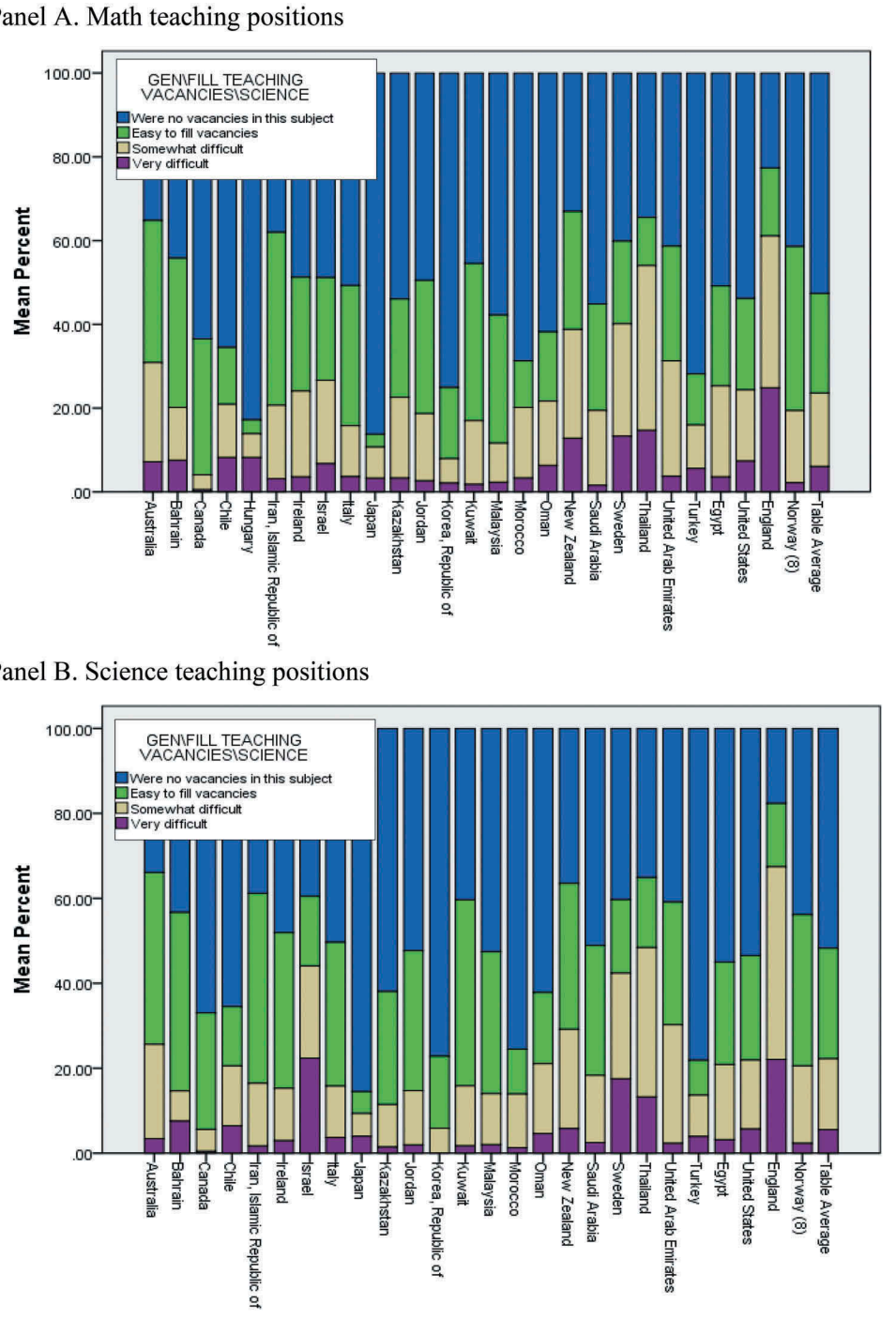

Figure 2. Reported Difficulty in Filling Math and Science Teaching Positions, by Country. Note: TIMSS includes both 8th and 9th graders for Norway, but these analyses only include 8th graders for sake of consistency

first two columns of Table 2 show results that group together all countries in our sample. Overall, on average, students that attended schools where it was easy to staff math teachers scored higher than students that attended schools with no vacancies and that were classified as hard to staff at

Table 2. Regression Coefficients Predicting the Relationship between Reported Math Teacher Staffing Difficulties and Math Achievement for the United States and Select Countries.

	Overall Average		United States		Chile		Japan	
	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
Staffing								
No Vacancy	−6.94*	5.49*	−7.85	−11.01~	1.55	−4.83	−66.75*	−46.31
Some Diff	−8.38*	−3.98~	−14.79	−13.02	6.55	−6.30	−75.39*	−47.54
Very Diff	−15.38*	−9.25*	−39.04*	−19.82	−31.36*	−22.16*	−94.85*	−64.64*
School SES		−12.31*		−14.65*		−22.19*		−14.14*
Resource Shortage		−1.50*		−1.50		−5.66*		−2.50
Student SES		15.67*		15.86*		12.30*		22.01*
Female		−1.82*		5.76*		18.34*		0.62
Constant	481.14*	332.23*	527.68	381.47*	428.68*	319.68*	652.85*	388.04*

The reference group for reported staffing difficulties is "math positions are easy to fill." ~p <.10; *p <.05.

a statistically significant level (and marginally significantly higher than some difficulty in staffing). Students at hard-to-staff schools scored the lowest, on average, at almost 10 points below students at schools where it was easy to find math teachers, controlling for all model variables. Student SES and the percent of disadvantaged students were also statistically significant predictors of math achievement across the sample and in almost all individual countries. Resource shortage was significant for the entire sample, but only in a handful of individual countries.

Two countries where attending a hard-to-staff school was particularly related to lower math achievement were Chile (a country with high inequality) and Japan (a country with lower inequality) and we report findings for these two countries for comparison in Table 2. In Japan, although there were not many students who attended a hard-to-staff school, attending a hard-to-staff school was associated with around two-thirds of a standard deviation lower math score (−64.64) than students at school where it was easy to hire math teachers. These results are shown in the final column of Table 2. Notably, student SES was also a highly salient predictor in Japan despite the relative low inequality in the country. Conversely, it was not as surprising to see how in Chile, attending a hard-to-staff school as well as school SES and having a perceived resource shortage were all inversely related to math achievement at statistically significant high levels. In sum, attending a hard-to-staff school appears to be harmful to student achievement in math, but the relationship is not more pronounced in countries with more inequality including the U.S.

Science results

Overall, students attending schools where it was hard to find science teachers performed worse than those in easy to staff schools in 18 of 25 countries (Hungary and South Korea not included here). On average, attending a hard-to-staff science teacher school was related to almost a 20 point disparity in achievement, compared to easy-to-staff schools (p <.05). Students at hard-to-staff schools in Egypt, Japan, Kuwait, United Arab Emirates, Australia, and Canadaall scored more than 40 points lower than their peers at schools where it was easy to find science teachers, while Turkey and the U.S. both had over 35 point disparities. Conversely, students at hard-to-staff schools in Kazakhstan actually scored over 114 points – or more than one standard deviation – higher than their peers in easy to staff schools. Even with the relatively low inequality in Kazakhstan, we would not expect such an anomaly. Further, only one other country, Israel, had a marginally significant advantage for students at hard-to-staff schools, albeit much smaller than Kazakhstan.

Similar to math teacher vacancies, the multivariate analysis for science achievement reveals that while attending a hard-to-staff school was inversely related to science achievement, socioeconomic variables were usually more salient predictors. Controlling for all model variables, attendance at

a hard-to-staff school was associated with almost 13 fewer points on the science test ($p < .05$). However, on average, an increase of one standard deviation in student SES was associated with over 27 point increase on a student's science score. In terms of school SES, an increase in % disadvantaged category was also related to science achievement at a statistically significant level.

Despite the overall relationship between hard-to-staff schools and achievement, we only found a statistically significant effect in a few countries. Controlling for the model variables, attendance at a hard-to-staff science teacher school in the U.S. was associated with lower performance on the science test than students at an easy to staff school. On average, American students at hard-to-staff schools scored almost 16 points less than their peers where it was easy to find science teachers ($p < .10$). Notably, the two countries with the largest science achievement deficit between hard-to-staff and easy-to-staff schools were two countries with relatively lower inequality – Egypt and Japan. Students in Egypt's hard-to-staff schools scored almost 100 points, or 1 standard deviation, lower than their peers in easy to staff schools ($p < .05$). Although the science score disparity for Japanese students at hard-to-staff schools were not as large as the math scores for Japanese students attending schools where it was difficult to fill math positions, the difference for science was still quite large at almost 26 points ($p < .05$). Both Oceanic countries (New Zealand and Australia) as well as several Middle Eastern countries (Iran, United Arab Emirates, Turkey, and Kuwait)had marginallysignificantdisparities in science between students attending easy to staff and hard-to-staff schools ($p < .10$). Again, somewhat surprisingly, even when controlling for various student and school factors, students attending hard-to-staff schools in Kazakhstan outperformed their peers by almost an entire standard deviation (b = 91.76 points; $p < .05$). Importantly, student SES and school SES were consistently related to both math and science achievement. In Table 3, we report overall results and specific results for the United States, Egypt, and Japan. We selected Egypt and Japan as they stood out for having quite large, significant relationships between staffing and science achievement. Again, we found no evidence that the relationship with attending a hard-to-staff school on science was more pronounced in countries with more inequality and if anything the effect was actually more severe in countries with less inequality.

Further disentangling the relationship between SES and attending a hard-to-staff school can provide important insights for policy. While not causal, this post-hoc analysis can help us better understand the issue of access to high-quality teachers and to start thinking about how this access may affect other outcomes- both academic and socio-emotional ones. Lower-SES students were more likely to attend a school that had difficulty staffing math teachers, but some countries with less inequality did not follow the pattern. In the clustered bar graphs below (Figure 3a,b), we use multinomial logistic analysis to highlight countries where there were statistically significant differences between student SES and the likelihood of attending a hard-to-staff math teacher school (as compared to an easy-to-

Table 3. Regression Coefficients Predicting the Relationship between Reported Science Teacher Staffing Difficulties and Math Achievement for the United States and Select Countries.

	Overall Average		United States		Egypt		Japan	
	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
Staffing								
No Vacancy	−3.15~	−2.90~	7.44	−3.99	−11.19	−9.83	−19.35	−14.23
Some Diff	1.31	1.05	−11.06	−3.96	−28.28*	−18.25	−20.78	7.42
Very Diff	−18.63*	−12.80*	−35.31*	−15.74~	−105.35*	−92.61*	−46.46*	−25.97*
% Disadvantage		−11.80*		−13.61*		−5.78		−9.55*
Resource Shortage		−1.06*		−0.99		9.57*		−1.44
Student SES		27.31*		28.09*		18.20*		25.74*
Female		−8.60*		8.69*		−15.12*		0.40
Constant	485.53*	511.64*	529.84*	554.65*	385.01*	492.50*	590.41*	585.51*

The reference group for reported staffing difficulties is "science positions are easy to fill." ~p <.10; *p <.05

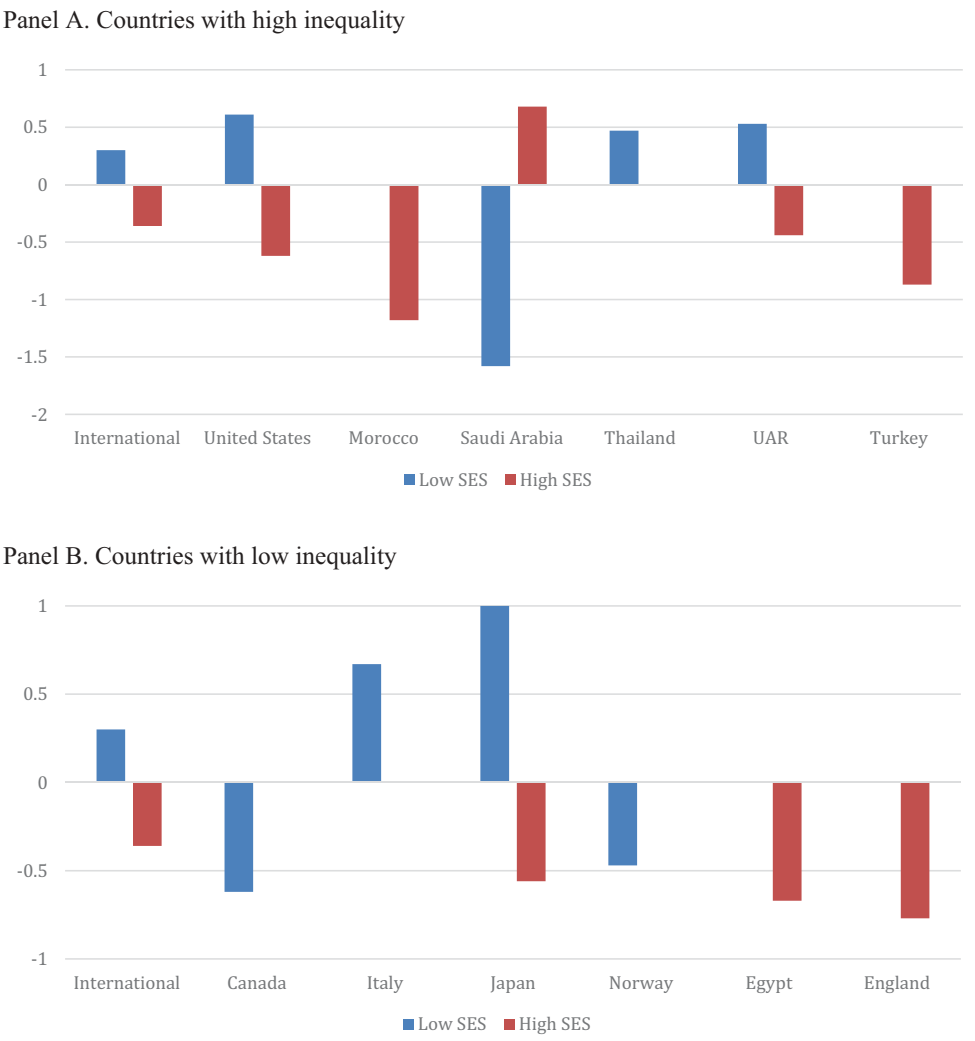

Figure 3. Multinomial logistic regression coefficients predicting the likelihood a student attends a hard-to-staff school, instead of an easy-to-staff schools, based on student's socioeconomic status. *Note*. Students' socioeconomic status (SES) and whether the principal of a school perceives teaching positions to be hard to staff are taken from the Trends in Mathematics and Science Study data, 2015.

staff school). Overall, when analyzing the full sample, we find that based on results for math teachers, lower-SES students were more likely to attend a hard-to-staff than an easy-to-staff school while higher-SES students were less likely to attend a hard-to-staff school. Results are generally similarly for science teachers (and are available from the authors upon request).

Figure 3 uses the Gini Index to focus on countries with higher inequality (Panel A) and lower inequality (Panel B). Of the countries with higher inequality, lower-SES students in the U.S., United Arab Emirates, and Thailand were statistically significantly more likely to attend hard-to-staff schools. In other words, poorer students tended to attend schools with teacher shortages. Conversely, higher-SES students in the U.S. and UAR, along with Turkey and Morocco, were statistically significantly more likely to attend schools where it was easy to replace math teachers (as noted by negative coefficients). Notably, Saudi Arabia was the only the country with higher inequality, according to the Gini coefficient, where lower-SES students were more likely to attend easy to staff schools and higher-SES students were more likely to attend hard-to-staff schools. Results are consistent when we

examined countries with less inequality. Lower-SES students were more likely to attend hard-to-staff schools in Italy and Japan and higher-SES students were more likely to attend easy to staff schools in Japan, England, and Egypt. However, lower-SES students in Canada and Norway – two countries associated with socially progressive policies – were more likely to attend easy to staff schools.

Discussion

In this study, we use international data to better understand the relationship between attending ahard-to-staff school and STEM achievement. Numerous studies document that lower-SES students in the U.S. are more likely to attend hard-to-staff schools as well as the extent that attendance at such schools is related to negative social and academic outcomes. However, this study examines whether the U.S. is exceptional in this regard or whether these trends are universal – either amongst other countries with high levels of inequality or all countries regardless of economic disparities. Overall, we find that many U.S. students attend hard-to-staff schools and these students perform worse than their peers at easier-to-staff schools, but these trends are not particularly unique compared to other countries.

Our results generally support our hypotheses that students in more unequal countries perform worse on average in math and science, lower-SES students are more likely to attend a hard-to-staff school, and attending a hard-to-staff school is inversely related with STEM achievement. However, despite the high level of inequality in the U.S., American 8th graders performed above average in math and science and the rates of attending hard-to-staff schools mirrored international averages. In terms of our second research question, we found that students in hard-to-staff schools in the U.S. performed far below the international average for math and science. Although the analysis of the full sample of students also suggested attendance at a hard-to-staff school was associated with lower scores, the margin for the U.S. was even larger. When we control for other factors such as student and school socioeconomic status, the relationship with math achievement ceases to be significant and it is only marginally significant for science for students in the U.S. This regression helps disentangle how much of overall math and science achievement was related to school and family resources and how much was attributable to attending a hard-to-staff school. Similar to most countries in the world, student socioeconomic status in the U.S. is a far stronger predictor than simply attending a hard-to-staff school. So while middle schools in the U.S. need to ensure students' access to a qualified math and science teacher, other social and financial factors warrant consideration.

The fact that many countries with low inequality such as Japan and Egypt had such large achievement disparities depending on staffing may suggest that staffing difficulties are actually more detrimental to achievement in countries with less educational resource inequality. When material resources differ little, human capital disparities such as staffing and the role of educational leaders may be more pronounced. It is also possiblethat other locational factors such as geographic isolation or environmental issues (e.g., high pollution area) contribute to staffing issues. It behooves these countries to explore exactly why certain schools experience difficulty in staffing and provide incentives and interventions to provide stability.

Our study suggests that school factors, students' socioeconomic status, and external, macroeconomic conditions are inter-relatedacross the world. Lower-SES students in the U.S. are more likely to attendhard-to-staff schools and the trend holds for most other countries globally. At the same time, we found thatin some cases, particularly in more socialized countries such as Canada and Norway, lower-SESstudents actually were less likely to attend hard-to-staff schools. This paradox may be explained by the fact that Canada's teacher pay scale is quite rigid regardless of where one teaches and salary is unrelated to student demographics or test scores. Conversely, in the U.S., many teachers may shy away from lower-SES students since lower-test score school districts often have lower salaries and less supportive working environments (Duncun & Murnane, 2011).Various policies could address this issue in the U.S.and abroad. The most promising policies would seek

systemic enrollment reform to break up rampant concentrations of poverty, but such initiatives remain unlikely in the U.S. due to political pressures from wealthier constituents. A more plausible course includes offering incentives – both financial and school supports – for teachers working at lower-SES schoolsin these countries.

Limitations and future directions of research

Although our study was quite comprehensive in how many students and countries we analyzed, the study also had key limitations. The TIMSS data is cross sectional meaning that staffing shortages in this analysis may not be chronic.TIMSS provided principal perceptions of staffing focused on the year prior to the students' assessment, but a longitudinal analysis over several years could allow for a more accurate identification of persistently understaffed schools to better understand if these schools were hard to staff due to low-academic performance. Following the students into high schools may also reveal detrimental effects on student learning as 8th grade is considered a key transitional year, preparing students for the next level. While the TIMSS data allowed us to capture some school contextual factors, the dataset did not have other key variables such as average salary of teachers at the school. Finally, we only analyze STEM achievement and we rely on one specific testing mechanism through TIMSS.

Given the exploratory nature of this analysis, it garners several areas of future research. As we discussed in the theoretical framework, many principals desire some level of turnover in order to reshape the school culture through hiring and what R. Ingersoll (2011) calls induction. In arecent study, Grissom and Bartanen (2019) discuss strategic retention, where principals consider how to support and retain their most effective teachers while cutting ties with less effective faculty. Although our study identifies which schools suffer the most from staffing issues and which students attend such schools using an international dataset covering 27countries, the nature of this type of large-scale data fails to capture the degree that schools hold onto their most effective teachers and what supports are in place to keep them (Brown & Wynn, 2009). Qualitative case studies or localized quantitative studies of hard-to-staff schools would complement our research by further disentangling the causes and consequences of school staffing challenges.

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