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Geographic and gender disparities in global education achievement during the COVID-19 pandemic

Mengfan Wu, Qiwei Yu, Sabrina L. Li, Liqiang Zhang

A State Key Laboratory of Earth Surface Processes and Resource Ecology, Faculty of Geographical Science, Beijing Normal University, Beijing 100875, China
B School of Geography and the Environment, University of Oxford, Oxford OX1 3QY, United Kingdom

1. Introduction

The rapid spread of the COVID-19 pandemic, caused by Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) (Anand et al., 2020) has urged governments worldwide to implement various Non-Pharmaceutical Interventions (NPIs) including school closures to control transmission of the virus in a population (Haug, 2020). By the end of December 2021, many schools globally have been fully or partially closed. Although schools were reopened in many jurisdictions (Schleicher, 2020), from the COVID-19 outbreak and the end of 2021, the average 141 days of school full closure and 234 days of school partially opened caused by COVID-19 in countries around the world (UNESCO. Methodological Note: Monitoring COVID-19 caused school and university closure, 2021). As of mid-April 2020, 1.5 billion children and young people in 195 countries have been affected by school closures, from pre-primary to higher education. 1.3 billion learners in 186 countries are still unable to attend school (UNESCO. Supporting learning recovery one year into COVID-19-The Global Education Coalition in action, 2021).

School closures induced a decrease in learning time, which declined Expected Years of Schooling (EYS) of students. Schools are closed for three months out of a 10-month school year. Without any mitigation, students would lose 0.3 years of school. Students learn far less through remote learning than in a traditional face-to-face setting (Selbergvik, 2020; Kuhfeld, 2020; Alam and Tiwari, 2020). The World Bank Group estimates that school closures have led to a decrease in students’ learning scores and proficiency in basic skills, such as reading, mathematics, and science skills during the COVID-19 pandemic (Azevedo et al., 2020), owing to vastly different approaches to remote learning adopted by governments worldwide. Learning losses experienced in seven low- and middle-income countries, i.e. Cambodia, Ecuador, Guatemala, Honduras, Paraguay, Senegal, and Zambia, demonstrate that third grade students have lost more than a full year’s worth of learning from a three-month school closure (Kaffenberger, 2021). A projection of learning loss estimation from Kindergarten to 12th grade (K-12) students in the United States reveals that returning students in autumn 2020 dropped by 32–37% for reading and 50–63% for mathematics outcomes, relative to a typical school year before the pandemic (Kuhfeld, 2020). School closures have also exacerbated inequities, disproportionately affected vulnerable groups including female students...
and students from poor families as well as low- and middle-income countries (Armitage and Nellums, 2020) as access to technology and infrastructure like the Information and Communications Technology (ICT) is likely to be more limited for households with low incomes (Thomas, 2020; World Bank. The Human Capital Index, 2020; Unicef, 2020). Measuring these disparities is crucial for understanding the potential widening of global learning outcomes.

To date, previous works assessing the impact of the COVID-19 pandemic on educational outcomes have mostly focused on high-income countries like the United States (Kuhfeld and Tarasawa, 2020; Kuhfeld et al., 2020; Christopher and Stern, 2020), but few on low- and middle-income countries due to lack of the latest education survey data (Kaffenberger, 2021; Altinok et al., 2018; Angrist et al., 2021; Patrinos and Angrist, 2000–2017, 2018). Globally, little is known about the following issues: Firstly, how have education outcomes, as measured in terms of learning losses, varied in different regions or income-level countries? Secondly, how have the implemented learning continuity measures affected learning loss across countries? Thirdly, how was the gender inequality of learning losses worldwide?

To bridge the above knowledge gaps, we need timely, comparable data across countries. HTS data are widely used global data for evaluating learning achievement of secondary school students (see “HTS data” in Methods) (Angrist et al., 2020). We have estimated the HTS of students caused by COVID-19 for 184 countries. Based on the estimated HTS, we perform a comprehensive evaluation on learning losses of students across countries due to COVID-19 (see “Estimating learning losses” in Methods). Our study quantifies learning losses including gender inequality through comparing the global modeled and validated learning scores in two scenarios ("COVID-19" and "no COVID-19"); the "no COVID-19" scenario refers to the counterfactual scenario without the COVID-19 pandemic). Furthermore, we make the attempt to explore the effect of learning continuity measures on reducing learning losses. The findings exemplify the decrease in global learning scores during the COVID-19 pandemic, and highlight the urgent need for COVID-19 containment and learning continuity measures to make up for the learning losses as soon as possible.

## 2. Methods

**HTS data.** HTS is an indicator of the cognitive competence of students in a country. It combines scores from several major International Standardized Achievement Tests (ISATs) and their regional counterparts (RSATs) (Angrist et al., 2020), including the Trends in International Mathematics and Science Study (TIMSS), Progress in International Reading Literacy Study (PIRLS), Programme for the Analysis of Educational Outcomes (PISA), Southern and Eastern Africa Consortium for Monitoring Educational Quality (SACMEQ), Programme for the Analysis of Education Systems (PASEC), and Early Grade Reading Assessment (EGRA) (Angrist et al., 2020). The HTS database harmonizes scores from seven ISATs and RSATs into HTS units by creating an exchange rate between ISATs such as PISA, TIMSS, and PIRLS and RSATs. This exchange rate is derived by comparing average scores for countries that participate in an RSAT and an ISAT in a given time period, schooling level (primary and secondary), and subject. This exchange rate is then applied to the country-level average scores for all countries in the test program (Angrist et al., 2020). The HTS uses TIMSS-equivalent units, where 300 is minimal attainment and 625 is advanced attainment (Angrist et al., 2020). The HTS data for 184 countries in 2010, 2017, 2018, and 2020 is derived from the Human Capital Index database published by the World Bank (World Bank. The Human Capital Index, 2020). The descriptive statistics of HTS in different regions and income-level groups are listed in Table 1.

**School closure data.** The United Nations Educational, Scientific and Cultural Organization (UNESCO) began monitoring the daily school closures across the world (https://en.unesco.org/sites/default/files/covid_impact_education.csv; the range of date: 2/16/2020–10/31/2021). The opening and closing of schools are divided into four stages, i.e. fully open, partially open and closed due to the COVID-19 and academic break (United Nations Educational Scientific and Cultural Organization. Global tracking of COVID-19 caused school closures and reopenings. https://en.unesco.org/sites/default/files/unesco-map-covid-19-caused-school-closures-and-reopening-methodological-note-en.pdf, 2020).

**Out of school rates across countries.** Out of school rates across countries are obtained from UNESCO Institute for Statistics (UIS) database (UNESCO Institute for Statistics (UIS) database. http://uis.unesco.org).
The out of school rate in our study refers to the proportion of youth in the official age range for primary and secondary education who are not enrolled in primary and secondary schools (UNESCO Institute for Statistics (UIS) database. http://uis.unesco.org/, 2015). UNESCO estimates that about 24 million learners, from pre-primary to university level, are at risk of not returning to school in 2020 following the education disruption caused by COVID-19 (UNESCO. How many students are at risk of not returning to school, 2020). Out of school rates have changed before and during the COVID-19 pandemic, which has a significant impact on the EYS of countries (UNESCO, UNICEF The World Bank. What have we learnt Overview of findings from a survey of ministries on national responses to COVID-19, 2020). The change in out of school rate and school closure data are used to calculate the loss time of learning during the COVID-19 pandemic.

Survey data of learning continuity measures. Learning continuity measures include remote learning and accelerated learning to ensure learning continuity during the COVID-19 pandemic (UNESCO, UNICEF The World Bank. What have we learnt Overview of findings from a survey of ministries on national responses to COVID-19, 2020). Remote learning is based on ICT. The percentage of individuals using the Internet in 2019 is collected from the ICT Eye (https://www.itu.int/net4/ITU-D/icteye/). The remote learning and accelerated learning data are captured from the Survey on National Education Responses to COVID-19 School Closures, which is supported by UNESCO, the United Nations Children’s Fund (UNICEF), and the World Bank (World Bank, 2020). The survey contains three waves in 121 countries. The first wave is from May to June 2020. The second wave ranges from July to October 2020 (World Bank, 2020). The third wave of data collection lasted from February to April 2021 (World Bank, 2020).

Economic-social and educational data across countries. We collected EYS, Gross Domestic Product (GDP) per capita, Gross National Income (GNI) per capita, unemployement rate, government expenditure on education, the rate of qualified teachers in schools, and international poverty rate in each studied country. The data of EYS in 2010, 2017, 2018 and 2020 are derived from the Human Capital Index database published by the World Bank (2020 Update) (World Bank. The Human Capital Index, 2020). GDP per capita and unemployment rates are captured from the International Monetary Fund (IMF) database and the World Economic Outlook report (World Bank, 2020). The GNI per capita is derived from the Human Development Report in 2019 (Conceição, 2020). Advised by the World Bank, countries are divided into low-income countries (< $1,036), lower-middle-income countries ($1,036 – $4,045), upper-middle-income countries ($4,046 – $12,535) and high-income countries (> $12,535) based on the 2019 GNI per capita across countries (Conceição, 2020). Government expenditure on education as a percentage of GDP and percentage of qualified teachers in schools are collected from UIS database (UNESCO Institute for Statistics (UIS) database. http://uis.unesco.org/, 2015). The international poverty rate is obtained from the Macro Poverty Outlook organized by the World Bank (2021).

Violent conflict and natural disaster data. We collected violent conflict and natural disaster data from the Uppsala Conflict Data Program (UCDP) (https://ucdp.uu.se/encyclopedia)EM-DAT, CRED, UCLouvain, Brussels (Sandberg and Melander, 2013; Stina, 2021) and the Emergency Events Database (EM-DAT) (https://www.emdat.be/) (EM-DAT, CRED, UCLouvain, Brussels, 2009) respectively. According to the method of constructing indices by the Institute for Economics & Peace (Institute for Economics Peace. Global Terrorism Index, 2022), we constructed violent conflict index and natural disaster index to present the risk of violent conflicts and natural disasters across countries. The violent conflict index is the weighted sum of the number of events of violent conflicts and the number of deaths resulting from violent conflicts across countries. Similarly, the natural disaster index is the weighted sum of the number of events of natural disasters and the number of deaths resulting from natural disasters across countries (Eq. (1)).

\[
\text{con}_j = w_y \times \text{RC}_y, j + w_{y-1} \times \text{RC}_{y-1}, j + w_{y-2} \times \text{RC}_{y-2}, j + w_{y-3} \times \text{RC}_{y-3}, j + w_{y-4} \times \text{RC}_{y-4}, j \\
\text{dts}_j = w_y \times \text{RD}_y, j + w_{y-1} \times \text{RD}_{y-1}, j + w_{y-2} \times \text{RD}_{y-2}, j + w_{y-3} \times \text{RD}_{y-3}, j + w_{y-4} \times \text{RD}_{y-4}, j
\]

where: \(\text{RC}_y, j\) presents the normalized number of events of violent conflicts of country \(j\) in \(y\) year, \(\text{RD}_y, j\) presents the normalized number of deaths resulting from violent conflicts of country \(j\) in \(y\) year. \(\text{ND}_y, j\) presents the normalized number of events of natural disasters of country \(j\) in \(y\) year, \(\text{DD}_y, j\) presents the normalized number of deaths resulting from natural disasters of country \(j\) in \(y\) year. \(w_y\) is the weight of the normalized number of events of violent conflicts and natural disasters (\(w_y = 1\)), \(w_d\) is the weight of the normalized number of deaths resulting from violent conflicts and natural disasters (\(w_d = 100\)). To account for the after effects of violent conflicts and natural disasters, we take into consideration the events and deaths of previous years as having a bearing on a country’s current index with a decreasing weight each year. \(w_y, w_{y-1}, w_{y-2}, w_{y-3}, w_{y-4}\) represent the weights of the risk of violent conflicts and natural disasters in years \(y, y-1, y-2, y-3, y-4\) year (\(w_y = 16, w_{y-1} = 8, w_{y-2} = 4, w_{y-3} = 2, w_{y-4} = 1\)). The violent conflict index and natural disaster index were added to the control variables of regression models in the study, so that we can more accurately estimate learning losses caused by the COVID-19 pandemic.

Framework for estimating learning losses. We need to construct the regression equation between HTS under the “no COVID-19” scenario and the associated variables with the learning scores. Thus, we explore the independent variables significantly correlated with HTS using the t-tests. The reduction of learning time in a country due to the COVID-19 pandemic is calculated based on the days of school closure, out of school rate, and survey data of learning continuity measures. The multiple linear regression model is used to estimate the HTS of each country under the “COVID-19” and “no COVID-19” scenarios. The difference between the HTS under the “COVID-19” scenario and those under the “no COVID-19” scenario is taken as the learning losses of students.

To identify the mitigation effect of the learning continuing measures on learning losses, two scenarios (with/without learning continuity measures) are considered in this study. We use the above multiple linear regression model to estimate HTS losses under the with/without learning continuity measures. Furthermore, we estimate HTS losses by gender based on EYS of female and male students.

Reduction of learning time. Due to school closures, the number of schooling days in 2020–2021 is much less than in previous years. The COVID-19 pandemic increases out of school rate and reduces the average learning times. Learning continuity measures can mitigate the losses of learning time, but the success of measures depends on access to the Internet and penetration of remote learning (Martin, 2021).
Referring to the approach to compute the loss of EYS in previous studies (World Bank. The Human Capital Index, 2020; Martin, 2021) and using the data of school closures, out of school rate and learning continuity measures, losses of learning times due to the pandemic are computed using Eq. (2).

\[ \text{LT}_{jg} = \Delta O_{jg} + (1 - \Delta O_{jg}) \cdot \{ C_j - L \cdot \{ C_j - P_{jg} \cdot D_j + R_j \cdot \Delta \} \} \]

where \( \text{LT}_{jg} \) denotes the loss of learning time of students by gender \( g \) in country \( j \). \( \Delta O_{jg} \) denotes the change of out of school rate of gender \( g \) in country \( j \) before and during the COVID-19 pandemic. \( C_j \) denotes the total days of school closures in country \( j \) due to the COVID-19 pandemic in 2020. \( L \) is equal to the sum of the days of school closures due to the COVID-19 and the days of partial school closures. According to previous studies (Martin, 2021; Ferreira and Gignoux, 2021), each day of partial school closures is assumed to be the rate of school closures in partial open days. \( L \) represents whether the estimated \( \text{LT}_{jg} \) is adjusted by the learning continuity measures. \( P_{jg} \) is the percentage of gender \( g \) who use the Internet in country \( j \); \( D_j \) is the percentage of students attending remote learning in country \( j \); \( R_j \) denotes the days of schools reopened in country \( j \). School reopened means that the days since school first opened due to COVID-19. \( A_j \) represents whether the country \( j \) has taken measures to accelerate learning. \( a \) is an adjustable coefficient indicating the degree of accelerate learning after school reopened. According to the UNESCO estimation, meaning learning is accelerated by 10% through accelerated learning measures (Ferreira and Gignoux, 2021).

Reduction of students’ learning time during the COVID-19 has brought down a country’s average EYS. Therefore, the EYS \( \text{EYS}_{g,j} \) of gender \( g \) in country \( j \) under the “COVID-19” scenario is estimated by Eq. (3).

\[ \text{EYS}_{g,j} = \beta_0 + \beta_1 \cdot \text{ey}_{g,j} + \beta_2 \cdot \text{gdp}_{g,j} + \beta_3 \cdot \text{edu}_{g,j} + \beta_4 \cdot \text{tea}_{g,j} + \beta_5 \cdot \text{pov}_{g,j} + \beta_6 \cdot \text{con}_{g,j} + \beta_7 \cdot \text{dis}_{g,j} + \varepsilon \]

where \( \text{ey}_{g,j} \) denotes the EYS of gender \( g \) in country \( j \) under the “no COVID-19” scenario. \( \text{LT}_{jg} \) represents the reduction of the learning time of gender \( g \) in country \( j \).

### 3. Results

#### 3.1. Learning losses across countries.

The prolonged school closures caused by COVID-19 disrupted students’ learning activities. South Asia experienced the largest learning losses, mainly because of national and long-time school closures (378 days) (Fig. 1a). Long school closures and income shock increased the risk of dropping out of school, especially in South Asia, Latin America & Caribbean, Sub-Saharan Africa, which increased by 5.9%, 2.5% and 2.3% of out of school youths, respectively (Fig. 1a, 1c). East Asia & Pacific, Europe & Central Asia, and North America had short school closures on average 184, 133 and 155 days, which only increased by 0.6%, 0.7%, and 0.7% of dropout youths, respectively (Fig. 1a and c). Low-income countries increased 2.3% of dropout youths, while high-income countries only increased 1.0% of dropout youths (Fig. 1b, 1d). Global students have lost an average of 93.9 days of learning time.

### Table 2

| Variable Names | Description | \( t \)-test P-value |
|---------------|-------------|---------------------|
| ey            | Expected years of school (years) | 2.77e-09 |
| gdp           | GDP per capita (current international $) | < 2e-16 |
| gni           | GNI per capita (current international $) | 0.26 |
| ur            | Unemployment rate (%) | 0.14 |
| edu           | Government expenditure on education as a percentage of GDP (%) | 0.07 |
| tea           | Percentage of qualified teachers in schools (%) | 2.85e-04 |
| pov           | International poverty rate (%) | 0.06 |
| con           | Violent conflict index | 0.09 |
| dis           | Natural disaster index | 0.08 |

where \( \text{ey}_{g,j} \) and \( \text{S}_{g,j} \) denote the estimated HTS of gender \( g \) in country \( j \) under the “no COVID-19” scenario and “COVID-19” scenario, respectively. \( \varepsilon \) denotes the EYS, \( \text{gdp}_{g,j} \) denotes GDP per capita (at constant prices), \( \text{edu} \) is government investment on education as a percentage of GDP. \( \text{tea} \) is the rate of qualified teachers in schools. \( \text{pov} \) is the international poverty rate. \( \text{con} \) presents the violent conflict index. \( \text{dis} \) presents the natural disaster index. \( \beta_0, \beta_1, \beta_2, \beta_3, \beta_4, \beta_5, \beta_6, \) and \( \beta_7 \) are the parameters to be estimated, and \( \varepsilon \) is the random error term. \( \text{LS}_{g,j} \) is the learning loss in a country \( j \) by gender \( g \) due to COVID-19. We compared the difference of HTS losses with/without learning continuity measures, which is equal to the HTS loss without learning continuity measures minus the HTS loss with learning continuity measures. We also compared the difference of HTS across gender under the “no COVID-19”/ “COVID-19” scenario and the difference of HTS losses across gender with/without learning continuity measures.
Students in South Asia had the longest loss of learning time (359 days). European & Central Asian and North American students had a short loss of learning time (39.4 and 46.6 days). In terms of the income-level groups, the loss of learning time in lower-middle-income countries is the largest (146.6 days), while the loss in high-income countries is the smallest (48.6 days) (Fig. 1e-f).

School closures and the increase in out-of-school youth have immediately caused students’ learning losses. Fig. 2 shows the estimated HTS learning losses of students globally in 2020–2021. Large differences in the learning losses existed across countries. India, Pakistan, Indonesia, Philippines, Angola, Bolivia, Argentina, and Mexico experienced higher learning losses than Russia, China, the United States, Australia, and western European countries (Fig. 2a). In terms of regions, South Asia experienced the largest HTS loss (5.82 points, 95 %CI: 1.72 – 9.92 points), while Europe & Central Asia experienced the smallest HTS loss (0.85 points, 95 %CI: –0.82 – 2.52 points) (Fig. 2b). In terms of the
The COVID-19 pandemic also caused the inequality of students’ learning scores. The standard deviation of the HTS was used to measure the inequality of learning scores (Angrist et al., 2021). Compared with the “no COVID-19” scenario, the difference of the HTS across countries within Latin America & Caribbean (std. from 24.6 to 25.6), South Asia (std. from 25.9 to 26.5) and Sub-Saharan Africa (std. from 29.8 to 30.6) under the “COVID-19” scenario had a remarkable increase (Fig. 2d). The difference of the HTS across upper-middle-income and low-income countries widened significantly (std. 21.4–22.2 and 20.0–20.8) (Fig. 2e).

Numerous countries adopted learning continuity measures (including remote learning and accelerated learning during school reopened) to compensate for learning loss. Based on the Survey on National Education Responses to COVID-19 School Closures (see “Survey data of learning continuity measures” in Methods). As shown in Fig. 3a, 68.8% of students worldwide could access the Internet. North America had the highest proportion (90.2%) and South Asia and Sub-Saharan Africa had a low proportion (16.7% and 27.5%). 86.2% and 71.3% of students used the Internet in high-income and upper-middle-income countries, compared with 11.8% of students in low-income countries (Fig. 3b). 100% and 94% of countries in South Asia and Middle East & North Africa adopted the accelerated learning measures, higher than other regions (Fig. 3c). 86% of low-income countries adopted the
measures, higher than high-income countries (Fig. 3d). 69.3%, 68.6%, and 67.5% of students attended remote learning in Latin America & Caribbean, European & Central Asia, and North America, while only 36.0% and 40.8% of students attended remote learning in Sub-Saharan Africa and South Asia. 65.1% and 71.8% of students in high-income and upper-middle-income countries accessed remote learning, while the proportions were only 47.3% and 15.6% in low-middle-income and low-income countries (Fig. 3e, 3f).

Under a scenario without learning continuity measures, we estimated the HTS losses, and compared them with those with learning continuity measures (see “Reduction of learning time” in Methods). As shown in Fig. 4a, the learning continuity measures in Russia, Japan, African and South Asian countries had little impact on reduction of the HTS losses while those measures in China, the United States, Canada, western European and Latin American countries significantly reduced HTS losses. As shown in Fig. 4b, the measures reduced the global average HTS loss by
1.64 points. In terms of regions, learning continuity measures in Latin America & Caribbean, North America and Middle East & North Africa reduced HTS losses by 2.55, 2.21 and 2.19 points, respectively, while Sub-Saharan African countries reduced average learning loss by only 0.74 points. The average learning loss was reduced in high-income and upper-middle-income countries by 1.97 and 2.30 points, respectively, reduced only by 0.57 points in low-income countries with/without learning continuity measures (Fig. 4c). Therefore, the learning continuity measures widen the difference of HTS across countries (standard deviations from 51.3 to 51.8) during the COVID-19 pandemic (Fig. 4d-e).

3.2. Learning losses across gender

As illustrated in Fig. 5a, due to the COVID-19 pandemic, the difference of HTS between female and male students was reduced in Iraq, Lebanon, Honduras, Belize, and Venezuela. From Fig. 5b, we note that the average HTS loss of global female students was larger than male students by 0.16 points, especially in North America (gender gap: 0.46 points), Latin American & Caribbean (gender gap: 0.44 points) and South Asia (gender gap: 0.32 points). Female students in lower-middle-income countries had an average 0.32 points larger HTS loss than male students.
Fig. 5. The differences of HTS and HTS losses across gender during the COVID-19 pandemic in different regions and income-level groups. a, The difference of HTS losses between female and male students in each country during the COVID-19 pandemic. b, Comparisons of HTS losses across gender among different regions. c, Comparisons of HTS losses across gender among different income-level groups. d, Comparisons of difference of HTS across gender among different regions. e, Comparisons of difference of HTS across gender among different income-level groups. In d and e, the mean and standard deviation of HTS are shown in parentheses.
Fig. 6. The difference of HTS and HTS losses across gender with and without learning continuity measures. 

a. The difference of HTS losses across gender by country.

b. HTS losses across gender in different regions.

c. HTS losses across gender in different income-level groups.

d. The difference of HTS in different regions.

e. The difference of HTS in different income-level groups. In d and e, the mean and standard deviation of HTS are shown in parentheses.
students (Fig. 5c). The main reason is that out of school rate and loss of learning time of female students were higher than male students (Fig. 1c-f). As shown in Fig. 5d, compared with the “no COVID-19” scenario, the average difference of HTS across gender under the “COVID-19” scenario increased by 0.32 and 0.17 points in South Asia and Sub-Saharan Africa, respectively. In Latin America & Caribbean, the difference was reduced by 0.44 points. In terms of income-level groups, the average difference of HTS across gender of lower-middle-income countries reduced from 0.57 to 0.27 points (Fig. 5d-e).

72.5% of global male students had access to the Internet, while the ratio of female students was only 64.7%, especially in South Asian, Sub-Saharan African, lower-middle-income, and low-income countries (Fig. 3a-b). The gender difference in the use of the Internet led to gender inequality in learning continuity measures. To estimate the impacts of the measures on reduction of learning losses between female and male students, we compared HTS across gender with and without learning continuity measures in each country (see “Reduction of learning time” in Methods). As shown in Fig. 6a, the learning continuity measures narrowed the difference of HTS across gender in most countries, especially Ghana, Nigeria, Bangladesh, Iraq, Honduras, and Belize. The measures reduced global average HTS loss of female students by 1.82 points, male students by 1.99 points, indicating that the measures had more positive impacts on the HTS of male students. As shown in Fig. 6b, the measures reduced less HTS losses of female students than male students in North America, Latin America & Caribbean, and South Asia (gender gap: 0.46, 0.44, and 0.32 points). Learning continuity measures have narrowed the gap in HTS across gender in Latin America & Caribbean (gender gap: from 3.13 down to 2.69 points) and Middle East & North Africa (gender gap: from 2.22 down to 2.01 points) (Fig. 6d). While the gender gap of HTS was widened through learning continuity measures in South Asia (from 1.07 up to 1.39 points) and Sub-Saharan Africa (from 1.21 up to 1.39 points). In terms of income-level groups, the measures reduced less HTS losses of female students than male students in lower-middle-income and low-income countries (gender gap: 0.32 and 0.04 points) (Fig. 6e). The difference of HTS across gender in upper-middle-income countries reduced by 0.23 points. The HTS difference across gender in low-income countries widened by 0.05 points (Fig. 6e).

4. Validation of the results

To validate our results, we use the constructed regression equation to estimate HTS of 2010, 2017, and 2018. Estimated HTS are consistent with actual HTS (R (Haug, 2020) is from 0.64 to 0.71) (Fig. 7). We further compare the estimated HTS losses with those obtained by the World Bank under optimistic, intermediate, and pessimistic scenarios (Azevedo et al., 2020). Our estimates with/without learning continuity measures all fall within the results of the World Bank, while Europe & Central Asia has a little underestimation (Table 4). In addition, we...
compared our estimated HTS losses in some African, Asian, and European countries with the results from previous studies (Azevedo et al., 2020; Martin, 2021; Koen and Amer, 2020; Blasko et al., 2021; Rahman and Sharma, 2021; Omoeva et al., 2016). Our results all fall within those of previous literatures (Table 4). The above validation shows that our results are plausible.

Except for the COVID-19 pandemic, other factors could potentially have an impact on school closures or directly on learning losses, such as violent conflicts and natural disasters (Frankenberg et al., 2013; Parolin and Lee, 2021). To validate our estimated learning losses mainly due to COVID-19, rather than other factors, we drop violent conflict index (con) and natural disaster (dis) from original equation (Eq. (4)) to generate the “dropdis” and “drop con anddis” equations. We compared the coefficients of regression equations and estimated HTS before and after dropping the violent conflict and natural disaster index. The coefficients of regression equations and estimated HTS before and after dropping the violent conflict and natural disaster index are shown in Table 4. The validation shows that all the above results are plausible.

### Table 4: Comparison of the results between our study and the studies from the literatures.

| Countries/Districts            | Our Result (without learning continuity measures) | Our Result (with learning continuity measures) | Results of the literatures | Source                                  |
|--------------------------------|--------------------------------------------------|-----------------------------------------------|---------------------------|-----------------------------------------|
| East Asia & Pacific            | -3.06                                            | -1.62                                         | Optimistic                | -2.39 World Bank (Azevedo et al., 2020) |
| Europe & Central Asia          | -2.72                                            | -0.85                                         | Intermediate             | -14.84                                  |
| Latin America & Caribbean      | -5.81                                            | -3.25                                         | Pessimistic               | -33.00                                  |
| Middle East & North Africa     | -4.20                                            | -2.01                                         | Optimistic                | -8.48                                   |
| North America                  | -3.14                                            | -0.93                                         | Intermediate             | -24.15                                  |
| South Asia                     | -6.96                                            | -5.82                                         | Pessimistic               | -40.07                                  |
| Sub-Saharan Africa             | -3.68                                            | -2.94                                         | Optimistic                | -1.41                                   |
| High-income                    | -2.96                                            | -0.99                                         | Intermediate             | -11.76                                  |
| Upper-middle-income            | -4.62                                            | -2.31                                         | Pessimistic               | -22.44                                  |
| Lower-middle-income            | -4.34                                            | -3.13                                         | Optimistic                | -0.17                                   |
| Low-income                     | -3.92                                            | -3.35                                         | Intermediate             | -12.33                                  |
| Global                         | -3.90                                            | -2.26                                         | Pessimistic               | -30.75                                  |
| Developing Asian countries     | -3.90                                            | -2.47                                         | Optimistic                | -1.48 Asian Development Bank (Martin, 2021) |
| The average of Ethiopia, Kenya, Liberia, Tanzania, Uganda | -5.58                                            | -4.76                                         | Intermediate             | -1.87                                   |
| Pakistan                       | -6.59                                            | -5.58                                         | Pessimistic               | -2.35                                   |
| 21 European countries          | -2.68                                            | -0.91                                         | Optimistic                | -2.53 Angrist, 2021 (Koen and Amer, 2020) |
| Bangladesh                     | -9.28                                            | -8.79                                         | Intermediate             | -9.25 Geven, 2020 (Blasko et al., 2021) |
|                                |                                                  |                                               | Pessimistic               | -21.33 Rahman and Sharma, 2021          |
|                                |                                                  |                                               | Optimistic                | 9.00 Zsuzsa, 2021 (Rahman and Sharma, 2021) |
|                                |                                                  |                                               | Intermediate             | 2.00 Rahman, 2021 (Omoeva et al., 2016) |
|                                |                                                  |                                               | Pessimistic               | 12.71 Omoeva, 2016                      |
|                                |                                                  |                                               | Optimistic                | 0.19                                    |
|                                |                                                  |                                               | Intermediate             | -12.42                                  |

Note: 21 European countries include Austria, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Finland, France, Germany, Hungary, Ireland, Italy, Latvia, Lithuania, Norway, Poland, Portugal, Slovakia, Spain, Sweden, and Belgium.

Developing Asian countries include Afghanistan, Armenia, Azerbaijan, Bangladesh, Bhutan, Brunei, Cambodia, China, Fiji, Georgia, India, Indonesia, Kazakhstan, Kiribati, Kyrgyzstan, Laos, Malaysia, Marshall Islands, Mongolia, Myanmar, Nauru, Nepal, Pakistan, Papua New Guinea, Philippines, Samoa, Singapore, Solomon Islands, South Korea, Sri Lanka, Tajikistan, Thailand, Timor-Leste, Tonga, Tuvalu, Uzbekistan, Vanuatu, Vietnam.
5. Discussion

We have estimated global learning losses among primary and secondary students in 2020–2021. Comparable analyses of the learning losses globally indicate that there is significant heterogeneity and widening disparities across regions and income-level groups. Female students have suffered higher learning losses from the COVID-19, and the pandemic has a significant impact on gender inequality in learning scores.

Several factors may explain these disparities. Due to school closure and the rising drop-out rate, the reduction in learning time has reduced EYS. The reduction in GDP per capita in 2020–2021 and the reduction in educational investment (Al-Samarrai et al., 2020), is another important factor in the inequality of learning losses across countries. In 2020, the education achievements among students from poor families were likely further exacerbated, and many poor students would lose their opportunities to study at school (UNESCO. Combining Data on Out-of-school Children, Completion and Learning to Offer a More Comprehensive View on SDG 4, 2019; Carvalho, 2020). The differences in the learning continuity measures also widen the global inequalities in learning scores. There is evidence that technology-aided after-school instruction programs can improve learning performance (Rafaeli and Hutchinson, 2020).

Our study reveals that the learning continuity measures play a key role in reducing the learning losses.

The educational opportunities for female students are less than male students in some countries. It is estimated that on a global scale, approximately 10 million secondary school-aged girls could be out of school as a result of the aftermath of the COVID-19 crisis in Sub-Saharan Africa (45). Evidence suggests that girls’ access to education in crisis affected areas is low. Girls in fragile countries are half as likely to progress to secondary schools compared to the global average, and typically only receive 8.5 years of education (Plan International. Adolescent Girls in Crisis: Voices From Beirut - Final Report, 2020a). In addition, the online learning approach adopted by many countries could increase the gender gap. In a study about online learning during the Ebola crisis in Sierra Leone, it was found that only 15% of surveyed girls could participate in home study, compared to 40% of boys (UNESCO. Addressing the gender dimensions of COVID-related school closures, 2020). On the other hand, due to school closures, loss of livelihood, significant stress on families and lack of access to safe spaces and services, girls and women face great risks. They are more frequently exposed to gender-based violence and experience higher rates of early marriage, unwanted pregnancies and school dropout (Birchall, 2018; [52]; Brides, 2020; World Vision. COVID-19 After shocks: A Perfect Storm - Millions more children at risk of violence under lockdown and into the ‘new normal’, 2020b; Aid, 2018). The female students are more vulnerable to the reduction of family income than the counterpart (Local Burden of Disease Educational Attainment Collaborators, 2020). Our findings reveal that the learning loss of female students is higher than male students; and learning continuity measures have widened the gender inequality of learning scores.

It is important to develop an equitable policy to close the global gap in secondary education. Our study provides evidence for such decision-making and advocacy. The results show that due to COVID-19, global learning disparities are associated with regions and income levels of countries. South Asian countries need to contain the COVID-19 pandemic and reopen schools more quickly. Due to large learning losses, South Asian and Sub-Saharan African countries need to pay attention. More support measures for girls need to be implemented. Lower-middle-income and low-income countries need to reduce out of school rate and let more girls use the Internet. In addition, our findings highlight the importance of the priority of investing in education systems, especially in primary and secondary education in vulnerable countries, for which most funding is not going to the countries that need it most(57,58).

There are a few limitations in this study. The estimates presented are subject to uncertainty, given that the pandemic situation is still ongoing, and that effects may only be seen retrospectively, when more datasets become available. We only explore short-term learning losses in 2020–2021, and the long-term impact of the pandemic on student academic performance needs to be further investigated. In addition, we fail to explore the negative impacts of school closures and remote learning on education outcomes at the subnational level. However, the recent study (Al-Samarrai et al., 2020) demonstrates that the large socio-

### Table 5

| Variables | Coefficient | Std. Error | Coefficient | Std. Error | Coefficient | Std. Error |
|-----------|-------------|------------|-------------|------------|-------------|------------|
| Intercept | 258.566     | 18.183     | 251.991     | 17.759     | 252.277     | 17.775     |
| gy         | 7.266       | 1.199      | 7.074       | 1.195      | 7.229       | 1.191      |
| edu        | 1.638       | 0.908      | 1.612       | 0.909      | 1.764       | 0.904      |
| tea        | 0.599       | 0.164      | 0.689       | 0.154      | 0.660       | 0.153      |
| pov        | -0.275      | 0.148      | -0.299      | 0.147      | -0.369      | 0.139      |
| con        | -0.056      | 0.041      | -0.057      | 0.041      |             |            |
| dis        | -0.087      | 0.054      |             |            |             |            |

Note: original equation: Eq. (4). “dropdis” equation: drop natural disaster index. “drop con and dis” equation: drop violent conflict and natural disaster index.

### Table 6

| HTS          | Between original equation | Between original equation | RMSE | RMSE |
|--------------|---------------------------|---------------------------|------|------|
| 2020 HTS-bothsxes (no COVID-19) | 0.997 | 2.908 | 0.993 | 4.107 |
| 2020 HTS-female students (no COVID-19) | 0.997 | 2.752 | 0.994 | 4.002 |
| 2020 HTS-male students (no COVID-19) | 0.997 | 2.756 | 0.994 | 4.344 |
| 2020 HTS-bothsxes (COVID-19) | 0.997 | 2.928 | 0.994 | 4.136 |
| 2020 HTS-female students (COVID-19) | 0.999 | 2.174 | 0.998 | 1.383 |
| 2020 HTS-male students (COVID-19) | 0.999 | 1.390 | 0.998 | 2.173 |
| 2018 HTS-bothsxes | 0.995 | 3.634 | 0.995 | 3.789 |
| 2018 HTS-female students | 0.995 | 3.692 | 0.995 | 3.810 |
| 2018 HTS-male students | 0.994 | 3.684 | 0.994 | 3.810 |
| 2017 HTS-bothsxes | 0.999 | 1.910 | 0.998 | 2.827 |
| 2017 HTS-female students | 0.999 | 1.996 | 0.998 | 2.901 |
| 2017 HTS-male students | 0.999 | 2.022 | 0.998 | 2.915 |
| 2016 HTS-bothsxes | 0.997 | 2.662 | 0.994 | 3.969 |
| 2016 HTS-female students | 0.999 | 1.436 | 0.997 | 2.767 |
| 2016 HTS-male students | 0.999 | 1.460 | 0.997 | 2.785 |

Note: original equation: Eq. (4). “dropdis” equation: drop natural disaster index. “drop con and dis” equation: drop violent conflict and natural disaster index.
economic, geographic and demographic disparities have exacerbated inequalities in learning outcomes in the United States due to school closure. Thus, we can infer that more subnational inequalities of education performance exist in other countries, especially in low-income and middle-income countries.

6. Data availability

The datasets used in the paper are available on the following websites. School closures data is collected from UNESCO website (https://en.unesco.org/covid19). HTS and EYS data are downloaded from the World Bank Human Capital Website (https://www.worldbank.org/en/publication/human-capital/Data). GDP per capita and unemployment rates are captured from the IMF database and the World Economic Outlook report (https://www.imf.org/en/Publications/WEO). GNI per capita is derived from the Human Development Report (https://hdr.undp.org/en). Government expenditure on education as a percentage of GDP and percentage of qualified teachers in schools are collected from UIS database (http://data.uis.unesco.org/). International poverty rate is obtained from the Macro Poverty Outlook organized by World Bank (https://www.worldbank.org/en/publication/macro-poverty-outlook). The percentage of individuals using the Internet in 2019 is collected from the ICT Eye (https://www.itu.int/en/ITU-D/icteye/). The remote learning and accelerated learning data are captured from the Survey on National Education Responses to COVID-19 School Closures (https://covid19.uis.unesco.org/data/). Violent conflict and natural disaster data are collected from UCDP (https://ucdp.uwe. BRIT/encyclopedia) and EM-DAT (https://www.emdat.be/) respectively.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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