




Global estimates of the implications of COVID-19-related preprimary school closures for children's instructional access, development, learning, and economic wellbeing

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Funding information

This work was funded by UKRI Collective Fund Award (Grant Ref: ES/T003936/1); UKRI ESRC GCRF, Harnessing the power of global data to support young children's learning and development: Analyses, dissemination and implementation.

Abstract

Observational data collected prior to the pandemic (between 2004 and 2019) were used to simulate the potential consequences of early childhood care and education (ECCE) service closures on the estimated 167 million preprimary-age children in 196 countries who lost ECCE access between March 2020 and February 2021. COVID-19-related ECCE disruptions were estimated to result in 19.01 billion person-days of ECCE instruction lost, 10.75 million additional children falling “off track” in their early development, 14.18 million grades of learning lost by adolescence, and a present discounted value of USD 308.02 billion of earnings lost in adulthood. Further burdens associated with ongoing closures were also forecasted. Projected developmental and learning losses were concentrated in low- and lower middle-income countries, likely exacerbating long-standing global inequities.

The COVID-19 pandemic has adversely affected the health and wellbeing of millions of children around the world. Beyond the direct clinical impacts of COVID-19,

measures to contain the spread of disease have left nearly 1.6 billion preprimary through post-secondary students—more than 90% of those enrolled—at least

Abbreviations: ECCE, early childhood care and education; ECDI, Early Childhood Development Index; ISCED-0, International Standard Classification of Education Level 0; MICS, Multiple Indicator Cluster Surveys; PISA, Programme for International Student Assessment; SDGs, Sustainable Development Goals; UIS, Institute for Statistics; USD, United States Dollars.

Special issue: The impact of COVID-19 on Child Development around the World.

temporarily out of school (UNESCO, 2020a). Whereas a growing literature has highlighted the likely substantial adverse impacts of primary and secondary school disruptions on students' physical, psychological, behavioral, educational, and financial outcomes (Azevedo et al., 2020; Lee, 2020; Liu et al., 2020; Psacharopoulos et al., 2020; Rundle et al., 2020; Wang et al., 2020), relatively little empirical evidence is currently available on the effects of the pandemic on the developmental and learning outcomes of younger children (López Bóo et al., 2020).

Children's access to high-quality early childhood care and education (ECCE) services (e.g., preprimary schools) has been shown to benefit not only early skill development, but also longer-term physical and mental health, educational attainment, and earnings (Barnett, 2011; Barnett & Nores, 2015; Duncan et al., 2010; Engle et al., 2011; Heckman, 2006; McClelland et al., 2013; Robson et al., 2020). Building on this evidence, the purpose of this study is to apply simulation methods to pre-pandemic, observational data from 196 countries to estimate the short- and long-run implications of COVID-19-related ECCE closures on children's access to ECCE instruction, early development, adolescent learning, and adult earnings globally. In doing so, we aim to forecast the non-health-related consequences that COVID-19-related ECCE closures are likely to have for children, families, and societies over time in order to draw attention to the importance and urgency of mitigating their effects.

Global impacts of ECCE

Over the past several decades, there has been growing public interest in investing in access to high-quality ECCE around the world. The Sustainable Development Goals (SDGs) launched by the United Nations in 2015 have explicitly prioritized access to "quality early childhood development, care and pre-primary education" for all children by 2030 as part of Target 4.2 (United Nations, 2016). This ambitious goal reflects increasing recognition that the expansion of ECCE across the globe can support young children's individual development and future social and economic wellbeing, as well as improve long-term societal outcomes (Black et al., 2017; Britto et al., 2017; Lu et al., 2020; Richter et al., 2017).

Robust evidence for the positive impacts of ECCE on individual and societal outcomes has been key to promoting public investments in early educational programs. Numerous studies from around the world have identified positive associations between high-quality ECCE participation and children's short- and long-term outcomes (e.g., Nores & Barnett, 2010; Rao et al., 2017, 2019). In particular, findings from Nores and Barnett's (2010) meta-analysis of experimental and quasi-experimental studies of 26 early educational programs in more than

20 countries indicate that ECCE programs can lead to substantial improvements in early childhood development across cognitive ($d = 0.35$), behavioral ($d = 0.27$), and health ($d = 0.23$) domains. Importantly, the average effects of these ECCE programs were found to be larger than those provided by other commonly used approaches (e.g., nutritional programs, conditional cash transfers).

ECCE programming is also thought to confer benefits beyond the early childhood period. For example, the same meta-analysis described above also found longer-term impacts of ECCE programming on schooling outcomes, including attendance and years of schooling ($d = 0.41$; Nores & Barnett, 2010). Meta-analyses of several decades' worth of studies from high-income countries like the United States have also shown participation in high-quality ECCE programs to reduce adolescent special education placement and grade retention, and to increase academic achievement and high school graduation rates (Gorey, 2001; McCoy et al., 2017). Results from the very limited set of ECCE studies that have followed participants into adulthood have also shown positive economic impacts, including reduced rates of poverty, unemployment, and welfare dependence (Gorey, 2001). Although this evidence supports the short- and long-term causal impacts of high-quality ECCE programming, it is important to recognize that the estimates of these effects come from a relatively limited set of programs within a similarly small number of country contexts. As such, further evidence supporting the associations between ECCE participation and later-life outcomes from a more representative set of contexts is needed.

Despite the anticipated benefits of early educational programs, access to ECCE has remained limited in many settings, even before the COVID-19 pandemic (Nugroho et al., 2020; UNESCO, 2020b). Global data also have indicated substantial inequities among and within countries in ECCE availability. Using nationally representative data from 63 countries, for instance, children in high-income nations were found to be more than 4.5 times more likely to participate in ECCE relative to children from low-income countries (McCoy et al., 2018). Within countries, children living in households from the top quintile of the wealth distribution were found to be on average 2.5 times more likely to participate in ECCE relative to other children from the same country residing in households from the bottom wealth quintile (Lu et al., 2020; McCoy et al., 2018). Considering the documented benefits of ECCE, these inequities are likely a major driver of the social and economic disparities currently observed across the lifespan in many settings.

COVID-19, child development, and ECCE

The COVID-19 pandemic has had enormous impacts on children and families around the world. Since the start of the outbreak, more than 80 countries have

implemented partial or full lockdowns with direct effects on approximately 1.4 billion children, and an additional 100 countries have introduced restrictions on movement (Gromada et al., 2020). Researchers and practitioners have warned that the disruptions to ECCE programs caused by these lockdown measures are likely to have immense implications for children's development (López Bóo et al., 2020; UNICEF, 2020a; Van Lancker & Parolin, 2020; Yoshikawa et al., 2020). Indeed, as early as April 2020, it was estimated that up to 180 million children were facing disruptions in their ECCE access due to COVID-related restrictions and widespread school closures across the globe (Nugroho et al., 2020).

Although research is currently limited, pandemic-related interruptions to ECCE services are likely to impart especially strong and lasting impacts on children's long-term wellbeing for several reasons. First, early childhood constitutes a developmental period during which the brain is particularly sensitive to environmental inputs, both positive and negative (Berens & Nelson, 2019; Black et al., 2017; Shonkoff & Garner, 2011). Accordingly, absence of positive stimulation and learning opportunities in this age period may have even more far-reaching consequences than disruptions in schooling for older children, which have already been shown to be large (Azevedo et al., 2020). Second, whereas losses associated with secondary and to some extent also primary school closures can potentially be offset by online or remote learning, the scope and feasibility of such services are currently limited for younger children, precluding their access to alternative or compensatory learning opportunities (UNICEF, 2020a).

Lastly, young children require substantial supervision and direct care, and their learning is strongly dependent on high-quality, responsive, and emotionally warm interactions with caregivers (Black et al., 2017; Britto et al., 2017). With many parents forced to continue both formal and informal work activities during the pandemic, the extent to which the loss of ECCE services can be adequately offset by home-based care is likely limited, particularly among vulnerable populations experiencing exceptionally high levels of stress and limited access to supports. Indeed, several recent studies have shown that parents and caregivers of young children have experienced considerable mental health challenges in the months following the initial outbreak (Gonzalez et al., 2020; Patrick et al., 2020). In turn, caregivers' reports of pandemic-related stress have been shown in multiple contexts to compromise their provision of the types of nurturing and stimulating learning environments that might offset negative impacts of ECCE closures (Brown et al., 2020; Chung et al., 2020; Cuartas, 2020; Liu et al., 2020; Spinelli et al., 2020; Yoshikawa et al., 2020). Collectively, this evidence suggests that the conditions of children receiving care at home may actually be worse in the context of the pandemic than it was before, again reinforcing the potential protective role that ECCE might play during the COVID-19 crisis.

Opportunities provided by simulation methods

Despite growing consensus regarding the risks facing children around the world, assessing the long-term impact of the pandemic on young children's wellbeing will require years or decades. Furthermore, large-scale data collection and research on the shorter-term effects of COVID-19-related risks on children have already been constrained by physical distancing and other barriers imposed by the pandemic. Accordingly, many researchers across fields have relied on simulation models to estimate the short- and long-term consequences of the pandemic on children. For instance, one study (Robertson et al., 2020) employed three hypothetical scenarios in which coverage of essential maternal and child health interventions was reduced by different percentages to predict that there could be more than 200,000 additional child deaths per month due to such service disruptions. Another study (Fabbri et al., 2020) used nationally representative data from Nigeria, Mongolia, and Suriname to model anticipated effects of COVID-19 on violence against children in the home. Exploiting known empirical relationships between risk factors and violence outcomes, the study predicted increases in violent discipline of up to 46% due to the pandemic. Similar methods have also been used to model the implications of school closures for older children, estimating average losses of between 0.3 and 0.9 years of learning globally (Azevedo et al., 2020).

The consequences of ECCE closures during the pandemic have been far less studied. One recent study using data from 140 countries estimated that pandemic-related disruptions to preschool services may translate to total economic losses (i.e., discounted values of future earnings) between 0.89% and 2.94% of countries' annual gross domestic products (López Bóo et al., 2020). Nevertheless, the potential global developmental and learning consequences of ECCE closures remain, to our knowledge, completely unquantified in the literature.

The present study

The current study uses simulation methods applied to pre-pandemic data from 196 countries to produce global estimates of the implications of COVID-19-related ECCE closures for children's short- and long-term outcomes. In particular, we complement a growing literature on school closures and health (e.g., Esposito & Principi, 2020) to estimate the relations between global early childhood educational disruptions between March 2020 and February 2021 and (1) the number of person-days of ECCE instruction lost, (2) the number of children who will become "off track" in their early childhood development, (3) the number of grades of academic learning lost by adolescence, and (4) the total earnings lost into adulthood. To complement these primary analyses, we also provide information that will allow readers to

estimate further consequences of ECCE closures beyond February 2021. Although we hypothesize that estimates for all losses will likely be large, these analyses are predominantly exploratory given the lack of existing quantitative evidence on the pandemic's impact on children, as well as our use of simulation methods applied to pre-pandemic data. As such, future work will be needed to confirm and improve the precision of these findings using post-pandemic data. While these data are being gathered, we hope that these initial estimates can be used to inform near-term discussions regarding the costs and benefits of re-opening preprimary schools, as well as the necessity of alternative services to support young children and their families in different parts of the world.

METHODS

Sample and data sources

We used a variety of pre-pandemic data sources to complete our analyses. For all of our analyses, we used the most recently available data on school closures (covering March 11, 2020 to February 2, 2021) from UNICEF and UNESCO. We also used the World Bank's 2020 classifications to categorize countries into high-, upper middle-, lower middle-, and low-income groupings (World Bank, 2020). In addition to these sources, to estimate the number of person-days of ECCE instruction lost (Outcome 1), we used data on ECCE participation rates from UNESCO's Institute for Statistics (UIS), the UNICEF-supported Multiple Indicator Cluster Surveys (MICS), and other data sources, along with the number of ECCE-age children from UNESCO and the World Population Prospects. Second, to estimate the number of children who became off track in their early childhood development (Outcome 2), we used data on ECCE and early childhood development from the MICS. Third, to estimate the number of grades of academic learning lost by adolescence (Outcome 3), we used data on ECCE and adolescent learning from the Programme for International Student Assessment (PISA). Each of these data sources is described in detail below. Finally, to estimate the total earnings lost into adulthood (Outcome 4), we extracted rates of returns (% increase in wages) to schooling from a prior review by Fink and colleagues (2016) and used random-effects meta-analysis to compute average returns to schooling for country income groups.

Data on ECCE participation

Our full sample comprises all countries with national data on ECCE participation ($N = 196$ countries, representing 99% of the global under-five population). Our primary source of ECCE participation data was UNESCO's UIS ECCE database (<http://data.uis.unesco.org/>;

$n = 143$ countries), which provides information on net ECCE enrollment, defined as the total number of preschool-age children enrolled in preschool education, and expressed as a percentage of the total population in that age. We prioritized data from UNESCO given that it is the source of information for tracking ECCE participation in the SDGs, and it is also available for the largest number of countries. Where UNESCO data were not available, we extracted ECCE data from MICS surveys (<https://mics.unicef.org/>, $n = 30$), which report data on ECCE attendance, defined as the percentage of children 36–59 months currently attending an early childhood educational program. Where neither source was available, we used an online search of official and recognized sources such as Ministries of Education, national censuses, and national household surveys to find the latest participation rates for individual countries ($n = 23$ countries). Table S1 in the Supporting Information details the final list of countries included in our analysis and the source and definition of ECCE participation data for each.

Although UNESCO and the MICS use different definitions of ECCE participation, both sources consider a wide and inclusive set of program types, including public, private, and non-profit programs, as well as full- and part-time programs. Appendix A in the Supporting Information provides further details regarding analyses examining differences in country-level ECCE participation rates reported by UNESCO versus MICS for countries in which both data sources were available. In sum, these analyses suggested no evidence for systematic differences across these datasets.

Table 1 Column 4 shows overall rates of ECCE participation by country income group prior to the COVID-19 pandemic. Rates of participation ranged from a low of approximately 20% in low-income countries to nearly 80% in high-income countries.

Data on number of ECCE-age children

Data on the total number of ECCE-age children in each country were obtained from UNESCO ($n = 193$ countries) and the World Population Prospects ($n = 3$ countries). The UNESCO definition of ECCE-age children targets children age 3 years until the starting age of primary education, which is 6 years in most countries (UNESCO, 2012). Accordingly, the ECCE target population typically comprises three annual birth cohorts in each country. Table S1 presents further details on the official starting age of primary education by country, and Table 1 Column 3 shows the total number of ECCE-aged children in millions by country income group. In total, 347 million children were estimated to be of ECCE age prior to COVID-19, the majority of whom lived in lower (150 million) and upper (105 million) middle-income countries.

TABLE 1 Pre-COVID-19 ECCE-age population, ECCE participation rates, number of children in ECCE, and percent instruction days lost to COVID-19

Country income group	N countries	Pre-COVID-19 ECCE-age population (millions)	Pre-COVID-19 ECCE participation rate (%)	Pre-COVID-19 number of children in ECCE (millions)	Average instruction days lost due to COVID-19-related ECCE closures (%)
Low	30	54.79	20.66	10.28	50.70
Lower middle	45	150.53	40.17	58.13	56.18
Upper middle	58	105.21	55.41	70.24	57.82
High	63	36.77	79.03	28.57	46.38
Total	196	347.30	54.18	167.22	52.67

Note: This table aggregates populations of children across countries, but presents averages for country-level participation rates.

Data on early childhood development

To estimate short-term associations between ECCE and early childhood development, we used data from 174,018 3- and 4-year-old children in 61 countries participating in the MICS (*M* age = 47.33 months, range = 36–59 months; 49% girls; race/ethnicity not available). MICS include nationally representative data on child and family wellbeing, with a focus on low- and middle-income countries (UNICEF, 2006). Standard MICS questionnaires include questions regarding whether 3- and 4-year-old children currently attend ECCE programs (yes/no). The early development of these same children is also measured using the Early Childhood Development Index (ECDI). The ECDI includes 10 caregiver-reported items capturing 3- and 4-year-old children’s early literacy/numeracy (three items), physical (two items), social-emotional (three items), and approaches to learning (two items) skills (Loizillon et al., 2017). Following MICS recommendations, children were considered developmentally off track in the ECDI if they failed more than one item in two or more of these domains. Despite criticisms regarding the coarseness of this measure (McCoy et al., 2016), the ECDI is highly policy-relevant given its current status as the indicator of early childhood development for SDG 4.2.1 (United Nations, 2019). Since the countries that participated in the MICS varied across years, we chose the most recently available dataset for each country. Table S1 lists the specific countries included in our MICS dataset.

Data on adolescent learning

To estimate associations between ECCE and medium-term learning outcomes, we used data for 426,125 adolescents in 76 countries participating in the PISA (*M* age = 15.79 years, range = 15.08–16.33 years; 52% girls; race/ethnicity not available). The PISA is an international survey program that includes direct assessments of reading, mathematics, and science literacy every 3 years for nationally representative samples of 15-year-old students enrolled in school, focusing on higher-income countries (OECD, 2019). The PISA also includes a retrospective item in which respondents report how many years of school- or center-based ECCE they attended, as defined by the International Standard Classification of Education Level 0 (ISCED-0). Similar to the MICS data, we chose the most recently available PISA dataset for each country. Table S1 lists the specific countries included in our PISA dataset.

Data on COVID-19-related school closures

For all of our analyses, we used the most recently available data on school closures caused by COVID-19

from UNICEF and UNESCO (<https://data.unicef.org/resources/one-year-of-covid-19-and-school-closures/>). Specifically, we estimated the number of instructional days lost in each country by adding the total number of days that schools were closed plus half the number of days that schools were partially closed between March 11, 2020 and February 2, 2021. We then calculated the proportion of instruction days lost due to COVID-19 for each country by dividing this number by the total number of possible instructional days during this period (see Figure 1). As shown in Table 1 Column 6, globally children lost an average of 52.67% of ECCE instructional days during the first 11 months of the pandemic, with the largest percentages of instructional days lost in middle-income countries.

Statistical analyses

Our primary analyses estimating the implications of COVID-19-related ECCE closures on each of our study's four primary outcomes are described below.

Estimated implications of COVID-19 for ECCE instruction

First, we estimated the total number of person-days of ECCE instruction lost due to COVID-19-related school closures during the first 11 months of the pandemic (i.e., between March 2020 and February 2021). To do so, we began by multiplying the latest available estimates of the proportion of children participating in ECCE prior to COVID-19 by the total number of ECCE-age children in

each country. The resulting total number of children participating in ECCE in each country prior to COVID-19 was then multiplied by the number of instructional days lost between March 2020 and February 2021 in each country (Equation 1):

$$\text{Person Days of ECCE instruction lost} = \text{Population} \quad (1) \\ * \text{Enrollment Rate} * N \text{ Days of Instruction Lost}$$

We then summed each country's total number of person-days of ECCE instruction lost to COVID-19 within country income groups.

Estimated implications of ECCE disruptions for early childhood development

Second, we used MICS data to estimate the likely implications of ECCE closures during the first 11 months of the pandemic for early childhood development. To do so, we used a series of country-specific logistic regression models in which a binary indicator for whether children were developmentally off track (OffTrack_i) was regressed on a binary indicator representing whether children were attending ECCE versus receiving alternative forms of care (most typically staying home with their parents or other caregivers; ECCE_i). These equations also included a vector of control variables, including child i 's age in months, gender, household wealth, maternal educational attainment, an indicator for rural versus urban residence, and a sum index of caregivers' engagement in six play and learning activities (i.e., reading, singing, telling stories, playing, taking the child outside for a walk, and counting) that has been shown to

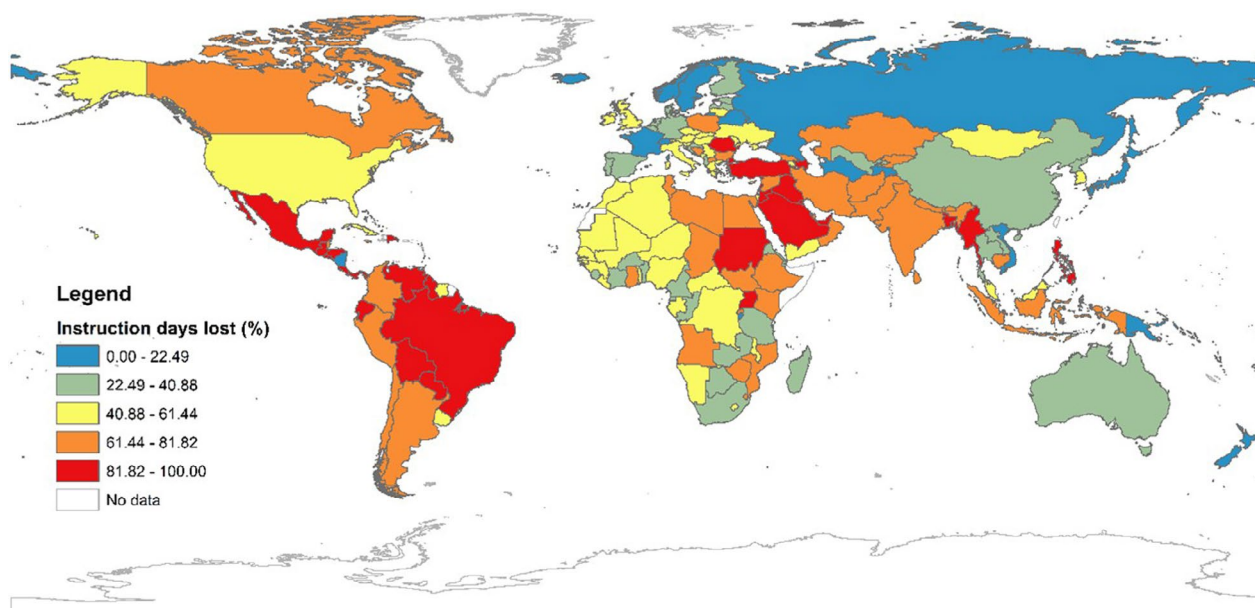


FIGURE 1 Estimated percentage of days of ECCE instruction lost due to COVID-19-related ECCE closures between March, 2020 and February, 2021, by country. *Note.* See Table S3 for country-level details

predict early childhood development (Jeong et al., 2017; Equation 2):

$$\text{OffTrack}_i = \alpha + \beta * \text{ECCE}_i + \text{Control}_i * \theta + \epsilon_i \quad (2)$$

We stored the estimated coefficients from these country-level models and employed them to obtain predicted values for the outcome variable. Using these predicted values, we estimated the likely increase in the proportion of children off track in their development by scaling the estimates by the median duration of ECCE participation in each country income group reported in the PISA dataset. According to the PISA dataset, the average duration of pre-COVID-19 ECCE attendance was 1 year in low- and lower middle-income countries, and 2 years in upper middle- and high-income countries. This implies, for example, that a 180-day closure of ECCE would result in a complete (100%) loss of the typical developmental benefits of ECCE for a child about to start ECCE in a low- or lower-middle income country with 180 instructional days per year, and to a 50% loss of the protective benefits in upper middle- and high-income countries with the same total instructional days per year. We then used random-effects meta-analysis to pool estimates of the likely increase in the proportion of children off track in their development by country income group from the country-level predictions from Equation 2. Finally, we applied these country income group-level estimates of the proportion of children who would fall developmentally off track as a result of ECCE closures to the total population of ECCE-age children to obtain estimates of the *number* of children whose early development might be compromised by ECCE disruptions in the first 11 months of the pandemic.

Estimated implications of ECCE disruptions for adolescent learning

Third, we used PISA data to predict the estimated consequences of ECCE closures between March 2020 and February 2021 on adolescent learning losses. For this analysis, we created a single academic achievement score summarizing students' performance in the reading, math, and science domains of PISA. This first principal component of the three scores captured 94% of total variance, suggesting a very high correlation across the domain-specific assessments. To facilitate interpretation, we standardized the composite PISA achievement variable to a mean of 0 and to a standard deviation of 1. Similar to the analyses predicting early development, we used multivariate regression models to estimate country-specific associations between the number of years adolescents reported participating in ECCE (Years ECCE_i ; where 0 indicates they received care outside of ECCE, e.g., at home) and their composite achievement scores ($z\text{PISA}_i$) while controlling for students' grade levels,

ages, household wealth, and parental educational attainment (Equation 3):

$$z\text{PISA}_i = \alpha + \beta * \text{Years ECCE}_i + \gamma * \text{Grade}_i + \text{Control}_i * \theta + \epsilon_i \quad (3)$$

Given that most countries in the PISA dataset capped reporting of years of ECCE at three and, according to UNESCO statistics, in most countries preprimary education comprised 3 years (between ages three and six), records reporting more than 3 years of ECCE participation (i.e., 20% of the sample) were top-coded at three. Furthermore, certain PISA datasets only reported the minimum number of years of ECCE ("at least one," "at least two," etc.); we used these minimums as proxies for actual ECCE exposure in these datasets (e.g., "at least one" was replaced with 1). Similar to the analyses for early childhood development described above, we first estimated country-specific associations between ECCE participation and adolescent learning outcomes, and then used random-effect meta-analysis to derive pooled estimates of these associations for each country income group. Given that PISA data are unavailable for low-income countries, we used the estimate derived for lower middle-income countries for the low-income group. In a set of sensitivity analyses, we also explored the extent to which results differed when assuming relative returns to ECCE in low-income countries of 50% and 150% of those observed in lower middle-income countries.

To translate composite PISA scores into a more easily interpretable (and more labor market-relevant) outcome measure, we converted additional PISA scores to school grade equivalents. To do so, we estimated the average increase in PISA scores associated with an additional grade completed in each country using the coefficient for Grade_i in Equation 3. Using meta-analysis, we then created a country income group-specific estimate of average annual improvements in academic achievement for each additional grade completed ($\Delta z\text{PISA}_{\text{grade}}$). This estimate then allowed us to convert observed academic achievement losses into (effective) grades of learning lost by adolescence taking into account the average days of instruction lost (Closures) as shown in Equation 4:

$$\text{Total years of learning lost} = \frac{\Delta z\text{PISA}_{\text{ECCE}}}{\Delta z\text{PISA}_{\text{grade}}} * (\text{Population} * \text{Enrollment Rate}) * \text{Closures} \quad (4)$$

Estimated implications of ECCE disruptions for adult earnings

Fourth, we converted the anticipated losses in adolescent learning due to COVID-19-related ECCE closures in the first 11 months of the pandemic into estimates of future reductions in labor market incomes. A large economics literature has highlighted the high labor market

returns to additional grades of schooling attainment (e.g., Psacharopoulos & Patrinos, 2004, 2018). We extracted rates of returns (% increase in wages) to schooling from a prior review by Fink and colleagues (2016) and used random-effects meta-analysis to compute average returns to schooling for country income groups. Following Fink and colleagues (2016), we estimated the net present value of future wage losses per child and cohort assuming that children will work in the labor market from age 20 to 60, with 2% annual growth in wages (net of inflation) and a 3% discount rate. To do so, we first estimated the effective grades of schooling lost by adolescence (Total grades of learning lost; see Equation 4) and then multiplied this figure by the expected wage increase per grade of education (return to education; RTE), the net present value of future wages (NPV(wages)), and the average days of instruction lost Closures, as shown in Equation 5:

$$\text{Income lost} = \text{Total learning lost} * \text{RTE} \\ * \text{NPV(wages)} * \text{Closures} \quad (5)$$

Similar to previous work (Fink et al., 2016), we assumed wages to correspond to two-thirds of each country's gross domestic product per capita (as reported by the World Bank, 2020). Given large variation in returns to schooling observed in the literature, as well as the difficulty associated with making appropriate real wage growth and interest rate projections for the future, we explored alternative assumptions in a set of sensitivity analyses. Specifically, we computed estimates under more modest and optimistic returns to education of 4, 8, and 10% per year of schooling, respectively, as well as with 0% and 3% net discounting of future benefits. In recent history, real interest rates have fluctuated between 0% and 5% (Borio et al., 2017), while real wage growth rates have been approximately 2% (Inclusive Labour Markets, 2015). The 0% scenario essentially assumes that real interest rates equal future real wage growth rates; the 3% net discounting scenario assumes that future interest rates will be 3% higher than real wage growth rates (i.e., wage growth rates net of inflation). Three percent net discounting would, for example, be appropriate with zero real (net of inflation) growth in wages, and a 3% discounting factor. It would also be appropriate for a more realistic real wage growth rate of 2% combined with a more conservative 5% discounting rate.

Forecasts beyond February 2021

Because we only had data available on actual ECCE closures through February 2, 2021, we also conducted a series of analyses to allow readers to forecast how ongoing disruptions to ECCE services may predict further losses. In particular, we estimated the implications of one additional month of ECCE shut-downs on each of

our outcomes. To do so, we used the same methods described above but replaced actual closure durations with a proportion of 0.083 (one-twelfth of 1 year).

Error estimation

For all analyses, we also present bootstrapped standard errors to account for statistical uncertainty in estimated (1) associations between ECCE attendance and probabilities of being developmentally off track using the MICS data, (2) associations between years participating in ECCE and adolescent PISA scores, (3) associations between schooling grade and PISA scores, and (4) economic returns to education. We employed 10,000 bootstrapped simulations and calculated the 2.5th and 97.5th percentiles of these draws to provide 95% confidence intervals around our estimated results.

RESULTS

Estimated implications of COVID-19 for ECCE instruction

As detailed above, we used UNESCO and UNICEF data on school closures between March 2020 and February 2021 along with data on the total number of children participating in ECCE prior to the COVID-19 pandemic to estimate the total number of person-days of ECCE instruction lost during the first 11 months of the pandemic. Across the 196 countries included in our analyses, closing ECCE services to the approximately 167 million children receiving ECCE at the start of the pandemic was estimated to amount to a loss of 19.01 billion instructional days, with the largest losses in middle-income countries (see Table 2 Column 2 for country income group-level results, and Figure 2 and Table S4 for country-level estimates). We also forecast that each additional month of global ECCE shutdowns beyond February 2021 could predict additional losses of 1.4 billion person-days of instruction (see Table S5 and S6).

Estimated implications of ECCE disruptions for early childhood development

To estimate the short-term implications of COVID-19-related ECCE closures in the first 11 months of the pandemic for children's early childhood development, we estimated the odds of being developmentally off track for children who were and were not participating in ECCE using pre-pandemic data from 61 MICS countries (see Figures S2–S5 for country-specific estimates). We then aggregated country-level estimates to country income groups using random-effects meta-analysis (see Table 3) and applied these results to our estimated

TABLE 2 Predicted implications of ECCE closures between March 2020 and February 2021 for ECCE instruction, early childhood development, adolescent learning, and future earnings

Country income group	Total person-days of instruction lost due to COVID-19-related ECCE closures (in millions)	Predicted increase in number of children off track in early development due to COVID-19-related ECCE closures (in millions)	Grades of learning lost per student and year of ECCE	Predicted total grades of learning lost due to COVID-19-related ECCE closures (in millions)	Total wage losses due to COVID-19-related ECCE closures at 3% discounting, USD Billion (purchasing power parity)
Low	1285.78	2.35 [1.92–2.79]	0.17 [0.15–0.18]	1.04 [0.94–1.15]	3.90 [3.49–4.32]
Lower middle	8778.81	6.26 [5.03–7.50]	0.17 [0.15–0.18]	6.99 [6.29–7.71]	48.15 [43.28–53.12]
Upper middle	6694.06	1.43 [0.98–1.88]	0.14 [0.12–0.15]	4.99 [4.50–5.47]	136.11 [123.01–149.34]
High	2255.83	0.71 [0.13–1.29]	0.09 [0.09–0.10]	1.16 [1.06–1.27]	119.85 [108.02–132.12]
Total	19,014.47	10.75 [8.05–13.45]	0.14 [0.12–0.15]	14.18 [12.79–15.59]	308.02 [277.79–338.91]

duration of ECCE closures. Our findings suggest that prior to COVID-19, approximately 84 million children globally were developmentally off track according to the current indicator for SDG 4.2.1, the ECDI. We predict that an additional 10.75 million (95% CI 8.05, 13.45) children around the world could become off track in their early development as a result of ECCE closures in the first 11 months of the pandemic (Table 2 Column 3). Additional analyses suggest that each additional month of ECCE closures beyond February 2021 could be associated with an additional 1.49 million (95% CI 1.13, 1.85) children becoming off track in their early development (see Table S5 and S6).

Figure 3 and Table S4 show the estimated total number of children (in millions) in each country who could become off track as a result of ECCE closures during the first 11 months of the pandemic. Low- and lower middle-income countries account for more than 90% of overall increases, with total losses concentrated in countries with large child populations (e.g., China, India). Figure S9 shows the number of additional children who could become off track in their early development per 100 ECCE-age children. When adjusting for the size of the child population in each country, countries in Sub-Saharan Africa and South Asia were shown to have the largest increases in children predicted to become off track. For example, we estimate that 11.71 out of every 100 children in Nepal and 7.67 out of every 100 children in Ghana may become off track as a result of ECCE closures in the first 11 months of the pandemic.

Estimated implications of ECCE disruptions for adolescent learning

To estimate the implications of ECCE closures in the first 11 months of the pandemic for adolescent learning, we first estimated country-specific associations between ECCE participation and math, reading, and science achievement at age 15 from the PISA in 76 countries (see Figures S6–S8 for these estimates). Similar to above, we combined country-level estimates within country income groups using random-effects meta-analysis (see Table 4) and applied these to our estimated ECCE closure durations. We then converted losses in PISA scores into (effective) grades of learning lost by scaling results by the average gains in students’ PISA scores for one grade. Net learning losses per child and year of ECCE ranged between 0.09 grades (95% CI 0.09, 0.10) in high-income countries and 0.17 grades (95% CI 0.15, 0.18) in low- and lower middle-income countries (Table 3 Column 4). Applying these estimates to the cohort of children participating in ECCE prior to COVID-19 implies total losses of 14.18 (95% CI 12.79, 15.59) million grades of learning attributable to ECCE disruptions in the first 11 months of the pandemic (Table 3 Column 5). For each additional month of ECCE closures beyond February

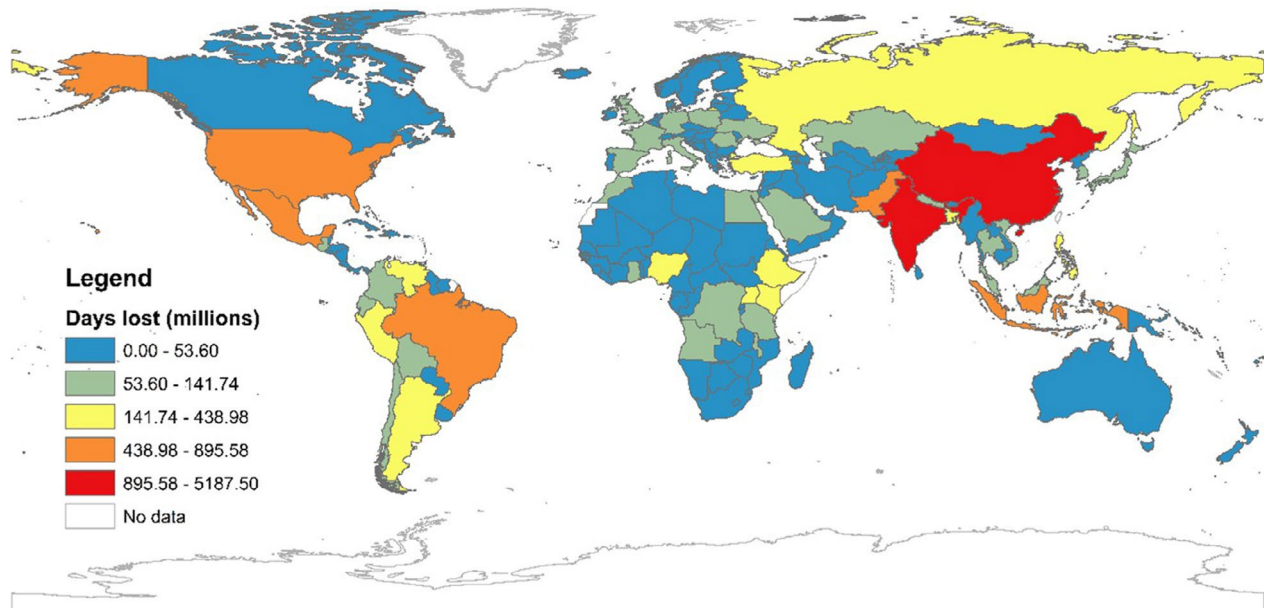


FIGURE 2 Person-days of ECCE instruction lost due to COVID-19-related closures between March, 2020 and February, 2021, by country (in millions). *Note.* See Table S4 for country-level details

TABLE 3 Average associations from random-effects meta-analysis between ECCE participation and being off track in early childhood development, by country income group

	Child is developmentally off track according to the ECDI			
	(1)	(2)	(3)	(4)
	Low-income	Lower middle-income	Upper middle-income	High-income
Attends ECCE (=1)	0.58 [0.55–0.62]	0.59 [0.56–0.62]	0.71 [0.65–0.76]	0.74 [0.59–0.94]
Number of children	58,744	64,391	47,258	3625
Number of countries	13	22	22	4

Note: Outcome variable in all models is a binary indicator of children being developmentally off track according to the ECDI. Estimated coefficients are odds ratios with 95% CIs in brackets. Country income group estimates were generated using random-effects meta-analyses of country-specific logit model estimates shown in Figures S2–S5.

2021, we estimate that an additional 1.98 million (95% CI 1.79, 2.18) grades of learning may be lost (see Table S5 and S6).

Figure 4 and Table S4 illustrate the global distribution of predicted adolescent learning losses attributable to ECCE closures in the first 11 months of the pandemic. The largest aggregate losses were predicted for China, India, Pakistan, United States, Russia, Indonesia, and Brazil due to their large child populations and high ECCE participation rates. Figure S10 shows the average expected learning losses per child. These losses were estimated to be largest in Central and South America and a few countries scattered elsewhere (e.g., the Philippines, Sri Lanka, Romania, Mongolia, Georgia, Nepal, Ghana) due to relatively high ECCE participation rates, ECCE closures, and learning benefits associated with ECCE in these countries.

Estimated implications of ECCE disruptions for adult earnings

To calculate lifetime income losses resulting from the estimated adolescent learning losses, we computed future labor market incomes with and without the anticipated ECCE-related losses in educational achievement. We predict that ECCE closures during the first 11 months of the pandemic could result in a total global income loss of United States Dollars (USD) 308.02 billion (95% CI, 277.79, 338.91; Table 3 Column 6). We also estimate that each additional month of ECCE closures beyond February 2021 could predict additional global losses of USD 51.75 billion (95% CI 46.67, 56.91; see Tables S5 and S6).

Figure 5 and Figure S11 show total predicted earnings losses attributable to ECCE closures during the

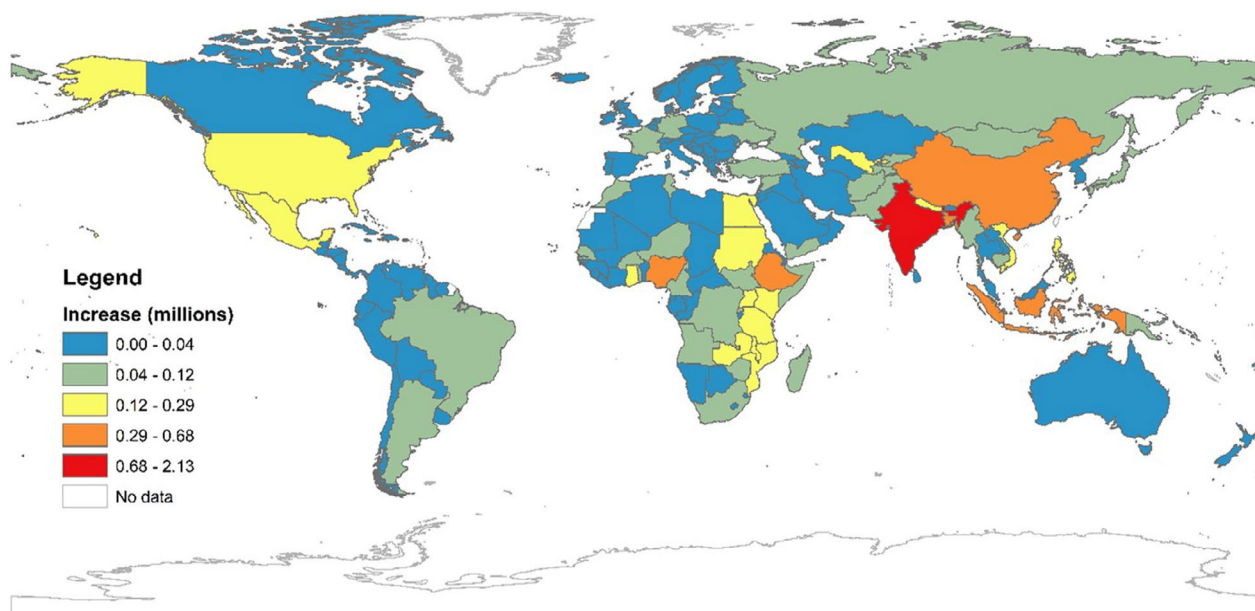


FIGURE 3 Predicted increase in the number of children off track in their early childhood development due to COVID-19-related ECCE closures between March, 2020 and February, 2021, by country (in millions). *Note.* See Table S4 for country-level details

TABLE 4 Average associations from random-effects meta-analysis between years of ECCE participation, grade, and composite adolescent learning scores, by country income group

	Composite educational attainment scores		
	(1)	(2)	(3)
	Lower middle-income	Upper middle-income	High-income
Years participating in ECCE	0.05 [0.05–0.06]	0.04 [0.04–0.04]	0.04 [0.04–0.05]
Grade	0.32 [0.32–0.33]	0.29 [0.28–0.29]	0.47 [0.46–0.47]
Number of students	50,358	148,621	227,146
Number of countries	10	25	41

Note: Outcome variables in all models are composite, standardized PISA score across reading, math, and science. Regression coefficients represent OLS estimates with 95% CIs in brackets, and can be interpreted as SD differences in adolescent PISA scores. Country income group coefficients were estimated with random-effects meta-analyses using the coefficients and standard errors from country-specific logit models shown in Figures S6–S8.

first 11 months of the pandemic by country at the aggregate level (in millions) and per ECCE-age child (in thousands), respectively. At the country level, economic losses were predicted to be largest in the United States and China due to their relatively high income and large child populations. At the child level, the highest average earning losses were largely concentrated in OECD countries, where both enrollment rates and wages are high.

Finally, Tables S7–S9 present results of sensitivity analyses examining different specifications and assumptions of our models. Results of the sensitivity analysis were generally similar in magnitude, with estimates of the economic implications of ECCE closures ranging between USD 149.02 billion and 429.90 billion.

DISCUSSION

Around the world, governments and families are facing difficult decisions regarding when and how to send children back to school. The goal of our study is to complement a growing body of public health research on the clinical implications of school re-openings to consider the potential instructional, developmental, learning, and economic costs of ECCE closures. In particular, we use existing, pre-pandemic data from 196 countries to simulate the possible short- and longer-term consequences of COVID-19-related ECCE closures on children’s ECCE instruction, early development, adolescent learning, and adult income.

Our results suggest that disruptions to ECCE associated with the COVID-19 pandemic could have large and

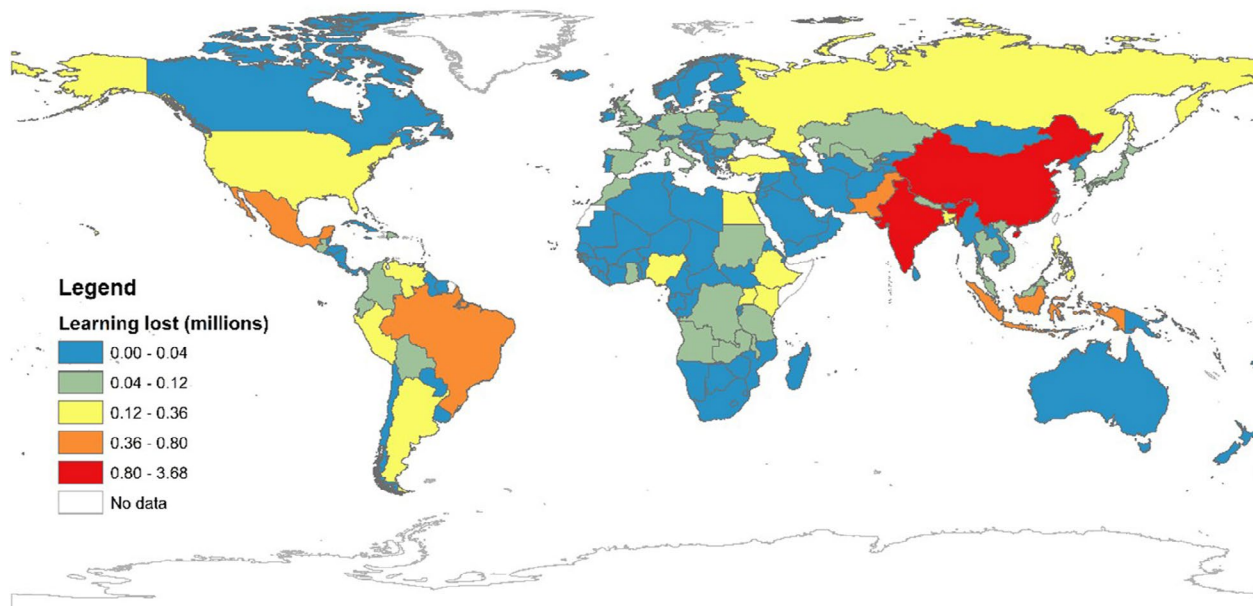


FIGURE 4 Predicted total number of grades of learning lost by adolescence due to COVID-19-related ECCE closures between March, 2020 and February, 2021, by country (in millions). *Note.* See Table S4 for country-level details

lasting negative consequences for young children around the world. We estimate that at least 167 million children have lost access to early educational supports, with an estimated total of 19 billion person-days of instruction lost between March 2020 and February 2021. We also estimate that these ECCE closures in the first 11 months of the pandemic have potentially derailed the early development of more than 10 million children, and have reduced global learning by adolescence by 14 million grades. In turn, we estimate that these learning-related losses could predict total future income losses amounting to more than USD 300 billion. These estimated economic losses exceed the pre-COVID-19 total annual governmental expenditures on preprimary education globally by nearly USD 50 billion, and represent approximately seven times the total projected annual cost of expanding ECCE service access to become universal in low- and lower middle-income countries (see Appendix B for details on these calculations). Importantly, we also estimate that ongoing ECCE closures could add to these existing burdens, with each additional month of shut-downs beyond February 2021 predicted to lead to 1.39 billion more person-days of instruction lost, 1.49 million additional children becoming off track in their early development, 1.98 million additional grades of learning lost by adolescence, and 51.75 billion additional USD in income lost into adulthood. The projected losses also have important implications for countries' abilities to meet SDG 4, which includes targets for ECCE access and early childhood development (Target 4.2) and academic proficiency (Target 4.1), as measured by the same data sources used in our study.

Although we found that the total estimated economic consequences of COVID-19-related ECCE closures are

likely to accrue more to large, high-income countries with high pre-pandemic ECCE participation and high returns to education (e.g., the United States, China), our findings suggest that lower middle-income countries are likely to be hit hardest by service disruptions with regard to early childhood development and adolescent learning, despite their relatively lower pre-COVID-19 ECCE participation rates. These findings are consistent with previous suppositions that the pandemic will widen existing inequalities based on both country-level resources, as well as individual sources of marginalization, such as household income, gender, urbanicity, disability, and refugee status (Van Lancker & Parolin, 2020). Historically, children from disadvantaged contexts have benefited more from ECCE services than their more advantaged counterparts (Cornelissen et al., 2018; Duncan & Sojourner, 2013; Magnuson & Waldfogel, 2005), but have had less access to high-quality ECCE services or home-based learning options (e.g., access to books, stimulating activities; McCoy et al., 2018). These groups also appear to be impacted most by the pandemic in terms of health and finances (Ahmed et al., 2020; Patel et al., 2020), further affecting their ability to compensate for ECCE shutdowns.

Although our study is the first to our knowledge to comprehensively estimate the global implications of COVID-19-related ECCE shutdowns, these analyses have limitations. First, the measures used in this work are limited in several important ways. In particular, a lack of universal data on ECCE participation forced us to combine estimates of the proportion of children just prior to primary school entry who were enrolled at all in ECCE with estimates of the proportion of slightly

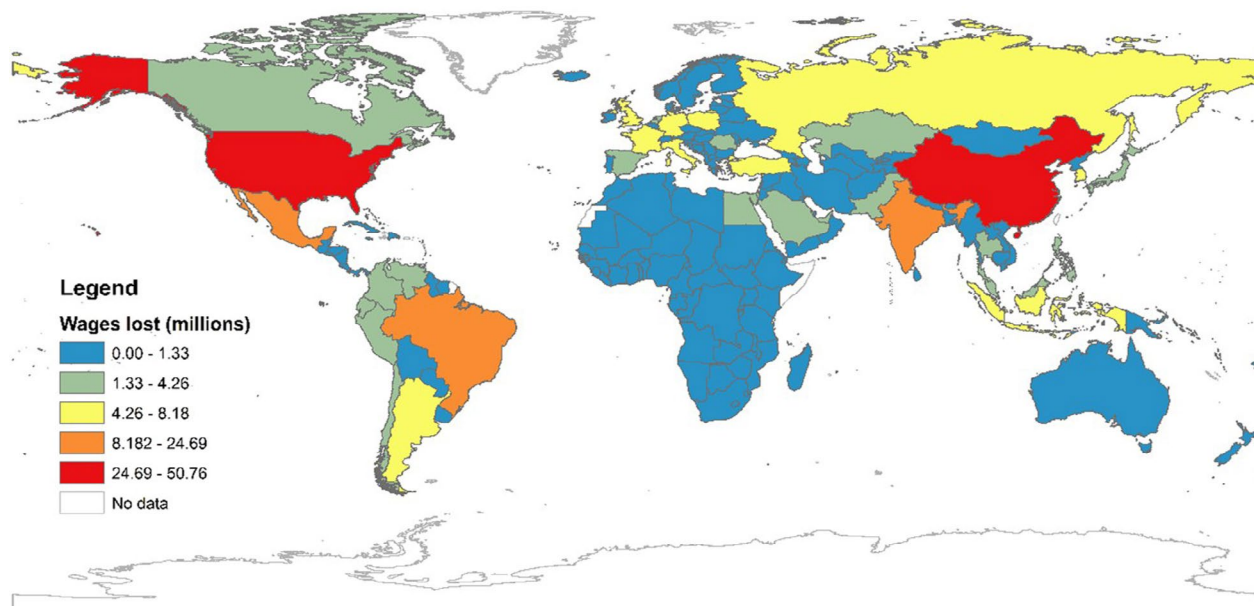


FIGURE 5 Predicted total wage losses attributable to COVID-19-related ECCE closures between March, 2020 and February, 2021, by country (in USD million, purchasing power parity). *Note.* See Table S4 for country-level details

younger children (ages 3 and 4) who were currently attending ECCE. Even though we do not identify systematic discrepancies between our primary sources of ECCE participation data (i.e., no source was systematically higher or lower than the other for countries for which we have both; see Appendix A), measurement error could introduce noise into our estimates. Relatedly, children's participation in the large number of informal and community-based ECCE programs in many countries, especially low-income countries, may be missed in our estimates, which in turn could mean that we have misrepresented the overall losses associated with ECCE closures globally. In addition to our measure of ECCE participation, our index of children's early childhood development (the ECDI) is also known to be coarse, limited, and—in the case of some items—potentially age-inappropriate (McCoy et al., 2016). The cutoff used for off track in the ECDI is also arbitrary, and may suggest a false dichotomy between children who score highly and those who do not. Nevertheless, we have used the ECDI in this paper due to the fact that it is the measure of early childhood development that is available for most countries, and we have retained UNICEF's definition of off track development given its policy relevance as the indicator for tracking SDG 4.2.1.

Second, the MICS and PISA each cover different countries globally; as such, the pooled estimates from these datasets likely do not describe the true associations between ECCE and children's outcomes accurately for all countries/children, limiting the generalizability of results. Similarly, we were unable to account for variation in how the pandemic unfolded across contexts. Although our analyses take into account differences in the duration of ECCE closures across countries, our results do

not reflect other sources of country-level variation that may have shaped these closures' impacts on children, such as the severity of the pandemic and the speed and intensity of governmental responses.

Third, although we focus on the most recent data available from each source, some information used for this study was collected a decade or more prior to the pandemic. Although we have made the choice to use these older data over not having any data at all for a given country, it is possible that we underestimate the implications of closures given that ECCE participation rates have generally been rising with time. Fourth, our estimates on the returns to education may not accurately capture the true full impacts of additional schooling, especially in light of likely inevitable macroeconomic shifts post-pandemic. It is possible that returns to education may increase in the future due to a changing global economy; it also seems likely that higher educational attainment will yield non-monetary benefits such as better health or improved well-being that are not captured in our model. Although we show that our results are not very sensitive to the specific assumptions regarding the returns to education, we recommend that future studies replicate our work with more updated information regarding the pathways through which education in a post-pandemic world might shape economic well-being.

Last, our predictions are based on comparisons of children who did and did not participate in ECCE prior to the COVID-19 pandemic and accordingly do not allow for deterministic or causal claims. In particular, R-squared values from our models were relatively low and variable (range = .01–.59 across country/data source), suggesting that ECCE predicted only a limited proportion of the variance in children's development

and learning outcomes. Furthermore, our reliance on observational data means that we were not able to control for the factors that determined ECCE participation, including parental mindsets about the value of ECCE. Although we find that our estimates of the associations between ECCE participation and early childhood development are relatively comparable with those identified in smaller-scale but more empirically rigorous randomized control trials of pre-pandemic ECCE programming in a limited number of countries around the world (average $d = 0.20\text{--}0.35$; Nores & Barnett, 2010), it is possible that issues of selection bias may result in our overestimation of the effects of ECCE closures on child outcomes.

On the other hand, it is also possible that the conditions for children staying home with their families have deteriorated during the pandemic to such a degree that pre-pandemic estimates of the associations between ECCE and child outcomes could under-represent the benefits of ECCE participation during the COVID-19 period. A growing literature suggests that remote learning opportunities for young children around the world are quite limited (Lau & Lee, 2021; Proulx et al., 2021), and that children of all ages are learning far less during school closures than they were before the pandemic (Andrew et al., 2020). Furthermore, research suggests that the pandemic has heightened parental stress and mental health symptoms, and, in doing so, limited children's receipt of responsive care in the home (Brown et al., 2020; Cuartas, 2020; Jiao et al., 2020; Roberton et al., 2020). Taken together, this work suggests that children in households not attending ECCE during the pandemic may be worse-off than those not attending ECCE prior to the pandemic. In this sense, it is possible that ECCE may serve a larger role in protecting and promoting children's development during the pandemic than before.

Beyond addressing these study-specific limitations, it will also be important for future research to consider additional pathways through which the COVID-19 pandemic has affected young children around the world. Growing evidence suggests that the pandemic's effects on non-ECCE-related inputs—including increases in parental stress and mental health challenges, child abuse and neglect, household financial insecurity, and non-education-related service disruptions—appear to be large (Cuartas, 2020; Griffith, 2020; The Alliance for Child Protection in Humanitarian Action, 2020; UNICEF, 2020b), and likely will have long-lasting, negative impacts on children in multiple domains not captured here. Future research should also estimate the longer-term implications of pandemic-related impacts on broader ECCE systems. Unlike primary and secondary school systems, ECCE programs are often non-compulsory and non-publicly funded (Kammerman, 2000; Spier et al., 2019). Although global policies (e.g., SDG Target 4.2) have increasingly encouraged access for the more than 150 million children globally who were not

receiving preprimary schooling prior to COVID-19, emerging evidence suggests that, even in wealthy countries like the United States, many ECCE facilities may not have financial resources to re-open after the pandemic is over (Jessen-Howard & Workman, 2020). Particularly in the context of substantial reductions in educational aid (UNESCO, 2020a), these sustained ECCE shortages may result in limited access to critical educational opportunities for millions more children beyond those affected by the immediate closures modeled in this study. Impacts on program quality may also be profound, particularly for the numerous informal ECCE providers operating with limited institutional supports.

Collectively, the results of this paper suggest that the negative consequences of ECCE closures during the COVID-19 pandemic will likely be large and lasting. Although evidence regarding new variants and asymptomatic carriers is still emerging, there is increasing consensus among the public health community that young children are less likely to be infected and impacted by the COVID-19 virus than adolescents or adults (Wu & McGoogan, 2020). Given this, experts have increasingly argued that decisions to close down educational services should be made not only based on issues related to public health, but also on the potential instructional, developmental, educational, and economic consequences of these shutdowns (Esposito & Principi, 2020). When shutdowns of ECCE services are needed, additional efforts by governments and agencies to support young children and their families will be critical, both in the near-term and well into the future. In particular, developmentally appropriate remote-learning programs (e.g., virtual instruction, television and radio shows, family-friendly apps) should be complemented by services that support parents and other caregivers to provide warm, stimulating care, while also ensuring their own mental health and financial security (Yoshikawa et al., 2020). Intervention may also be needed to support the long-term viability of fragile ECCE systems and ensure access to high-quality early educational services during and after the pandemic.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

How to cite this article: McCoy, D. C., Cuartas, J., Behrman, J., Cappa, C., Heymann, J., López Bóo, F., Lu, C., Raikes, A., Richter, L., Stein, A. & Fink, G. (2021). Global estimates of the implications of COVID-19-related preprimary school closures for children's instructional access, development, learning, and economic wellbeing. *Child Development*, 92, e883–e899. <https://doi.org/10.1111/cdev.13658>