From Population Growth to Demographic Scarcity: Emerging Challenges to Global Primary Education Provision in the Twenty-first Century*

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Abstract

Demographic trends shape the challenge of primary education provision in disparate ways around the world. In some societies, ever-increasing child cohorts continue to exert expansionary pressures. In others, declining child cohorts create pressures for system consolidation. We show that recent demographic trends constitute a highly dis-equalizing force on primary educational provision globally, with persistent expansionary pressures affecting some of the world's least-resourced educational systems. Strikingly, in recent decades, system responses to demographic pressures have produced a converging trend in child-teacher ratios while generating distinct patterns and trends in school size. Ultra-low-fertility Korea offers a stark illustration of the emerging salience of rural-urban spatial hierarchies as child populations decline: non-metropolitan areas bore the brunt of past school closures and teacher losses while metropolitan areas saw increases in schools and teachers, despite student declines. Demographic pressures and associated policy responses constitute an essential yet neglected research agenda for understanding global educational inequalities.

Keywords: Demographic transition, school enrollments, low- and middle-income countries, pupil-to-teacher ratio, depopopulation, LMICs, low- and middle-income countries, Sub-Saharan Africa, Western Europe, East Asia, Korea

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Introduction

Global population trends are changing the nature of what might be termed the "demographic challenge" to primary educational systems. The traditional demographic challenge, which continues in some countries, is that of population expansion. As observed the 2022 *United Nations World Population Prospects* Gaigbe-Togbe et al. (2022), "[e]xpanding educational opportunities and ensuring quality education for all can be particularly challenging for low- and lower-middle income countries with growing cohorts of children and youth," and the least developed countries are among the world's most rapidly growing (Gaigbe-Togbe et al. 2022). In high-fertility countries with large proportions of children and youth, spending per capita on the human capital of young people is typically less than half as much as in countries with older population age structures (Sánchez et al. 2023).

In contrast, an emerging regime of sparse and declining child cohorts—demographic scarcity associated with some combination of age structure effects, fertility decline, or urbanization and hollowing out of rural communities—eases demographic pressures on educational expenditures (Sánchez et al. 2023). At the same time, demographic scarcity poses the challenge of designing systems that can serve dispersed, sparse school-age populations (OECD and European Commission 2021), as noted in a recent OECD report:

> Population decline ...will lead to a decline in the number of students in rural areas, raising additional challenges for the attraction of teachers and principals in these locations, and exacerbating the costs of educational provision (OECD and European Commission 2021).

Challenges extend beyond simply attracting educational resources. Even countries with ample resources face difficulties in educational planning amidst demographic contractions. Once the number of teachers and schools increases, it becomes challenging to reduce them, which places a financial burden on local governments and school districts (Adams 2024; Lee 2022; Tieken and Auldridge-Reveles 2019).

Research has traced recent and pending global demographic shifts (Bloom and Luca 2016; Crimmins and Zhang 2019; Settersten and Angel 2011) and their implications for the structure of

labor markets (Korenman and Neumark 1997), economic growth (Bloom, Canning, and Sevilla 2001; Mason et al. 2009), and intergenerational-inequality (Dolls et al. 2019; Prettner 2013; Weizsäcker 1996). However, to the best of our knowledge, scholars have yet to investigate the relationship between demographic changes in the school-age population and primary school system responses. In this paper, we describe trends in the size of the child population and investigate how educational systems are responding to demographic pressures in terms of two indicators of primary school provision: teacher and school counts.[1] Leveraging differing degrees of data availability at different levels of aggregation, we conduct global, regional, and within-country analyses. Globally, we investigate child population changes and changes in the provision of teachers. We then focus on responses in terms of the provision of schools and teachers in two low-fertility regions—Western Europe and East Asia—to look at system response. Finally, we focus on the case of South Korea, at the vanguard of low fertility, to illustrate the importance of attention to how geospatial hierarchies shape system responses within countries as child populations decline.

Data and Methods

We construct a novel population and education dataset by combining multiple sources of data. First, we use the World Development Indicators from the World Bank spanning the years 1960 to 2021 to examine global trends in the school-age population and educational system responses, focusing on primary education (World Bank Indicators 2023). We use the population aged 0 to 14 as a proxy for the primary-age population, and we use the number of primary school teachers—one of the only long-term indicators linked to school resource availability at the national level—as a global measure for shifts in primary school resources. We focus our analysis on variations over time in child population and educational resources by seven World Bank analytical groupings.

Second, given the lack of availability of international datasets with information on both the

[1] Our paper also complements school- and class-size effects literature that has sought to identify the optimal allocation of resources while holding existing population patterns fixed (Barrett et al. 2019; Filges, Sonne-Schmidt, and Nielsen 2018; Leithwood and Jantzi 2009).

number of schools and teachers across countries,[2] we gather official national statistics on the number of schools, teachers, and students from economies in East Asia and Western Europe, two regions that have been experiencing downward child population pressures. Specifically, we gather data from mainland China, Japan, South Korea, Taiwan, Austria, Germany, France, the Netherlands, and Switzerland. Third, we collect subnational data from South Korea, which has seen one of the fastest rates of reduction in child population in recent decades. We group subnational Korean administrative units into metropolitan and non-metropolitan areas. Metropolitan areas include the capital area and metropolitan cities. Non-metropolitan areas encompass all other areas that are not included in the metropolitan areas.

Combining the data, we present levels and compute percentage changes in the number of schools, teachers, students, and children over time. To quantify relative changes in the number of children compared to relative changes in the number of teachers, we also compute population-teacher elasticities, which we define as the ratio of percentage changes in teachers divided by the percentage changes in population over the same period of time. Additionally, to measure changes in per individual school resource availability, we calculate children to teacher and pupil to teacher (pupil-teacher) as well as children to school and pupil to school (pupil-school) ratios when possible. We present details of data sources and construction of measures in Appendix B and C, with the compiled dataset and code accessible on our project's website.

Results

Global: Population Analyzing sixty years of global country-level primary-school-age child population data, we identify three groups of world regions: regions where the school age population has been increasing steadily (Sub-Saharan Africa, SSA, and Middle East and North Africa, MEA), regions where school age populations have recently peaked and are beginning to trend downward (Latin America and the Caribbean, LAC, North America, NAC, and South Asia, SAS), and regions that are in longer-term decline (Europe and Central Asia, ECA, and

[2] It is worth noting that, to the best of our knowledge, there is no publicly available comprehensive dataset that provides information on the number of schools at the country level. In contrast, the number of students and teachers, for different geographies, is available from multiple sources such as the World Bank Open Data, UNESCO Institute for Statistics, OECD Data, and Eurostat (Teacher Task Force 2021).

East Asia and Pacific, EAS).

Figure 1 contains panels for these three groups of regions and shows trends in the child population between 1960 and 2020, expressed as percentage differences relative to the reference year of 2020.[3] The SSA and the MEA regions have seen steady growth of child population that accumulated to six-decadal increases of 390.0% and 206.4% respectively. In contrast, LAC, NAC, and SAS experienced initial growth and plateauing in recent decades: overall school-age population grew by 8.8%, 120.8%, and 66.7% respectively between 1960 and 2020, but growth rates between 2000 and 2020 have plateaued to -0.3%, 2.6%, and -7.1%, respectively. While the five aforementioned regions saw school-age population growth overall across the six decades, child population in EAS has decreased by 18.8% from its peak in 1977 (an overall increase of 12.3% from 1960); in ECA, child population peaked in 1968, and has fallen by 16.5% by 2020 from its peak.[4]

These opposing regional trends have led to dramatic shifts in the distribution of children across the world over the past six decades, with implications for shifting school resource pressures. The joint share of SSA and MEA regions in the global child population increased by 2.5 times from 12.6% to 31.1% between 1960 and 2020. In contrast, the joint EAS and ECA share of the global child population shrunk by 40%, decreasing from 53.0% in 1960 to 31.7% in 2020. Jointly, the LAC, NAC and SAS regions' share of global child population has been relatively stable, increasing from 34.4% in 1960 to 37.2% in 2020. These shifts in relative shares have happened in a setting where the overall number of children globally has increased by 75.5% from 1.13 billion in 1960 to 1.98 billion in 2020.

Global: Population and Teachers We turn to the educational response to global school age population change, with attention to the implications of demographic context for educational resources. In this section, we complement child population data with data on the number of

[3] For consistency across regions, the reference year for the percentage changes in all figures is 2020. However, in the text, the calculated percentage changes follow the conventional approach, where the reference year is the earlier year. For variations across time in child population *levels* by region, see Appendix Figure A.1.

[4] While there are substantial heterogeneities across countries within each of these seven World Bank analytic regions, the regional aggregate findings are broadly consistent with country-specific results. Country-specific child population changes are shown in Appendix Table A.1. We provide additional discussions of country-specific results as well as patterns of changes in the number of primary school students in Appendix Section A.1.

primary school teachers, which is one of the only indicators linked to school resource availability and quality that exists over time at the national level. To allow for global comparisons, we present the children-teacher ratio. Panel (a) of Figure 2 presents the children-teacher ratios across regions in 1980, 2000, and 2020, and panel (b) presents bi-decade percentage changes in the number of primary teachers plotted against percentage changes in the child population.[5]

Despite the diverging tripartite patterns of child population changes examined in the prior section, the children-teacher ratios have consistently decreased across regions between 1980 and 2020, with all regions of the world trending toward NAC, where the children-teacher ratio has been the lowest.

The children-teacher ratio in SSA increased from 129.1 in 1980 to 137.4 in 2000 and fell to 93.4 in 2020. More specifically, the population-teacher elasticity was 0.85 between 1980 to 2000, with teacher growth (60.1 percent) falling slightly behind school-age population growth (70.5 percent); the elasticity increased to 2.23 between 2000 and 2020, with teacher growth (138.1 percent) more than doubling school-age population growth (61.8 percent). MEA also has experienced a child population explosion; despite that, its children-teacher ratio fell from 96.2 in 1980 to 62.2 and 53.7 in 2000 and 2020, a 44.1% overall reduction.

For the regions with plateauing populations, the number of teachers expanded despite population stagnation. LAC saw its children-teacher ratio drop by 32% from 76.0 to 51.6 between 1980 and 2020. Among all regions, SAS experienced the largest reduction in its children-teacher ratio, which halved from 173.6 in 1980 to 83.7 in 2020. Over the bi-decades, the rate of teacher growth was steady at 79.9% and 63.3%, but the population-teacher elasticity escalated from 2.10 to 24.32 as the pace of child population growth fell by almost 95% (from 38.1% to only 2.6%). During these decades, NAC kept the benchmark lowest children-teacher ratio, which increased slightly from 34.5 in 1980 to 37.2 in 2000 and stayed constant afterward.

In the EAS and ECA regions, as child population has declined, the number of primary teachers generally expanded, leading to 42.1% (71.0 to 41.1) and 28.4% (65.8 to 47.0) drops

[5] Appendix Figure A.2 provides the same information as in panel (b) of Figure 2, but with country name abbreviations. Figures A.2 and 2 include countries where we have data in both the pre- and post-millennial decades. Appendix Figure A.3 visualizes regional aggregates changes, Appendix Figure A.4 presents changes for all countries where we have data in either or both the pre- and post-millennial decades, and Appendix Table A.2 presents country-specific results.

in children-teacher ratios between 1980 and 2020, respectively. In both regions and across both periods, the population-teacher elasticities have been below -1, which means the number of primary teachers has grown at a faster rate than the pace at which primary age population fell. Specifically, in EAS, primary teachers grew by about one fifth in the pre- and post-2000 bi-decades as child population fell by 5.6% and 12.9%; in ECA, the number of primary teachers increased by 13.4% and 6.8% while child population fell by 10.7% and 2.2%.

Overall, a cross-region comparison shows a striking pattern of global convergence. Between 1980 and 2020, all regions except for NAC experienced between one quarter to one half reductions in the children-teacher ratio. In 1980, NAC had between two to five times as many primary teachers per child population as other regions. By 2020, relative to NAC's ratio, the children-teacher ratio is only about 10-50 percent larger in EAS, ECA, LAC, and MEA, and only less than three times larger in SAS and SSA.

The cross-country efforts to increase the number of primary teachers per student, despite vastly different population challenges, indicate a global consensus on the importance of primary teacher availability for education. Going forward, SSA and MEA countries are likely to face greater challenges in maintaining their current rates of children-teacher ratio reduction toward NAC levels as their child populations continue to rise. Concurrently, for other regions, it can become more difficult to maintain the number of primary teachers as the number of children continues to fall.

Western Europe and East Asia: Population, Teachers, and Schools In this section, we focus on East Asia (a part of EAS) and Western Europe (a part of ECA), two sub-regions that are at the forefront of low fertility and declining school age cohorts.[6] Available governmental statistics from these economies permit the investigation of how both the number of schools as well as teachers have responded to changes in the number of primary school students. Figure 3 presents changes in the number of primary schools, teachers, and students in East Asian and Western European economies. Due to high enrollment rates, changes in the number of students and primary age population show similar patterns in Western Europe and East Asia. We provide

[6] In 2020, fertility rates in China (1.3), South Korea (0.8), and Taiwan (1.0) are 48 to 89 percent of the fertility rates in Austria (1.4), France (1.8), Germany (1.5), Netherlands (1.5), and Switzerland (1.5) (National Development Council 2021; The World Bank Group 2021).

additional results based on ages 0 to 15 child population in the Appendix.[7]

In congruence with our regional child population discussions, one general trend is the persistent decline in the number of students in recent decades. Interestingly, these declines have been more pronounced in East Asia compared to Western Europe. For instance, compared to 1980, primary school student numbers in South Korea, Taiwan, and Japan all decreased by approximately 50%, while China experienced a 27% reduction. Meanwhile, the number of primary school students declined by 13% and 11% in Austria and France. Switzerland, which has the highest share of children with migration backgrounds, has seen a 20% increase in the number of primary school students.

A key reason for the relative differences in primary school student changes is that the share of children with migration backgrounds is much larger in Western Europe. In 2018, the shares of PISA test takers who self-reporting as having migration-background in East Asia economies were all below 1 percent but above 13 percent in Western European economies, with Switzerland having the highest share of 33.9 percent (OECD 2020).[8] Additionally, UNDESA statistics, which estimate the number of children who are first-generation migrants, show that in 2020, the share of international migrants account for at most 2.3 percent of population below age 15 in East Asia and at least 4.6 percent in Western Europe.[9]

In terms of teachers, following our prior finding that the number of teachers in EAS and ECA regions has increased, the number of primary teachers in China, South Korea, and Taiwan grew by 17%–59% since 1980, with only Japan experiencing a 10% reduction. But in all the

[7] For additional details on percentage changes in schools, teachers, students, and children between 1960-2020, see Appendix Table A.4. For additional details on children and pupil to teacher as well as children and pupil-school ratios by decade, see Appendix Table A.5.

[8] According to OECD OECD (2020), the shares for Japan (0.6 percent), Korea (0.2 percent), Beijing-Shanghai-Jiangsu-Zhejiang of China (0.2 percent), and Taipei (0.7 percent) are below 1 percent, but the share reported for Austria (22.7 percent), France (14.3 percent), Germany (22.3 percent), Netherlands (13.8 percent), and Switzerland (33.9 percent) are between 14 and 34 percent. Furthermore, between 2000 and 2018, the percentages of PISA test takers reporting having migration background in Austria, France, Germany, and Switzerland have increased by 105%, 30%, 46%, and 64%, respectively.

[9] Based on UNPD United Nations Population Division (2021) estimates, in 2020, the share of international migrants below age 15 accounts 8.2, 4.6, 8.0, 5.6 and 10.0 percent of the population below age 15 in Austria, France, Germany, the Netherlands, and Switzerland. These are substantially higher than the share of migrants below age 15 in 1990, which were 5.3, 2.8, 3.0, 4.2, and 8.9 percent for the countries respectively. In contrast, the share of migrants below age 15 accounts for 0.07, 1.4, and 2.3 percent of the population below age 15 in China, Japan, and Korea, dramatically lower than Europe. Interestingly, these numbers have been rising in these three East Asian economies, in 1990, the percentages were even lower at 0.02, 0.8, and 0.1 in China, Japan, and Korea, respectively.

East Asian economies, the number of teachers has increased relative to the declining number of primary students. Consequently, the pupil-teacher ratios have steadily declined and converged to between 12-17 by 2020. This is in sharp contrast to the large gaps in the pupil-teacher ratio across countries that existed in 1980, when the ratio in South Korea was 48, Taiwan 32, China 27, and Japan 25. Western European countries also experienced similar increases in the number of teachers, with Austria, France, and Switzerland gaining 35%, 10%, and 117% more primary teachers between 1980 and 2020, Germany gaining 31% since 1990, and the Netherlands gaining 4% increase since 2000. These have led to lower than East Asia primary pupil-teacher ratios, which have converged to 9-12 by 2020.

As Western Europe and East Asia have increased the number of teachers, there is a broad trend of decreasing number of primary schools over time. In Western Europe, Austria and France saw 13% and 26% reductions in primary schools since 1980; Austria, Germany, France, and the Netherlands all experienced between 10% to 15% reductions in primary schools between 2000 and 2020. In East Asia, China and Japan closed 83% and 22% of their primary schools since 1980, respectively. Taiwan is an exception and has seen an 8% increase in the number of primary schools during the same time-frame. Korea shows stark changes over time: the number of schools decreased by 19% from 1981-2000 but increased by 16% between 2000 and 2020.

While the pupil-teacher ratios have all been trending downward and converging, there are greater diversities in the levels and trends of pupil-school ratios. Overall, the pupil-school ratios are substantially lower in Western Europe than in East Asia. In Japan, South Korea, and Taiwan, due to much faster reductions in students relative to changes in the number of schools, there have been substantial reductions in pupil-school ratios. The ratios approximately halved in South Korea and Taiwan from around 900 to around 450 between 1980 and 2020, and the ratio decreased from 474 to 323 in Japan during the same time frame. Due to the massive scale of primary school closures in mainland China (Hannum, Liu, and Wang 2021; Hannum and Wang 2022), the pupil-school ratio has risen sharply in China, increasing from 159 to 679 between 1980 and 2020. In Europe, due to the reductions in primary schools and relatively limited decreases in the number of primary students, the pupil-school ratios have held relatively constant with some experiencing slight increases.

Jointly, in East Asia and Western Europe, our results show that school-system resource policy responses to broadly declining child population, jointly in terms of changes in the number of teachers and changes in the number of schools, have been heterogeneous across countries and time with the common feature of decreasing class sizes. By 2020, Western Europe and East Asia present three emerging models: a model of growing schools with small classes (e.g., China), a model of declining medium-size schools with small classes (e.g., Japan, South Korea, and Taiwan), and the European model of small schools with small classes. These patterns show different response paradigms exhibited by different countries that are at the forefront of declining school-age populations.

As countries experience primary-age population reductions, deciding on the appropriate number of teachers to maintain to support the dwindling child population, and choosing whether to downsize, relocate, or consolidate schools will remain a critical problems for economies in East Asia and Western Europe. Such decisions are on the horizon in economies shifting toward lower fertility and primary-age population reductions.

Korea: Population, Teachers, and Schools in Metropolitan and non-Metropolitan Areas

International comparisons from prior sections shed light on patterns of aggregate variation across countries, but there can also be variation in population dynamics and changes in school and teacher availability within countries. While each country faces unique regional challenges, as a country that has experienced substantial overall school-age population decline as well as substantial urbanization, South Korea provides a useful and possibly illustrative case study of how within-country population dynamics interact with shifting resources.

South Korea is at the forefront of school-age population decline. South Korea has experienced one of the fastest rates of child population reduction,[10] and reported a total fertility rate of .78 in 2022—-the lowest in the world (Kim 2023). The case of South Korea illustrates the new geospatial challenges in educational planning in the context of ultralow fertility. For our analysis in this section, we take advantage of sub-national data to analyze heterogeneities in population pressures and school responses within country and across time. In Figure 4,

[10] Appendix Table A.1 shows that at 50%, South Korea had the second highest global rate of child population reduction between 1980 and 2020 after Bosnia and Herzegovina.

we present percentage changes in the number of students, teachers, and schools as well as the pupil-teacher and pupil-school ratios in metropolitan and non-metropolitan areas from 1970-2020.[11]

First, we find a shift in population and school resources from non-metropolitan to metropolitan areas in the context of overall primary student population reductions. Between 1970 and 2020, non-metropolitan primary student counts declined by between 18 to 34 percent each decade. Metropolitan areas had relatively stable primary student counts in the 1980s and 1990s, but have seen 18% per decade reductions between 2000 and 2020. In terms of school resources, metropolitan areas experienced a continuous expansion in both teacher and school counts. From 1970 to 2020, the number of metropolitan teachers increased steadily by a total of 229%, and the number of metropolitan schools increased steadily by a total of 142%. In contrast, non-metropolitan areas saw a 4% increase in the number of teachers and a 36% decrease in the number of schools.

Overall, as metropolitan areas' share of national primary student population increased from 44% to 69% between 1970 and 2020, their shares of primary teachers and schools increased from 22% to 52% and from 37% to 65%, respectively. These changes led to large reductions in pupil-teacher and pupil-school ratios throughout South Korea. In metropolitan and non-metropolitan areas, given the fall in students and rise in teacher and school counts, the pupil-teacher ratio decreased dramatically, falling from 68 and 51 to around 15 and 12, respectively. The pupil-school ratio decreased at the same time dropping from around 1900 and 690 to 600 and 280 for metropolitan and non-metropolitan areas, respectively.

In addition to the aggregate changes over time, in non-metropolitan areas, despite steady reductions in primary students across the decades, we find a dramatic shift in school system responses from contraction to stabilization before and after 2000. From 1980 to 2000, non-metropolitan teacher and school counts decreased by 21% and 40%, respectively. Post-2000, the number of non-metropolitan primary schools remained constant and the number of primary teachers increased by 24%. Beginning in the 1970s, non-metropolitan areas began facing heightened pressure from population reduction. The number of non-metropolitan primary school

[11] For changes in students, teachers, and schools by each metropolitan city and non-metropolitan province, see Appendix Figure A.5 and Table A.6.

students decreased from 3.2 million to 1.2 million between 1970 and 2000. The reduction in students was met with dramatic reductions in non-metropolitan primary school teachers and school counts, as the number of non-metropolitan teachers decreased from 67.5 thousand in 1980 to 53.5 thousand in 2000 and the number of non-metropolitan schools fell from 4,652 thousand to 2,955. In the most extreme case, Jeonnam Province experienced a 70% reduction in the number of primary school students between 1980 and 2000, a concurrent 52% reduction in the number of primary schools, and a 40% reduction in the number of primary school teachers.

However, a policy shift occurred in 2000 in response to the resistance from local communities to resource reductions in prior decades (Korean Ministry of Education 2016). The surge in school closures during the 1990s sparked public outcry due to the perceived adverse effects on local communities (Lee, Kim, and Ma 2010). Subsequent resistance from these communities effectively halted additional school closures in non-metropolitan areas after 2000. Consequently, between 2000 and 2020, the number of non-metropolitan primary schools only shifted by one from 2,955 to 2,956, and the number of primary teachers increased from 53.3 thousand to 66.2 thousand, recouping nearly all reductions between 1980 and 2000. The shift in policy occurred despite the continued fall in the number of primary students in non-metropolitan areas, which decreased from 1.2 million to 0.8 million between 2000 and 2020.

The dramatic policy shift in Korea highlights the challenges that local community and school systems face when confronted with dramatic falls in child population. Overall, Korea experienced four policy episodes across time and space. First, in metropolitan areas, prior to 2000, while the number of metropolitan primary students remained stable, the number of teachers and schools increased sharply. Second, post 2000, despite metropolitan primary student reductions, metropolitan areas continued on the same trajectory of expanding schools and teacher counts. Third, in non-metropolitan areas, prior to 2000, school resources in terms of teachers and schools adjusted downward as rural population fell. Fourth, since 2000, non-metropolitan school resources have been relatively stable while rural primary school students continued to fall sharply. The latter three policy episodes dealt with decreasing primary students with policies of increasing, decreasing, and stabilizing school and teacher counts. The Korean experience shows the challenge in reallocating teachers and schools in the face of population reductions,

and illustrates the importance of geospatial hierarchies that, in many settings, are making rural populations particularly vulnerable to institutional losses. Further research from Korea on the relative effects of heterogeneous policy responses to population reduction could help prepare other countries for a future of child population reductions.

Discussion

This paper has sought to describe the changing demographic context of primary school provision globally, with attention to the implications of an emerging trend of school age demographic scarcity. We would like to highlight three main observations. First, across countries and regions, demographic pressures have been changing globally in ways that carry potentially disequalizing implications for educational quality. In the period under study, growing child cohorts remained a daunting challenge in countries in Sub-Saharan Africa. There, ever-increasing cohorts of school-aged children placed pressures to expand capacity on the world region with the highest rates of educational exclusion (UNESCO Institute for Statistics 2019). At the other demographic extreme, Europe and East Asia are experiencing sharp drops in school-aged populations. This trend reverses expansionary pressures in educational systems that include some of the world's most high-performing on comparative tests (OECD 2023), and, in principle, could allow for higher quality educational experiences via shifts toward smaller pupil-teacher ratios in these educationally-advantaged settings. However, this trend also places pressure on primary education systems to potentially close schools in areas with dwindling populations.

Second, within countries, new considerations around spatial inequalities and school system design are emerging in the context of depopulation and demographic scarcity. As we have shown in this paper, in Korea, schools in metropolitan areas have grown and those in non-metropolitan areas have declined sharply, even though the number of students in both kinds of areas have been declining. In China, rural children in poorer parts of the country have been highly susceptible to the policy response of consolidation and boarding at schools (Hannum and Wang 2022), for children as young as primary school age. A recent OECD report highlights that rural schools in OECD countries are facing smaller schools and class sizes as a result of declining student numbers, and suggests that preparing rural schools for the future will require rethinking of

traditional approaches to education provision in ways that go beyond relocating rural students to larger, more distant schools (OECD 2021).[12]

Finally, studying the diverse response strategies of countries at the forefront of school-age demographic decline is important, as growing numbers of countries will face the same phenomenon. We have shown that national responses to demographic decline are heterogeneous across systems. While reduced children-teacher and pupil-teacher ratios are relatively common as expansionary pressures have eased over the long term, school systems differ dramatically in the degree to which they are changing the numbers of schools in relation to population decline. These findings highlight the potential value in study of divergent policy responses to common, emerging demographic changes.

[12] Further complicating the geospatial considerations, in some countries, immigration into certain parts of the country may buffer the effects of low fertility on population structures, and in many countries internal migration may change the spatial distribution of school age children substantially at subnational levels.

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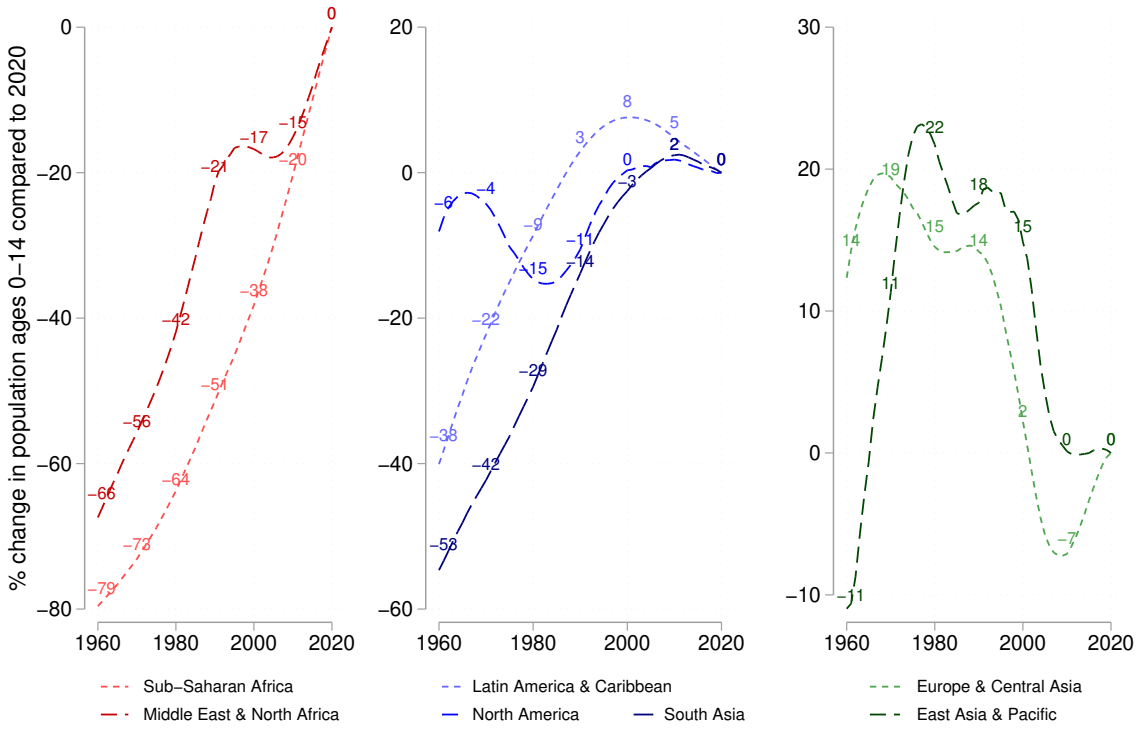
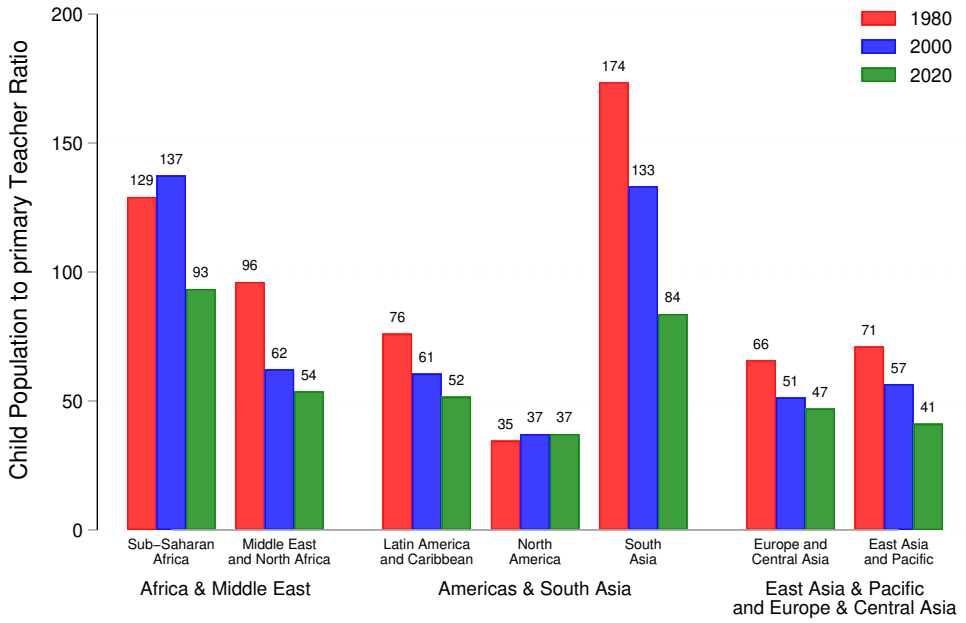
Fig. 1. 1961-2020 School Age Population % Change by Region



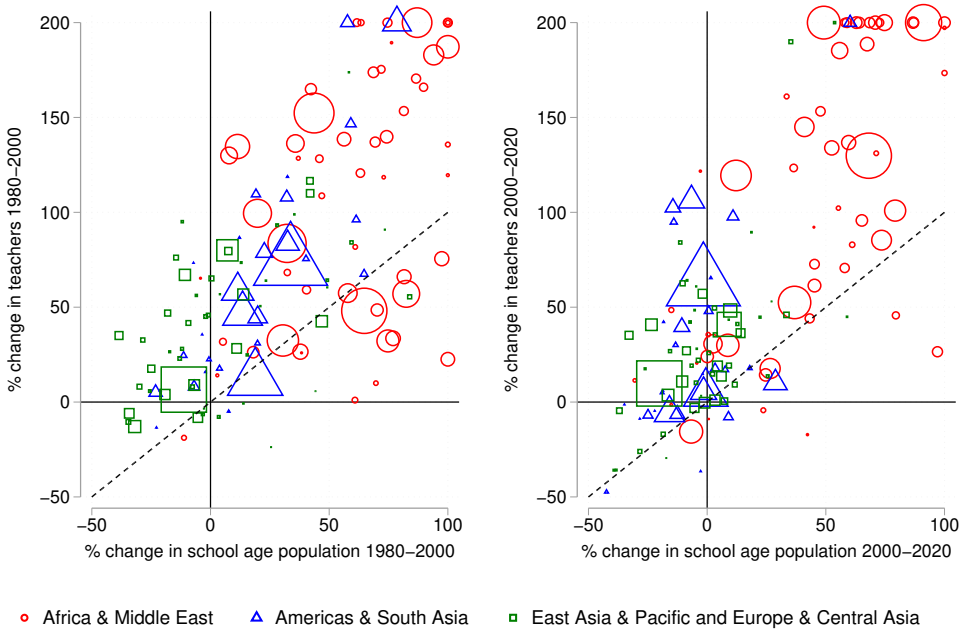
Note: The data source is the World Bank World Development Indicators. We treat the child population ages 0 to 14 as the school age population. To facilitate comparisons of trends across countries, for each region, the value shown along the y-axis is the percentage change in school age population with year 2020 as the base year, which is computed as: $\%\text{ChgBase2020} = \left(\text{Pop}_{\text{y,region}} - \text{Pop}_{\text{2020,region}}\right) / \left(\text{Pop}_{\text{2020,region}}\right) \times 100$. Percentage change by year 2020 with respect to base year y is equal to $\%\text{ChgBaseY} = -\%\text{ChgBase2020} / \left(\%\text{ChgBase2020} + 100\right)$.

Fig. 2. Changes in child population and teachers, 1980-2020

(a) Child population to primary teacher ratio, 1980-2020



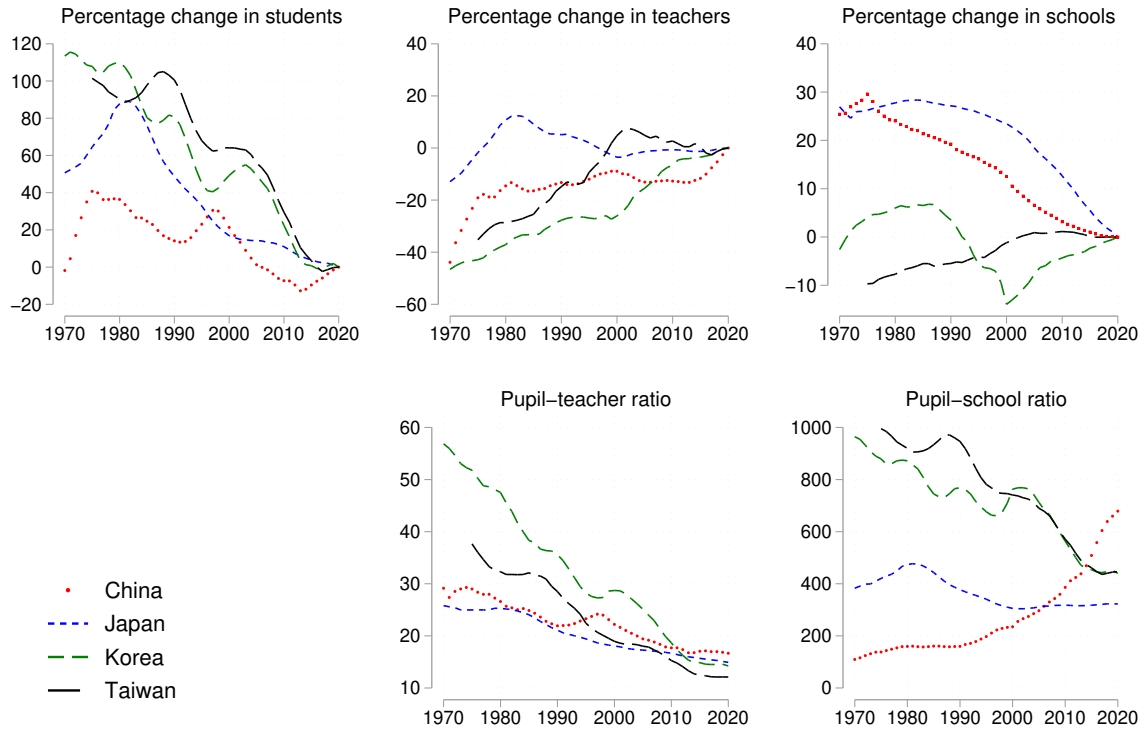
(b) Percentage change in the primary school-age population and teacher counts, 1980-2020



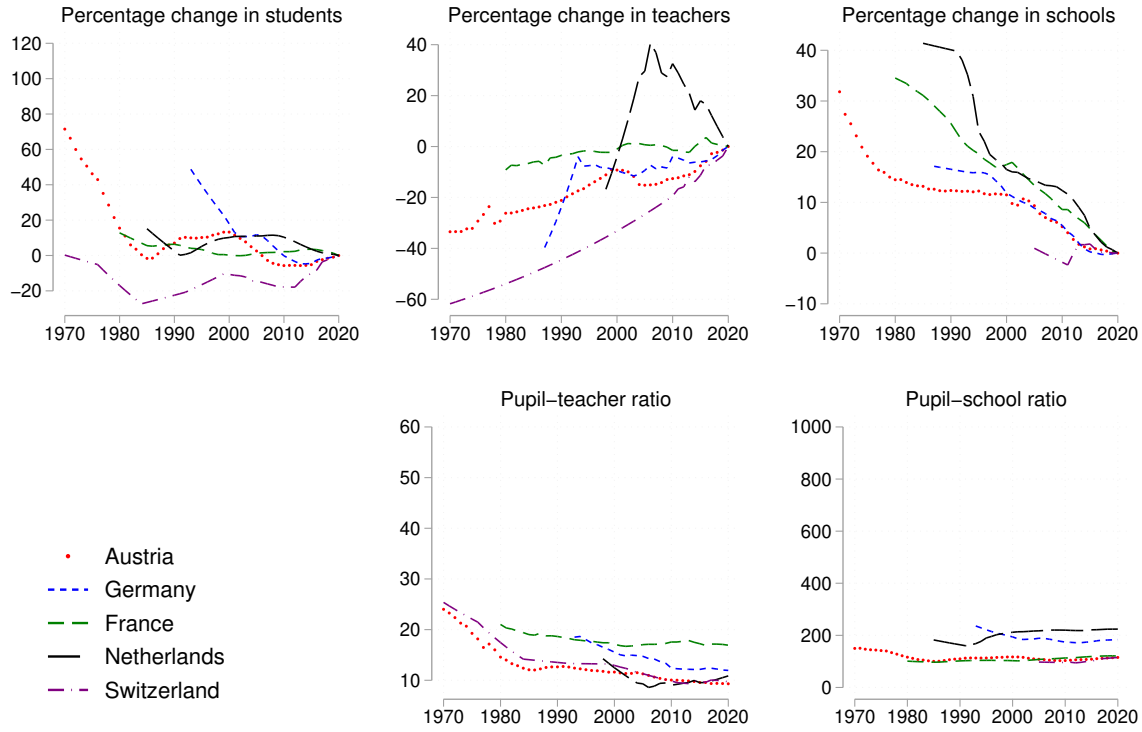
Note: The data source is the World Bank World Development Indicators. For simplicity, we treat the child population ages 0 to 14 as the school age population. Countries are included when both primary pupil to teacher ratio and primary school age population data are available for beginning and end years in both figures for computing changes. 134 countries are included among 211 countries. See Appendix Table A.2 for a full list of countries. Countries above the 45 degree line experience a reduction in the children to teacher ratio, and countries below the 45 degree line experience an increase.

Fig. 3. Primary education in East Asia and Western Europe: demographic contraction, schools, and teachers between 1970 and 2020

(a) East Asia

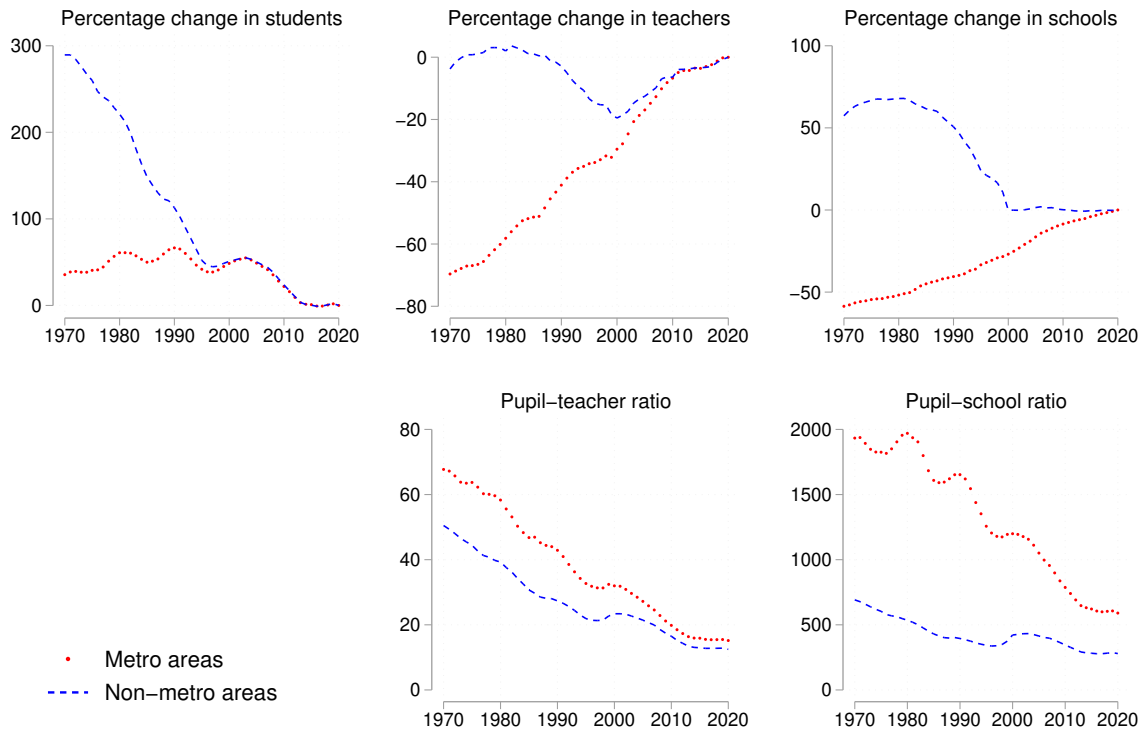


(b) Western Europe



Note: The data source is corresponding country's official website. For detail on the data source, see Appendix B. To facilitate comparisons of trends across economies, the value shown along the y-axis for the top three figures of each panel (a) and (b) is the percentage change in each corresponding variable as of 2020, which is computed as: $\frac{\text{Outcome}_{\text{year,country}} - \text{Outcome}_{\text{2020,country}}}{\text{Outcome}_{\text{2020,area}}} \times 100$. Due to the scale difference between China and other economies, we rescaled the percentage change in schools in China by 1/20. A twenty percent change in schools in China represents a one percent change in the figure.

Fig. 4. Primary education in Korea: demographic contraction, schools, and teachers in metropolitan and non-metropolitan areas between 1971 and 2020



Note: The data source is Korean Educational Statistics Service (KESS). Both private and public schools are included. The metropolitan areas include the capital area (Seoul, Incheon, Gyeong-gi), metropolitan cities (Busan, Daegu, Daejeon, Ulsan, Gwangju), and Sejong. Non-Metropolitan areas refer to all other areas excluding Metropolitan areas (Gangwon, Chungbuk, Chungnam, Jeonbuk, Jeonnam, Gyeongbuk, Gyeongnam, Jeju). To facilitate comparisons of trends across areas, for each area, the value shown along the y-axis for the top three figures is the percentage change in each corresponding variable as of 2020, which is computed as: $\frac{\text{Outcome}_{\text{year,area}} - \text{Outcome}_{\text{2020,area}}}{\text{Outcome}_{\text{2020,area}}} \times 100$.

ONLINE APPENDIX

From Population Growth to Demographic Scarcity: Emerging Challenges to Global Primary Education Provision in the Twenty-first Century

Emily Hannum, Jeonghyeok Kim, and Fan Wang

A Additional Results

In this online appendix section, we provide additional visualization and details on changes in global child population patterns (Section A.1), how primary school resources in the form of primary teachers have changed globally (Section A.2), shifts in population, teachers and schools in Western Europe and East Asia (Section A.3, and shifts in these patterns within South Korea (Section A.4).

A.1 Global: Child population

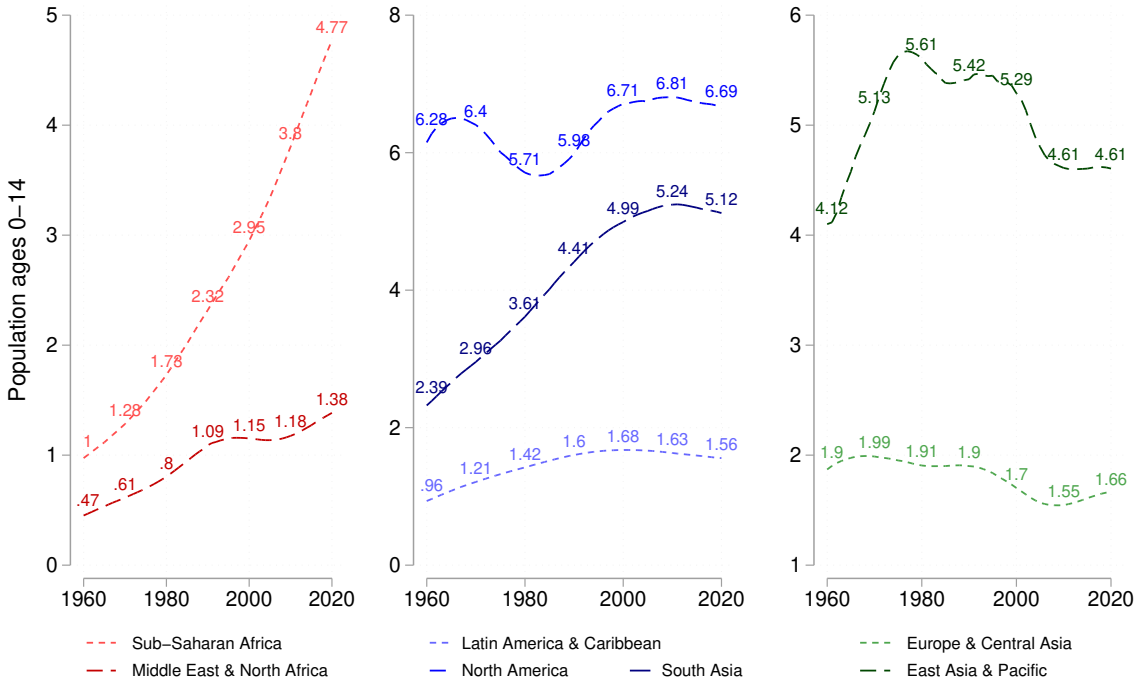
In Appendix Figure A.1, we provide changes in population levels from 1960 and 2020 for the three groups regions we identified as exhibiting increasing, plateauing, and falling child population.

In Appendix Table A.1, we present the number of children (ages 0 to 15) at both regional and country levels, along with their percentage changes for the periods 1980-2000, 2000-2020, and 1980-2020. These information complement Figure 1 from the main text where we showed percentage changes in child population for these regions.

Country-specific results on child population changes reflect of regional aggregate findings presented in the main text. The country-specific results show that nearly all countries in the SSA and MEA regions (with the exception of Malta, Mauritius, and Seychelles) experienced increases in child population between 1980 and 2020. Country-specific results from the LAC, NAC, and SAS regions show that while most countries experienced increases in child population between 1980 and 2020, but between 2000 and 2020, the majority of countries in these regions have begun experiencing child population reductions. Results from ECA shows the vast majority of ECA countries, with the exception of several central Asia economies, experiencing child population reductions between 1980 and 2020. Results from EAS shows child population reductions between 1980 and 2020 or 2000 and 2020 for most East Asian economies, but population increases for smaller island economies in the Pacific along with Australia.

To complement our results here which are focused on the number of children between 0-14, on our website, we also present levels and changes in the number of primary school students globally—Table: Global primary school students.

Fig. A.1. 1961-2020 school-age population by region



Unit: 10 million for North America, 100 million for others

Note: The data source is the World Bank World Development Indicators. For uniformity of comparisons, we treat the child population ages 0 to 14 as the school age population. To facilitate comparisons of trends across countries, for each region, the unit of the value shown along the y-axis varies by region. The y-axis unit is 10 million for the Euro Area and North America, but 100 million for all other regions.

Table A.1: Changes in global child population

Country by region	Ages 0-14 population (1000s)				Ages 0-14 population changes (%)		
	1960	1980	2000	2020	2000/1980	2020/2000	2020/1980
Panel A: Global regions							
Sub-Saharan Africa	97,324	172,959	294,882	477,202	70%	62%	176%
Middle East & North Africa	45,133	80,465	115,244	138,455	43%	20%	72%
Latin America & Caribbean	93,310	142,229	167,538	155,704	18%	-7%	9%
North America	61,490	57,098	67,118	66,903	18%	0%	17%
South Asia	232,284	361,420	499,156	512,158	38%	3%	42%
Europe & Central Asia	187,008	190,631	170,203	166,458	-11%	-2%	-13%
East Asia & Pacific	410,016	560,642	529,048	460,563	-6%	-13%	-18%
Panel B: Sub-Saharan Africa (SSA)							
Angola	2,298	3,846	7,739	15,248	101%	97%	296%
Benin	937	1,661	3,099	5,085	87%	64%	206%
Botswana	219	435	635	786	46%	24%	80%
Burkina Faso	1,995	3,110	5,429	9,275	75%	71%	198%
Burundi	1,226	1,858	3,194	5,381	72%	68%	190%
Cabo Verde	85	134	184	156	37%	-15%	16%
Cameroon	2,067	3,852	6,995	11,166	82%	60%	190%
Central African Republic	571	928	1,575	2,103	70%	33%	127%
Chad	1,230	2,035	4,084	7,636	101%	87%	275%
Comoros	79	138	239	339	73%	42%	146%
Congo, Dem. Rep.	6,612	11,755	21,452	41,015	82%	91%	249%
Congo, Rep.	425	820	1,319	2,277	61%	73%	178%
Côte d'Ivoire	1,497	3,636	7,180	10,949	97%	53%	201%
Equatorial Guinea	96	97	246	516	153%	109%	430%
Eritrea	438	767	1,048		37%		
Eswatini	154	294	432	434	47%	0%	48%
Ethiopia	9,627	15,856	30,770	45,891	94%	49%	189%
Gabon	155	286	504	829	76%	65%	190%
Gambia	155	278	620	1,062	123%	71%	283%
Ghana	2,928	5,185	8,184	11,538	58%	41%	123%
Guinea	1,412	2,109	3,826	5,654	81%	48%	168%
Guinea-Bissau	247	340	546	825	60%	51%	143%
Kenya	3,776	8,223	14,463	20,750	76%	43%	152%
Lesotho	373	614	813	691	32%	-15%	12%
Liberia	460	832	1,216	2,042	46%	68%	145%
Madagascar	2,177	4,024	7,119	11,094	77%	56%	176%
Malawi	1,604	2,868	5,137	8,224	79%	60%	187%
Mali	2,149	3,124	5,097	9,519	63%	87%	205%
Mauritania	378	701	1,145	1,845	63%	61%	163%
Mauritius	307	344	306	212	-11%	-31%	-38%
Mozambique	3,017	5,044	7,883	13,772	56%	75%	173%
Namibia	263	492	754	936	53%	24%	90%
Niger	1,637	2,882	5,470	12,024	90%	120%	317%
Nigeria	18,781	32,353	53,321	89,645	65%	68%	177%
Rwanda	1,403	2,474	3,520	5,113	42%	45%	107%
Senegal	1,408	2,586	4,380	7,132	69%	63%	176%
Seychelles	16	24	23	23	-4%	1%	-4%
Sierra Leone	889	1,442	2,025	3,218	40%	59%	123%
Somalia	1,174	2,749	4,188	7,335	52%	75%	167%
South Sudan	1,180	1,997	2,779	4,626	39%	66%	132%
Sudan	3,395	6,831	11,947	17,452	75%	46%	155%
São Tomé and Príncipe	21	46	63	92	38%	45%	101%
Tanzania	4,586	8,582	14,997	26,017	75%	73%	203%
Togo	679	1,263	2,130	3,364	69%	58%	166%
Uganda	3,096	5,854	11,745	21,048	101%	79%	260%
Zambia	1,407	2,840	4,834	8,092	70%	67%	185%
Zimbabwe	1,724	3,681	4,998	6,229	36%	25%	69%
Panel C: Middle East & North Africa (MEA)							
Algeria	4,930	8,904	10,667	13,499	20%	27%	52%
Bahrain	67	124	200	311	61%	55%	150%
Djibouti	36	167	294	286	76%	-3%	71%
Egypt	11,215	17,661	25,370	34,713	44%	37%	97%
Iran	9,361	16,852	22,288	20,784	32%	-7%	23%

Continued on next page

Table A.1: Changes in global child population

Country by region	Ages 0-14 population (1000s)				Ages 0-14 population changes (%)		
	1960	1980	2000	2020	2000/1980	2020/2000	2020/1980
Iraq	3,022	6,395	10,088	15,169	58%	50%	137%
Israel	771	1,281	1,766	2,564	38%	45%	100%
Jordan	406	1,165	2,029	3,352	74%	65%	188%
Kuwait	93	551	580	917	5%	58%	66%
Lebanon	751	1,013	1,195	1,711	18%	43%	69%
Libya	605	1,541	1,814	1,909	18%	5%	24%
Malta	125	75	77	74	3%	-4%	-2%
Morocco	5,512	8,656	9,642	9,880	11%	2%	14%
Oman	241	520	842	1,148	62%	36%	121%
Qatar	20	75	152	393	103%	158%	422%
Saudi Arabia	1,763	4,228	7,909	8,598	87%	9%	103%
Syrian Arab Republic	2,126	4,372	6,731	5,386	54%	-20%	23%
Tunisia	1,816	2,661	2,869	2,871	8%	0%	8%
United Arab Emirates	41	287	816	1,465	185%	80%	411%
West Bank and Gaza			1,397	1,843		32%	
Yemen	2,233	3,938	8,518	11,582	116%	36%	194%
Panel D: Latin America & Caribbean (LAC)							
Antigua and Barbuda	23	23	22	21	-7%	-2%	-9%
Argentina	6,360	8,485	10,494	11,088	24%	6%	31%
Aruba	24	16	21	19	32%	-12%	16%
Bahamas, The	46	78	87	85	12%	-3%	9%
Barbados	88	75	59	48	-21%	-19%	-36%
Belize	42	67	101	116	50%	15%	73%
Bolivia	1,508	2,279	3,177	3,526	39%	11%	55%
Brazil	31,157	46,094	52,329	44,019	14%	-16%	-5%
Chile	3,208	3,824	4,193	3,678	10%	-12%	-4%
Colombia	7,498	10,767	12,909	11,288	20%	-13%	5%
Costa Rica	603	880	1,235	1,061	40%	-14%	21%
Cuba	2,504	3,124	2,402	1,803	-23%	-25%	-42%
Curaçao	51	46	33	28	-27%	-16%	-39%
Dominican Republic	1,589	2,482	2,958	2,977	19%	1%	20%
Ecuador	1,972	3,356	4,434	4,833	32%	9%	44%
El Salvador	1,244	2,013	2,157	1,725	7%	-20%	-14%
Grenada	44	36	34	27	-4%	-22%	-25%
Guatemala	1,896	3,185	5,068	5,621	59%	11%	76%
Guyana	266	331	266	218	-19%	-18%	-34%
Haiti	1,557	2,306	3,406	3,703	48%	9%	61%
Honduras	944	1,745	2,815	3,030	61%	8%	74%
Jamaica	675	859	853	692	-1%	-19%	-19%
Mexico	17,267	30,335	33,820	33,310	11%	-2%	10%
Nicaragua	839	1,536	2,010	1,954	31%	-3%	27%
Panama	497	809	969	1,143	20%	18%	41%
Paraguay	913	1,352	2,048	2,061	52%	1%	52%
Peru	4,445	7,428	9,113	8,141	23%	-11%	10%
Puerto Rico	1,002	1,012	897	517	-11%	-42%	-49%
St. Lucia	40	52	51	33	-2%	-35%	-36%
St. Vincent	40	44	34	24	-23%	-28%	-45%
Suriname	136	143	154	156	8%	2%	9%
Trinidad and Tobago	363	369	324	281	-12%	-13%	-24%
Uruguay	707	785	815	706	4%	-13%	-10%
Venezuela	3,748	6,257	8,219	7,752	31%	-6%	24%
Virgin Islands (U.S.)	13	36	28	20	-21%	-27%	-43%
Panel E: North America (NAC)							
Canada	6,040	5,579	5,881	6,000	5%	2%	8%
United States	55,450	51,519	61,237	60,903	19%	-1%	18%
Panel F: South Asia (SAS)							
Afghanistan	3,791	6,168	10,160	16,281	65%	60%	164%
Bangladesh	20,191	35,607	47,179	44,062	32%	-7%	24%
Bhutan	94	178	235	192	32%	-18%	8%
India	182,271	274,326	366,905	361,018	34%	-2%	32%
Maldives	35	72	113	106	57%	-6%	47%
Nepal	4,084	6,218	9,807	8,394	58%	-14%	35%

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Table A.1: Changes in global child population

Country by region	Ages 0-14 population (1000s)				Ages 0-14 population changes (%)		
	1960	1980	2000	2020	2000/1980	2020/2000	2020/1980
Pakistan	17,668	33,455	59,733	76,914	79%	29%	130%
Sri Lanka	4,150	5,397	5,024	5,191	-7%	3%	-4%
Panel G: Europe & Central Asia (ECA)							
Albania	646	961	937	489	-3%	-48%	-49%
Armenia	724	938	792	617	-16%	-22%	-34%
Austria	1,567	1,549	1,348	1,285	-13%	-5%	-17%
Azerbaijan	1,540	2,146	2,507	2,373	17%	-5%	11%
Belarus	2,369	2,197	1,849	1,617	-16%	-13%	-26%
Belgium	2,152	1,986	1,801	1,966	-9%	9%	-1%
Bosnia and Herzegovina	1,225	1,201	777	476	-35%	-39%	-60%
Bulgaria	2,053	1,963	1,279	1,018	-35%	-20%	-48%
Channel Islands	24	23	25	26	8%	3%	11%
Croatia	1,139	968	774	589	-20%	-24%	-39%
Cyprus	210	171	211	200	23%	-5%	17%
Czechia	2,471	2,412	1,684	1,686	-30%	0%	-30%
Denmark	1,154	1,067	986	949	-8%	-4%	-11%
Estonia	280	319	246	219	-23%	-11%	-31%
Finland	1,347	970	939	877	-3%	-7%	-10%
France		12,367	11,517	11,895	-7%	3%	-4%
Georgia	1,043	1,140	849	753	-26%	-11%	-34%
Germany			12,885	11,606		-10%	
Greece	2,279	2,280	1,630	1,461	-29%	-10%	-36%
Hungary	2,529	2,358	1,718	1,405	-27%	-18%	-40%
Iceland	61	63	65	71	4%	9%	13%
Ireland	875	1,041	817	1,039	-22%	27%	0%
Italy	12,587	12,401	8,157	7,721	-34%	-5%	-38%
Kazakhstan	3,602	4,791	4,097	5,466	-14%	33%	14%
Kyrgyz Republic	788	1,336	1,712	2,148	28%	26%	61%
Latvia	467	511	423	312	-17%	-26%	-39%
Lithuania	754	796	701	433	-12%	-38%	-46%
Luxembourg	67	68	83	98	21%	19%	44%
Moldova	650	729	686	416	-6%	-39%	-43%
Montenegro	167	156	130	112	-17%	-14%	-28%
Netherlands			2,941	2,739		-7%	
North Macedonia	566	574	460	338	-20%	-26%	-41%
Norway	929	906	897	928	-1%	3%	2%
Poland	9,945	8,548	7,483	5,767	-12%	-23%	-33%
Portugal	2,595	2,522	1,650	1,344	-35%	-19%	-47%
Romania	5,315	5,953	4,172	2,989	-30%	-28%	-50%
Russian Federation	36,412	29,975	26,746	26,461	-11%	-1%	-12%
Serbia	1,974	1,818	1,541	1,060	-15%	-31%	-42%
Slovak Republic	1,280	1,303	1,062	849	-18%	-20%	-35%
Slovenia	438	445	314	318	-29%	1%	-28%
Spain	8,334	9,728	5,978	6,820	-39%	14%	-30%
Sweden	1,679	1,628	1,634	1,825	0%	12%	12%
Switzerland	1,315	1,279	1,253	1,292	-2%	3%	1%
Tajikistan	833	1,671	2,643	3,555	58%	34%	113%
Turkmenistan	639	1,195	1,638	1,857	37%	13%	55%
Türkiye	11,511	17,434	19,354	20,193	11%	4%	16%
Ukraine	11,627	10,742	8,418	7,057	-22%	-16%	-34%
United Kingdom	12,134	11,839	11,209	11,882	-5%	6%	0%
Uzbekistan	3,381	6,475	9,188	9,859	42%	7%	52%
Panel H: East Asia & Pacific (EAS)							
Australia	3,102	3,717	4,000	4,957	8%	24%	33%
Brunei Darussalam	36	75	102	98	35%	-4%	29%
Cambodia	2,618	2,749	5,056	5,170	84%	2%	88%
China	265,642	352,612	312,994	249,901	-11%	-20%	-29%
Fiji	190	249	284	260	14%	-8%	4%
French Polynesia	34	61	77	62	25%	-19%	2%
Guam	27	36	47	40	32%	-15%	12%
Hong Kong SAR, China	1,250	1,277	1,124	948	-12%	-16%	-26%
Indonesia	35,049	60,593	64,919	70,941	7%	9%	17%
Japan	28,211	27,548	18,752	15,665	-32%	-16%	-43%

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Table A.1: Changes in global child population

	Ages 0-14 population (1000s)				Ages 0-14 population changes (%)		
Country by region	1960	1980	2000	2020	2000/1980	2020/2000	2020/1980
Kiribati	19	23	34	43	44%	27%	83%
Korea, Dem. People's Rep.	4,311	6,402	5,947	5,115	-7%	-14%	-20%
Korea, Rep.		12,911	9,691	6,502	-25%	-33%	-50%
Lao PDR	894	1,448	2,308	2,324	59%	1%	61%
Macao SAR, China	70	56	98	93	73%	-5%	65%
Malaysia	3,711	5,449	7,737	7,589	42%	-2%	39%
Micronesia	20	35	43	36	26%	-17%	4%
Mongolia	354	738	834	1,019	13%	22%	38%
Myanmar	8,804	14,129	15,190	13,867	8%	-9%	-2%
New Caledonia	30	52	65	60	23%	-7%	15%
New Zealand	780	847	876	988	3%	13%	17%
Papua New Guinea	957	1,558	2,325	3,145	49%	35%	102%
Philippines	12,353	20,425	30,003	32,921	47%	10%	61%
Samoa	54	72	71	74	-1%	4%	3%
Singapore	712	653	754	699	15%	-7%	7%
Solomon Islands	50	109	173	275	58%	59%	152%
Taiwan		5,739	4,703	2,963	-18%	-37%	-48%
Thailand	11,708	18,682	15,097	11,554	-19%	-23%	-38%
Timor-Leste	195	240	397	486	65%	22%	103%
Tonga	28	39	38	37	-3%	-3%	-5%
Vanuatu	29	51	77	118	49%	54%	129%
Vietnam	13,112	22,171	25,231	22,577	14%	-11%	2%

Note: The data source is the World Bank World Development Indicators. Global regions are aggregated into the seven world bank analytical groupings—Sub-Saharan Africa (SSA), Middle East and North Africa (MEA), Latin America and the Caribbean (LAC), North America (NAC), South Asia (SAS), Europe and Central Asia (ECA), and East Asia and Pacific (EAS). Percentage changes in the table are computed as: $\frac{\text{Outcome}_{\text{year}+\tau,\text{country}} - \text{Outcome}_{\text{year,country}}}{\text{Outcome}_{\text{year,country}}} \times 100$.

A.2 Global: Population and Teachers

We provide additional details on region- and country-specific results related to the joint pace of changes in child population and the number of teachers. Panel (b) of Figure 2, Appendix Figures A.2, A.3, and A.4 provide visualizations of the changing relative patterns of school age population and teachers across regions, countries, and the pre- and post-millennial decades.

Specifically, Panel (b) of Figure 2 and Appendix Figure A.2, we provide visualizations with and without labels for country names for "balanced" countries—where we have data in both the pre- and post-millennial decades. In Appendix A.4, we show all countries where we have data in either or both the pre- and post-millennial decades. In Figure A.3, we show results based on regional aggregates. In these figures, the x-axis shows the change in child population (age 0 to 15), and the y-axis shows changes in the number of primary school teachers. We mark out the 45 degree line, countries and regions to the top left of the line experience reductions in the population to teacher ratio.

In addition to the visualizations, Appendix Table A.2 presents child to teacher ratio, percentage changes in the number of child and teachers, and elasticity of the number of teachers with respect to the number of children at both regional and country levels.[A.1]

In the sections below, we summarize some country-specific findings in each region. The discussions here confirm the findings from the aggregate regional discussions presented in the main text.

SSA and MEA From 1980 to 2020, SSA and MEA countries—marked with red circles across the figures—experienced generally larger increases in both school-age population and teachers than other regions. Overall, SSA countries saw accelerating growth in the number of teachers that initially failed to keep pace with rapid school-age population increases; In MEA countries, growth in teachers doubled the relatively slower population growth throughout the decades. We discussed the regional patterns in the main text. Here, we provide additional details on country-specific results.

Nigeria and Egypt, the largest countries in SSA and MEA respectively, exemplify their regional patterns. In the two bi-decades, Nigeria saw child population growth of 64.8% and 68.1% and population-teacher elasticities of 0.74 and 1.91 as the growth rate of teachers accelerated. Egypt experienced child population growth of 43.6% and 36.8% and population-teacher elasticities of 3.50 and 1.43, as teacher growth far outpaced child population increases.

SAS, LNC, and NAC Across the figures, SAS, LNC, and NAC countries are marked as blue triangles. In the first two decades, countries in these regions largely take up space in the top right quadrant and over the 45 degree line, with concurrent increases in teachers and students. In the second set of decades, population stagnation in these regions is apparent from the shift of the blue triangles toward a concentration around zero population growth, but nearly all blue triangles remain over the 45 degree line, indicating a fall in population to teacher ratio as the number of primary teachers continued to grow despite population stagnation.

India and Brazil, the largest countries in SAS and LNC regions respectively, exemplify their regional patterns. In the two bi-decades, India saw child population growth of 33.7% and -1.6% and consistent teacher growth of 72.8% and 62.0%, respectively. Brazil experienced child population growth of 13.5% and -15.9% and teacher growth of 46.5% and -5.7%, as the number

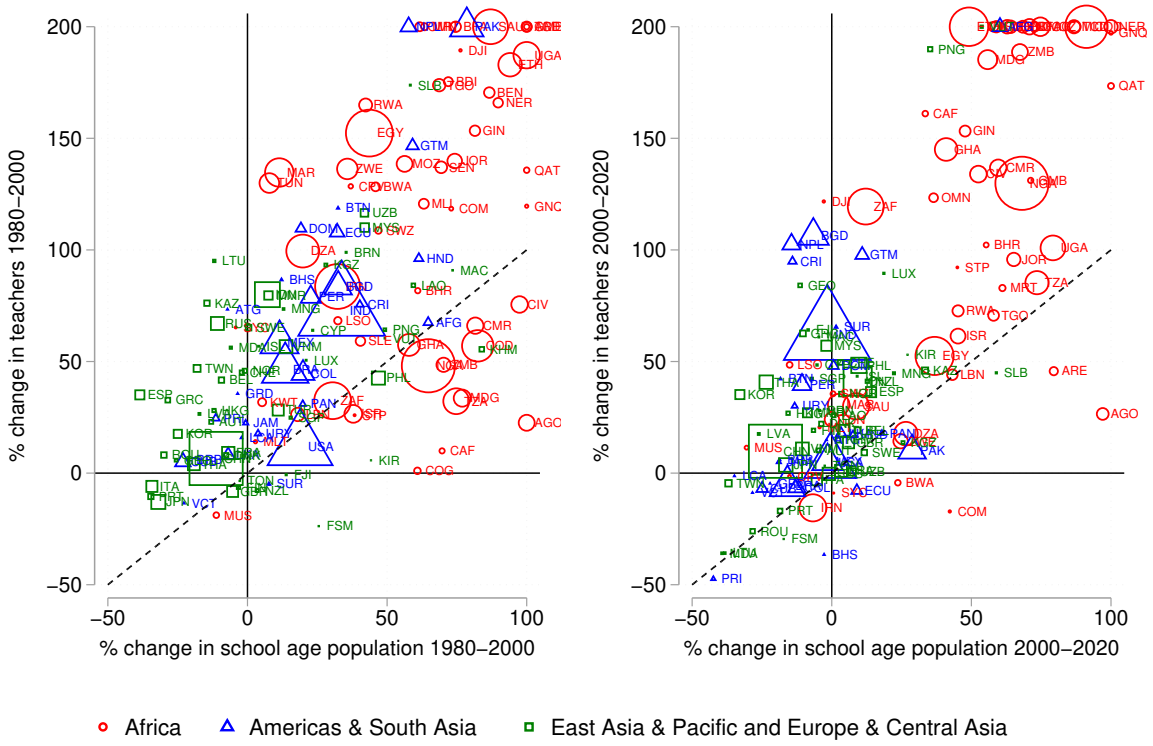
[A.1] Teacher information is more limited. For example, teacher data for Canada is available from 1983 to 2000. Therefore, in the table, we are unable to calculate the percentage changes and elasticity, and these fields are left blank.

of teachers first outgrew population earlier and fell more slowly than population drop more recently.

EAS and ECA Across the figures, EAS and ECA countries are marked as green rectangles. Across the decades, countries in these regions lie on both the left and right hand sides of the y-axis of zero percent population change, with a larger proportional share experiencing child population reduction. The dispersion of population shifts decreased significantly after 2000 as more countries experienced child population reductions. Similar to SAS, LNC and NAC regions, across the decades, nearly all EAS and ECA lie over the 45 degree line as the growth of teachers either outpaced the growth rate of child population or dropped less rapidly than the fall in child population.

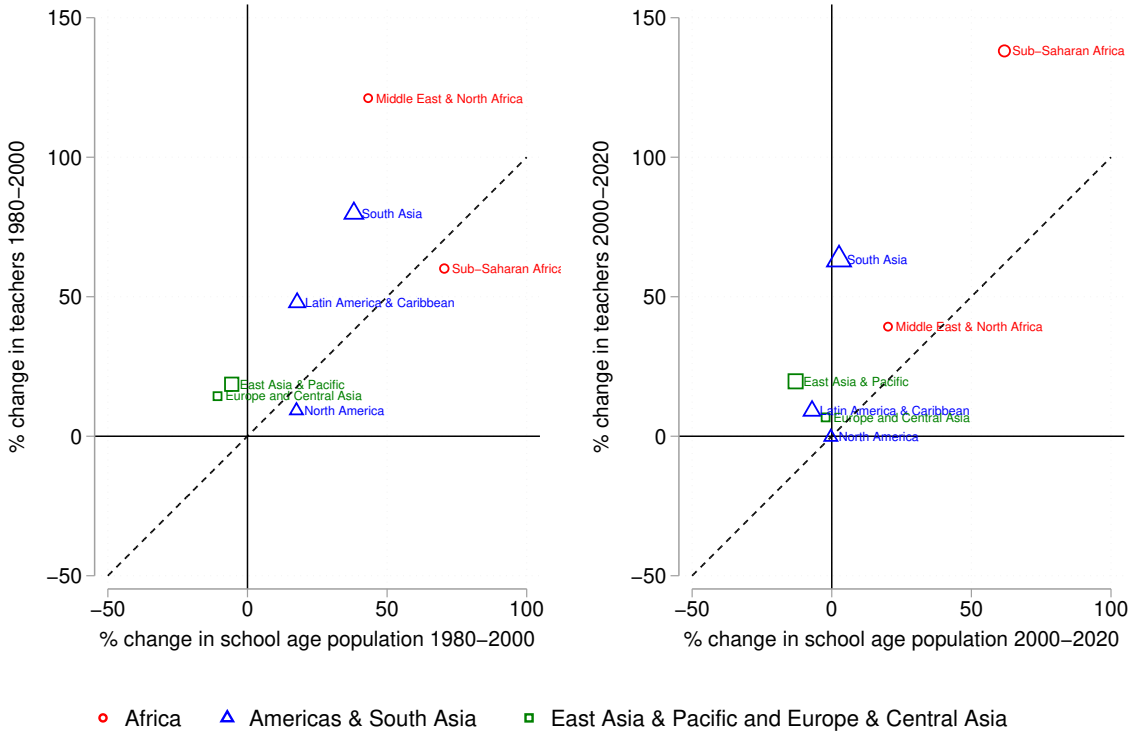
China and Russia, the largest countries in EAS and ECA regions respectively, exemplify their regional patterns. In the two bi-decades, China saw child population reductions of 11.2% and 20.2% and but persistent teacher growth of 6.6% and 9.8%, respectively. Russia, similarly, experienced child population reductions of 10.8% and 1.1% and teacher growth of 67.0% and -0.3%, with a corresponding population-teacher elasticities of -6.2 and 0.32.

Fig. A.2. Percentage change in the primary school-age population and teacher counts with country name, 1980-2020



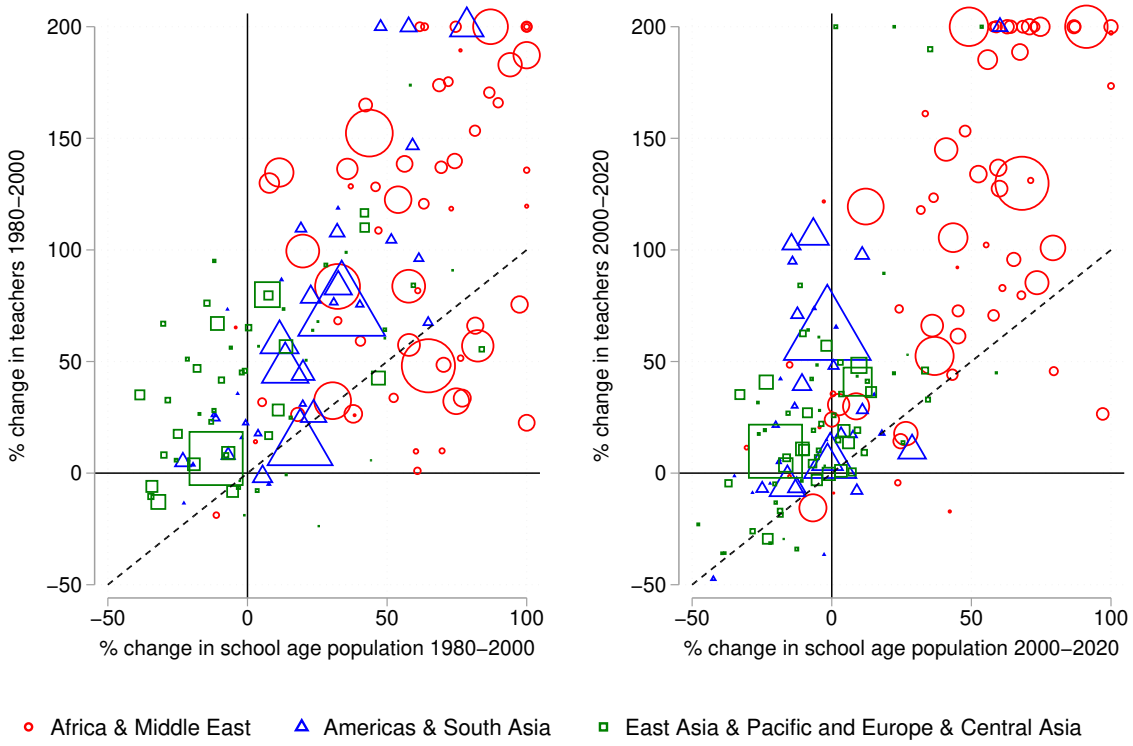
Note: The data source is the World Bank World Development Indicators. For uniformity of comparisons, we treat the child population ages 0 to 14 as the school age population. Countries are included when both primary teacher and primary school age population data are available for beginning and end years in both figures for computing changes. 134 countries are included among 211 countries. See Appendix B for a full list of countries. Countries above the 45 degree line experience a reduction in the children to teacher ratio, and countries below the 45 degree line experience an increase.

Fig. A.3. Percentage change in the primary school-age population and teacher counts by sub-region, 1980-2020



Note: The data source is the World Bank World Development Indicators. For uniformity of comparisons, we treat the child population ages 0 to 14 as the school age population. Regions above the 45 degree line experience a reduction in the children to teacher ratio, and regions below the 45 degree line experience an increase.

Fig. A.4. Percentage change in the primary school-age population and teacher counts, 1980-2020: unbalanced



Note: The data source is the World Bank World Development Indicators. For uniformity of comparisons, we treat the child population ages 0 to 14 as the school age population. Countries are included when both primary teachers and primary school age population data are available for beginning and end years in both figures for computing changes. 134 countries are included among 211 countries. See Appendix B for a full list of countries. Countries above the 45 degree line experience a reduction in the children to teacher ratio, and countries below the 45 degree line experience an increase.

Table A.2: Global changes in children (ages 0-14) and primary teachers

	Child to teacher			2000 to 2020			1980 to 2020		
	Ratios			% change		Elasticity	% change		Elasticity
Country by region	1980	2000	2020	Children	Teachers	Δ%T/Δ%C	Children	Teachers	Δ%T/Δ%C
Panel A: Global regions									
Sub-Saharan Africa	129	137	93	62%	138%	2.23	176%	281%	1.60
Middle East & North Africa	96	62	54	20%	39%	1.95	72%	208%	2.89
Latin America & Caribbean	76	61	52	-7%	9%	-1.29	9%	61%	6.47
North America	35	37	37	0%	0%	0.95	17%	9%	0.52
South Asia	174	133	84	3%	63%	24.32	42%	194%	4.65
Europe & Central Asia	66	51	47	-2%	7%	-3.07	-13%	22%	-1.74
East Asia & Pacific	71	57	41	-13%	20%	-1.52	-18%	42%	-2.35
Panel B: Sub-Saharan Africa (SSA)									
Angola	118	193	301	97%	27%	0.27	296%	55%	0.19
Benin	254	175	89	64%	222%	3.46	206%	771%	3.74
Botswana	82	52	68	24%	-4%	-0.18	80%	118%	1.47
Burkina Faso	891	311	106	71%	401%	5.66	198%	2,402%	12.11
Burundi	402	251	104	68%	306%	4.47	190%	1,019%	5.37
Cabo Verde	96	58	50	-15%	-1%	0.10	16%	125%	7.70
Cameroon	152	167	112	60%	137%	2.29	190%	293%	1.54
Central African Republic	232	357	183	33%	161%	4.81	127%	187%	1.48
Chad	544	307	167	87%	242%	2.79	275%	1,119%	4.07
Comoros	119	94	162	42%	-17%	-0.41	146%	81%	0.55
Congo, Dem. Rep.	118	137	63	91%	318%	3.49	249%	556%	2.23
Congo, Rep.	120	190	69	73%	379%	5.21	178%	384%	2.16
Côte d'Ivoire	148	166	108	53%	134%	2.55	201%	311%	1.55
Equatorial Guinea	127	146	103	109%	197%	1.80	430%	553%	1.29
Eritrea		168			51%				
Eswatini	90	63	47	0%	36%	77.55	48%	183%	3.85
Ethiopia	517	354	85	49%	519%	10.56	189%	1,652%	8.72
Gabon	82	96		65%			190%		
Gambia	202	133	99	71%	131%	1.84	283%	683%	2.42
Ghana	108	108	62	41%	145%	3.54	123%	286%	2.33
Guinea	308	221	129	48%	153%	3.21	168%	542%	3.22
Guinea-Bissau	110	160		51%			143%		
Kenya		99	69	43%	106%	2.43	152%		
Lesotho	121	95	54	-15%	49%	-3.21	12%	150%	12.10
Liberia		94	88	68%	80%	1.17	145%		
Madagascar	117	155	84	56%	185%	3.32	176%	281%	1.60
Malawi		127	89	60%	127%	2.12	187%		
Mali	443	327	150	87%	309%	3.56	205%	802%	3.92
Mauritania	376	145	128	61%	83%	1.36	163%	676%	4.14
Mauritius	54	59	37	-31%	11%	-0.37	-38%	-10%	0.25
Mozambique	303	198	110	75%	214%	2.86	173%	649%	3.75
Namibia		61	44	24%	74%	3.05	90%		
Niger	538	384	183	120%	361%	3.01	317%	1,125%	3.55
Nigeria	107	119	87	68%	130%	1.91	177%	240%	1.36
Rwanda	247	133	112	45%	73%	1.61	107%	358%	3.35
Senegal	282	201	107	63%	205%	3.27	176%	624%	3.55
Seychelles	59	34	38	1%	-9%	-13.12	-4%	51%	-14.19
Sierra Leone	159	140	69	59%	224%	3.80	123%	415%	3.37
Somalia	316	360		75%			167%		
South Sudan			184	66%			132%		
Sudan				46%			155%		
São Tomé and Príncipe	79	87	66	45%	92%	2.05	101%	142%	1.41
Tanzania	108	143	134	73%	85%	1.16	203%	145%	0.71
Togo	142	87	81	58%	71%	1.22	166%	367%	2.21
Uganda	152	106	95	79%	101%	1.27	260%	477%	1.84
Zambia	132	152	88	67%	189%	2.80	185%	329%	1.78
Zimbabwe	131	75	82	25%	14%	0.58	69%	170%	2.46
Panel C: Middle East & North Africa (MEA)									
Algeria	104	63	67	27%	18%	0.67	52%	135%	2.61
Bahrain	50	44	34	55%	102%	1.85	150%	268%	1.78
Djibouti	463	282	124	-3%	122%	-42.72	71%	542%	7.60

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Table A.2: Global changes in children (ages 0-14) and primary teachers

	Child to teacher			2000 to 2020			1980 to 2020		
	Ratios			% change		Elasticity	% change		Elasticity
Country by region	1980	2000	2020	Children	Teachers	Δ%T/Δ%C	Children	Teachers	Δ%T/Δ%C
Egypt	129	73	66	37%	53%	1.43	97%	285%	2.95
Iran	98	70	78	-7%	-16%	2.30	23%	55%	2.36
Iraq	69	59		50%			137%		
Israel	33	35	32	45%	61%	1.36	100%	104%	1.04
Jordan	84	61	51	65%	96%	1.47	188%	369%	1.97
Kuwait	71	57	27	58%	235%	4.06	66%	342%	5.16
Lebanon	45	42	42	43%	44%	1.02	69%	82%	1.19
Libya	48			5%			24%		
Malta	48	43	34	-4%	21%	-4.72	-2%	38%	-23.19
Morocco	159	76	59	2%	31%	12.43	14%	207%	14.62
Oman	145	67	41	36%	123%	3.38	121%	684%	5.67
Qatar	37	32	30	158%	173%	1.10	422%	545%	1.29
Saudi Arabia	92	41	35	9%	30%	3.43	103%	443%	4.29
Syrian Arab Republic	87	60		-20%			23%		
Tunisia	100	47	38	0%	24%	404.10	8%	185%	23.44
United Arab Emirates	58	48	59	80%	46%	0.57	411%	398%	0.97
West Bank and Gaza		130	79	32%	118%	3.70			
Yemen		82	67	36%	66%	1.84	194%		
Panel D: Latin America & Caribbean (LAC)									
Antigua and Barbuda	59	31	27	-2%	15%	-7.91	-9%	99%	-11.14
Argentina	44	43		6%			31%		
Aruba		43		-12%			16%		
Bahamas, The	64	38	59	-3%	-36%	13.27	9%	19%	2.04
Barbados	57	43	33	-19%	6%	-0.32	-36%	12%	-0.34
Belize		52	45	15%	35%	2.31	73%		
Bolivia		53	46	11%	28%	2.58	55%		
Brazil	83	64	57	-16%	-6%	0.36	-5%	38%	-8.47
British Virgin Islands					74%			177%	
Cayman Islands					46%			210%	
Chile		75	39	-12%	71%	-5.78	-4%		
Colombia	79	65	61	-13%	-6%	0.51	5%	36%	7.34
Costa Rica	70	56	25	-14%	95%	-6.75	21%	242%	11.80
Cuba	36	26	21	-25%	-7%	0.28	-42%	-2%	0.05
Curaçao				-16%			-39%		
Dominica					-14%			14%	
Dominican Republic	118	67	46	1%	48%	74.50	20%	210%	10.55
Ecuador	84	54	63	9%	-8%	-0.87	44%	92%	2.08
El Salvador		101	66	-20%	22%	-1.07	-14%		
Grenada	61	43	35	-22%	-5%	0.21	-25%	29%	-1.18
Guatemala	134	86	48	11%	98%	8.96	76%	388%	5.07
Guyana	83	64		-18%			-34%		
Haiti	171	66		9%			61%		
Honduras	106	88	81	8%	17%	2.24	74%	130%	1.76
Jamaica	98	79	61	-19%	5%	-0.26	-19%	29%	-1.47
Mexico	88	62	58	-2%	5%	-3.54	10%	67%	6.84
Nicaragua	115	86		-3%			27%		
Panama	65	60	60	18%	18%	0.99	41%	54%	1.31
Paraguay	71	53		1%			52%		
Peru	88	60	39	-11%	40%	-3.72	10%	150%	15.60
Puerto Rico	53	38	42	-42%	-47%	1.12	-49%	-34%	0.70
St. Kitts and Nevis					53%			65%	
St. Lucia	55	46	31	-35%	-1%	0.04	-36%	14%	-0.40
St. Vincent	37	33	26	-28%	-9%	0.31	-45%	-21%	0.47
Suriname	41	47	29	2%	65%	42.11	9%	57%	6.14
Trinidad and Tobago	57	40		-13%			-24%		
Turks and Caicos Islands					61%			119%	
Uruguay	53	47	31	-13%	30%	-2.26	-10%	53%	-5.31
Venezuela	71			-6%			24%		
Virgin Islands (U.S.)	32			-27%			-43%		
Panel E: North America (NAC)									
Bermuda					0%			99%	
Canada	39	42		2%			8%		

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Table A.2: Global changes in children (ages 0-14) and primary teachers

	Child to teacher			2000 to 2020			1980 to 2020		
	Ratios			% change		Elasticity	% change		Elasticity
Country by region	1980	2000	2020	Children	Teachers	Δ%T/Δ%C	Children	Teachers	Δ%T/Δ%C
United States	36	39	37	-1%	5%	-8.37	18%	17%	0.94
Panel F: South Asia (SAS)									
Afghanistan	319	314	119	60%	324%	5.39	164%	611%	3.73
Bangladesh	231	167	76	-7%	106%	-16.09	24%	279%	11.74
Bhutan	188	114	65	-18%	42%	-2.30	8%	211%	26.01
India	167	129	78	-2%	62%	-38.61	32%	180%	5.69
Maldives		35	19	-6%	74%	-11.73	47%		
Nepal	224	99	42	-14%	103%	-7.12	35%	624%	17.83
Pakistan	237	141	165	29%	10%	0.35	130%	231%	1.78
Sri Lanka	87	75	66	3%	18%	5.27	-4%	27%	-7.12
Panel G: Europe & Central Asia (ECA)									
Albania		75	51	-48%	-23%	0.48	-49%		
Andorra					26%			63%	
Armenia		67	77	-22%	-31%	1.42	-34%		
Austria	56	40	34	-5%	10%	-2.18	-17%	35%	-2.08
Azerbaijan		67	59	-5%	7%	-1.35	11%		
Belarus		56	74	-13%	-34%	2.71	-26%		
Belgium	45	29	26	9%	19%	2.09	-1%	69%	-70.66
Bosnia and Herzegovina			50	-39%			-60%		
Bulgaria		55	46	-20%	-5%	0.24	-48%		
Channel Islands				3%			11%		
Croatia		73	47	-24%	19%	-0.80	-39%		
Cyprus	78	59	37	-5%	48%	-9.18	17%	143%	8.52
Czechia	105	44		0%			-30%		
Denmark	30	26	20	-4%	22%	-5.92	-11%	32%	-2.89
Estonia		29	26	-11%	-3%	0.33	-31%		
Finland	39	40	32	-7%	19%	-2.93	-10%	12%	-1.21
France	42	36	37	3%	1%	0.31	-4%	10%	-2.64
Georgia	68	48	23	-11%	84%	-7.43	-34%	95%	-2.79
Germany		60	49	-10%	10%	-1.05			
Gibraltar					117%			53%	
Greece	63	34	19	-10%	63%	-6.06	-36%	116%	-3.22
Hungary		37	37	-18%	-19%	1.02	-40%		
Iceland	42	28	21	9%	43%	4.78	13%	125%	9.31
Ireland	73	38		27%			0%		
Italy	45	32	31	-5%	-3%	0.58	-38%	-9%	0.23
Kazakhstan		66	61	33%	46%	1.38	14%		
Kyrgyz Republic	134	89	98	26%	14%	0.54	61%	120%	1.97
Latvia	72	47	30	-26%	18%	-0.67	-39%	49%	-1.26
Liechtenstein					38%				
Lithuania	117	53	51	-38%	-36%	0.93	-46%	25%	-0.55
Luxembourg	38	31	19	19%	90%	4.80	44%	185%	4.25
Moldova	94	57	54	-39%	-36%	0.91	-43%	0%	0.00
Monaco					97%			116%	
Montenegro				-14%			-28%		
Netherlands		22	20	-7%	4%	-0.62			
North Macedonia		78	44	-26%	32%	-1.20	-41%		
Norway	36	24	18	3%	35%	10.29	2%	98%	39.63
Poland		23	26	-23%	-29%	1.28	-33%		
Portugal	37	27	26	-19%	-17%	0.92	-47%	-26%	0.55
Romania	100	65	63	-28%	-26%	0.92	-50%	-20%	0.40
Russian Federation	143	77	76	-1%	0%	0.32	-12%	66%	-5.67
San Marino					8%			91%	
Serbia			56	-31%			-42%		
Slovak Republic		60	56	-20%	-13%	0.66	-35%		
Slovenia		48	14	1%	240%	167.08	-28%		
Spain	75	34	29	14%	36%	2.58	-30%	84%	-2.81
Sweden	41	25	25	12%	9%	0.79	12%	80%	6.65
Switzerland	51	34	24	3%	50%	16.06	1%	117%	119.25
Tajikistan		83	84	34%	33%	0.96	113%		
Turkmenistan			82	13%			55%		
Türkiye	87	76	66	4%	19%	4.39	16%	53%	3.33

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Table A.2: Global changes in children (ages 0-14) and primary teachers

	Child to teacher			2000 to 2020			1980 to 2020		
	Ratios			% change		Elasticity	% change		Elasticity
Country by region	1980	2000	2020	Children	Teachers	Δ%T/Δ%C	Children	Teachers	Δ%T/Δ%C
Ukraine		81	63	-16%	7%	-0.43	-34%		
United Kingdom	44	45	42	6%	14%	2.27	0%	4%	11.71
Uzbekistan	116	76	81	7%	1%	0.07	52%	118%	2.25
Panel H: East Asia & Pacific (EAS)									
Australia	41	38		24%			33%		
Brunei Darussalam	45	31	23	-4%	28%	-6.41	29%	155%	5.26
Cambodia	95	113	100	2%	15%	6.51	88%	78%	0.89
China	64	53	39	-20%	10%	-0.49	-29%	17%	-0.58
Fiji	61	70	39	-8%	64%	-7.58	4%	63%	14.86
French Polynesia	43	32		-19%			2%		
Guam	40			-15%			12%		
Hong Kong SAR, China	71	49	32	-16%	27%	-1.72	-26%	62%	-2.42
Indonesia	85	50	39	9%	41%	4.42	17%	154%	9.00
Japan	59	46	37	-16%	4%	-0.22	-43%	-10%	0.22
Kiribati	54	73	61	27%	53%	1.95	83%	62%	0.74
Korea, Dem. People's Rep.			68	-14%			-20%		
Korea, Rep.	108	69	34	-33%	35%	-1.07	-50%	59%	-1.19
Lao PDR	97	84	67	1%	26%	37.29	61%	132%	2.18
Macao SAR, China	68	62	37	-5%	61%	-13.19	65%	207%	3.17
Malaysia	74	50	31	-2%	57%	-29.94	39%	230%	5.85
Micronesia	31	51	59	-17%	-29%	1.71	4%	-46%	-11.81
Mongolia	165	107	91	22%	45%	2.01	38%	151%	3.97
Myanmar	171	102	74	-9%	27%	-3.11	-2%	128%	-69.02
Nauru					-15%			-8%	
New Caledonia	40			-7%			15%		
New Zealand	40	45	36	13%	41%	3.23	17%	30%	1.81
Papua New Guinea	162	147	69	35%	190%	5.39	102%	376%	3.70
Philippines	81	83	62	10%	48%	4.97	61%	111%	1.82
Samoa	50	61		4%			3%		
Singapore	69	64	42	-7%	42%	-5.87	7%	78%	10.84
Solomon Islands	95	55	60	59%	45%	0.76	152%	297%	1.96
Taiwan	83	46	31	-37%	-5%	0.12	-48%	40%	-0.83
Thailand	66	51	28	-23%	41%	-1.74	-38%	46%	-1.22
Timor-Leste		173	64	22%	232%	10.35	103%		
Tonga	50	50	47	-3%	3%	-1.31	-5%	0%	0.05
Tuvalu					72%				
Vanuatu	52	49	8	54%	783%	14.59	129%	1,317%	10.19
Vietnam	102	74	60	-11%	11%	-1.03	2%	74%	40.25

Note: The data source is the World Bank World Development Indicators. Global regions are aggregated into the seven world bank analytical groupings—Sub-Saharan Africa (SSA), Middle East and North Africa (MEA), Latin America and the Caribbean (LAC), North America (NAC), South Asia (SAS), Europe and Central Asia (ECA), and East Asia and Pacific (EAS). If we are unable to calculate the percentage changes and elasticity due to the data limitation, the fields are left blank. Percentage changes in the table are computed as: $\frac{\text{Outcome}_{2020,\text{country}} - \text{Outcome}_{\text{year,country}}}{\text{Outcome}_{\text{year,country}}} \times 100$.

A.3 Western Europe and East Asia: Population, Teachers, and Schools

In this section, we provide additional details on changing patterns of primary school students, primary teachers, and schools in Western Europe and East Asia. Tables A.3 and A.4 present decade levels and percentage changes respectively, in the number of schools, teachers, students, and child population, covering the period from 1960 to 2020. Table A.5 presents pupil to teacher and pupil to school ratios from 1960 to 2020. The details in the tables complement Figure 3 in the main text.

Table A.3: East Asia and Western Europe: schools, teachers, students, and children levels

	East Asia				Western Europe				
Years	China	Japan	Korea	Taiwan	Austria	Germany	France	Netherlands	Switzerland
Number of primary schools (1000s)									
1960	726.5	26.9			4.4				
1970	961.1	24.8	6.0		4.0				
1980	917.3	24.9	6.5	2.4	3.5		60.7		
1990	766.1	24.8	6.3	2.5	3.4	18.0	56.7	9.3	
2000	553.6	24.1	5.3	2.6	3.4	17.3	53.0	7.8	
2010	257.4	22.0	5.9	2.7	3.2	16.3	49.0	7.5	4.5
2020	158.0	19.5	6.1	2.6	3.0	15.4	45.1	6.7	4.6
Number of primary school teachers (1000s)									
1960	2,693.0	360.7			21.5				17.4
1970	3,612.0	367.9	101.1		24.8				20.9
1980	5,499.0	468.0	119.1	69.1	27.5		291.5		25.2
1990	5,582.0	444.2	136.8	82.6	29.4	181.0	309.9		30.4
2000	5,860.0	407.6	140.0	101.6	33.9	215.4	317.7	131.7	36.6
2010	5,617.0	419.8	176.8	99.6	32.6	228.4	316.1	182.0	44.1
2020	6,434.2	422.6	189.3	97.0	37.3	237.8	321.0	137.3	54.8
Number of primary school students (mil.)									
1960	93.8	12.6			0.5				0.6
1970	105.3	9.5	5.7		0.6				0.5
1980	146.3	11.8	5.7	2.2	0.4		6.1		0.4
1990	122.4	9.4	4.9	2.4	0.4		5.8	1.5	0.4
2000	130.1	7.4	4.0	1.9	0.4	3.4	5.4	1.6	0.5
2010	99.4	7.0	3.3	1.5	0.3	2.8	5.6	1.6	0.4
2020	107.3	6.3	2.7	1.2	0.3	2.8	5.4	1.5	0.5
Number of children ages 0–14 (mil.)									
1960	265.6	28.2			1.6				1.3
1970	330.7	24.9	13.5		1.8				1.4
1980	352.6	27.5	12.9	5.7	1.5		12.4		1.3
1990	324.5	22.8	10.9	5.5	1.3	12.8	11.7	2.7	1.2
2000	313.0	18.8	9.7	4.7	1.3	12.9	11.5	2.9	1.3
2010	249.6	17.1	8.0	3.6	1.2	11.1	12.0	2.9	1.2
2020	249.9	15.7	6.5	3.0	1.3	11.6	11.9	2.7	1.3

Note: The data source is corresponding country's official website. For details on the data source, see Appendix B.

Table A.4: East Asia and Western Europe: schools, teachers, students, and children changes

	East Asia				Western Europe				
Years	China	Japan	Korea	Taiwan	Austria	Germany	France	Netherlands	Switzerland
Percentage change in primary schools									
2020 vs 1960	-78%	-27%			-31%				
2020 vs 1970	-84%	-21%	3%		-24%				
2020 vs 1980	-83%	-22%	-6%	8%	-13%		-26%		
2020 vs 1990	-79%	-21%	-3%	6%	-11%	-14%	-20%	-29%	
2020 vs 2000	-71%	-19%	16%	1%	-10%	-11%	-15%	-14%	
2020 vs 2010	-39%	-11%	5%	-1%	-5%	-5%	-8%	-11%	2%
Percentage change in primary school teachers									
2020 vs 1960	139%	17%			73%				214%
2020 vs 1970	78%	15%	87%		50%				162%
2020 vs 1980	17%	-10%	59%	40%	35%		10%		117%
2020 vs 1990	15%	-5%	38%	17%	27%	31%	4%		80%
2020 vs 2000	10%	4%	35%	-5%	10%	10%	1%	4%	50%
2020 vs 2010	15%	1%	7%	-3%	14%	4%	2%	-25%	24%
Percentage change in primary school students									
2020 vs 1960	14%	-50%			-33%				-7%
2020 vs 1970	2%	-34%	-53%		-42%				0%
2020 vs 1980	-27%	-47%	-52%	-47%	-13%		-11%		20%
2020 vs 1990	-12%	-33%	-45%	-50%	-7%		-6%	-2%	29%
2020 vs 2000	-18%	-14%	-33%	-39%	-12%	-15%	0%	-9%	12%
2020 vs 2010	8%	-10%	-18%	-23%	6%	0%	-2%	-9%	22%
Percentage change in children ages 0–14									
2020 vs 1960	-6%	-44%			-18%				-2%
2020 vs 1970	-24%	-37%	-52%		-30%				-5%
2020 vs 1980	-29%	-43%	-50%	-48%	-17%		-4%		1%
2020 vs 1990	-23%	-31%	-40%	-46%	-1%	-9%	2%	1%	10%
2020 vs 2000	-20%	-16%	-33%	-37%	-5%	-10%	3%	-7%	3%
2020 vs 2010	0%	-8%	-19%	-18%	4%	5%	-1%	-6%	10%

Note: The data source is corresponding country's official website. For details on the data source, see Appendix B. Percentage changes in the table are computed as: $\frac{\text{Outcome}_{2020,\text{country}} - \text{Outcome}_{\text{year,country}}}{\text{Outcome}_{\text{year,country}}} \times 100$.

Table A.5: East Asia and Western Europe: schools, teachers, students, and children ratios

	East Asia				Western Europe				
Years	China	Japan	Korea	Taiwan	Austria	Germany	France	Netherlands	Switzerland
Ratio (Primary school students)/(Pimrary Schools)									
1960	129	469			117				
1970	110	383	964		150				
1980	159	474	872	920	116		101		
1990	160	378	769	947	110		102	164	
2000	235	306	763	741	117	194	103	212	
2010	386	318	564	571	103	174	113	220	96
2020	679	323	440	446	115	184	120	224	115
Ratio (Children ages 0–14)/(Primary schools)									
1960	366	1,050			357				
1970	344	1,006	2,265		462				
1980	384	1,104	1,990	2,364	449		204		
1990	424	919	1,721	2,222	384	709	206	292	
2000	565	778	1,840	1,809	401	746	217	379	
2010	970	777	1,363	1,362	388	681	245	389	260
2020	1,582	802	1,062	1,126	426	751	264	411	280
Ratio (Primary school students)/(Primary school teachers)									
1960	35	35			24				33
1970	29	26	57		24				25
1980	27	25	48	32	15		21		17
1990	22	21	36	29	13		19		14
2000	22	18	29	19	12	16	17	12	13
2010	18	17	19	15	10	12	18	9	10
2020	17	15	14	12	9	12	17	11	10
Ratio (Children ages 0–14)/(Primary school teachers)									
1960	99	78			73				75
1970	92	68	134		74				65
1980	64	59	108	83	56		42		51
1990	58	51	80	67	44	71	38		39
2000	53	46	69	46	40	60	36	22	34
2010	44	41	45	36	38	49	38	16	27
2020	39	37	34	31	34	49	37	20	24

Note: The data source is corresponding country's official website. For details on the data source, see Appendix B.

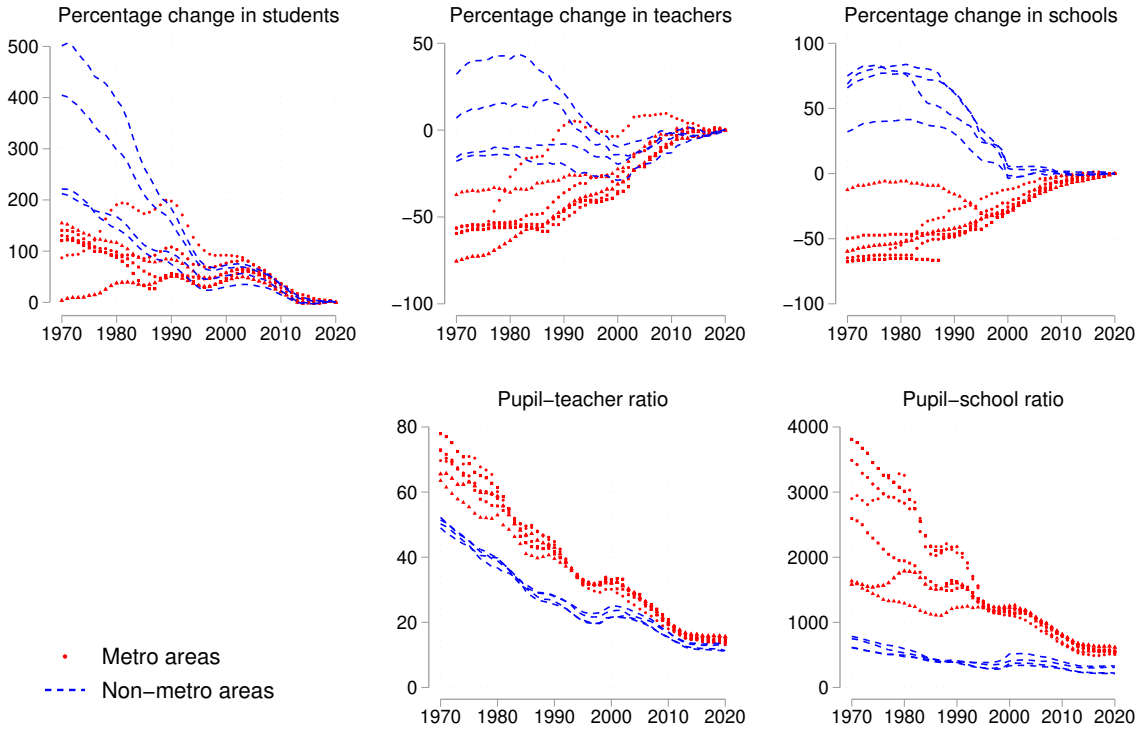
A.4 Korea: Population, Teachers, and Schools in Metropolitan and non-Metropolitan Areas

In this section, we provide additional details on the changing patterns of primary school students, primary teachers, and schools within South Korea. Figure A.5 presents province and metropolitan city level percentage changes in students, teachers, and schools. It also presents pupil-teacher and pupil-school ratios. While variations exist within both metro and non-metro areas, the contrast across these two categories is much more pronounced.

Figure A.6 presents the number of school closures categorized by closure types from 1982 to 2015, considering both closures of full primary schools as well as the closure of primary branch schools. Two notable observations are as follows: there is a significant shift in school closure policy around the year 2000, and this pattern is consistent across school types. However, the number of statistics from Korea indicate similar pattern, whether or not branch schools are included (see Appendix Figure A.6)

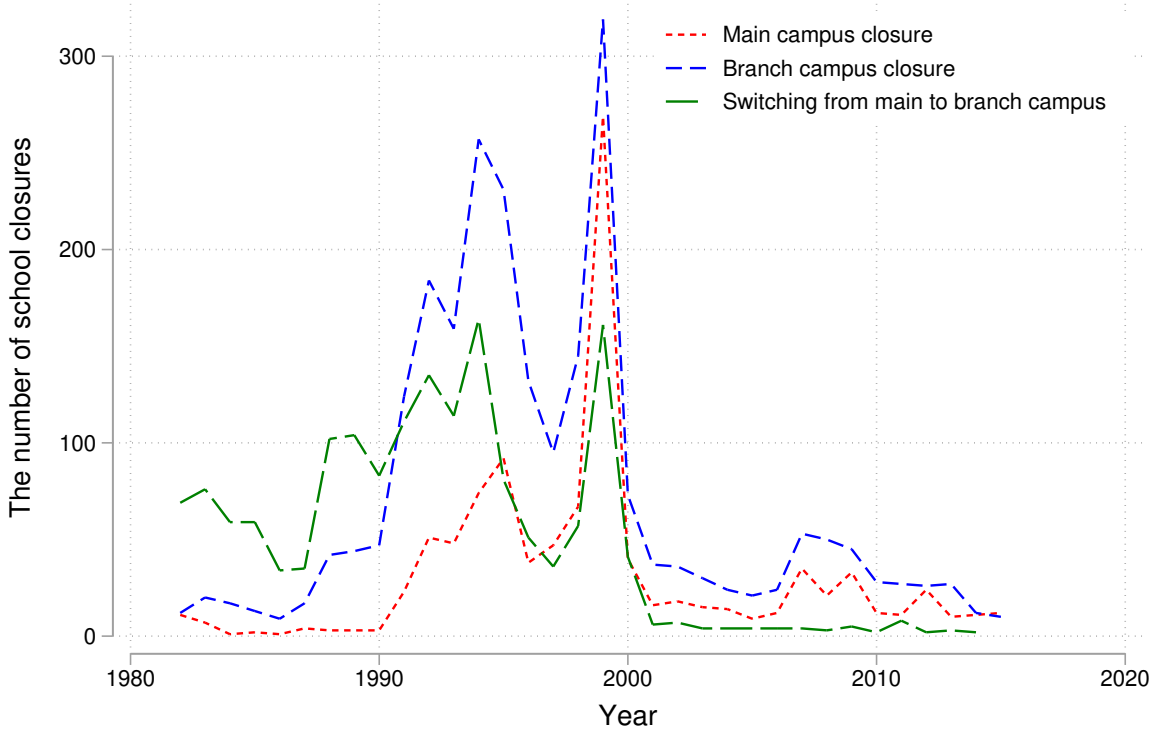
Lastly, in Table A.6, we present details on i) the number of primary school students, teachers, and schools, ii) percentage changes for the periods 2020-1970 through 2020-2010, and iii) primary school student and school and teacher ratios.

Fig. A.5. Primary education in Korea: demographic contraction, schools, and teachers in metropolitan cities and non-metropolitan provinces between 1971 and 2020



Note: The data source is Korean Educational Statistics Service (KESS). Both private and public schools are included. The metropolitan areas include the capital area (Seoul, Incheon, Gyeong-gi), metropolitan cities (Busan, Daegu, Daejeon, Gwangju, Ulsan), and Sejong. Non-Metropolitan areas include all other areas (Gangwon, Chungbuk, Chungnam, Jeonbuk, Jeonnam, Gyeongbuk, Gyeongnam, Jeju). To simplify the graph, I group neighbor provinces into bigger categories: Chungbuk-Chungnam (Chungcheong area), Jeonbuk-Jeonnam (Jeolla area), Gyeongbuk-Gyeongnam (Gyeongsang area), and Seoul-Incheon-Gyeong-gi (capital area). To facilitate comparisons of trends across areas, for each area, the value shown along the y-axis for the top three figures is the percentage change in each corresponding variable as of 2020, which is computed as: $\frac{\text{Outcome}_{\text{year,area}} - \text{Outcome}_{\text{2020,area}}}{\text{Outcome}_{\text{2020,area}}} \times 100$.

Fig. A.6. Primary education in Korea: primary school closures between 1982 and 2015



Note: The data source is the Korean Ministry of Education Press Release. Both private and public schools are included. "Branch campus" is used to refer to a location or subsidiary school that is derived from or affiliated with the main campus of an institution, where it is run by a few teachers. It is common in rural areas where the number of students is too small to run a separate complete school.

Table A.6: Korea: schools, teachers, and students

	Capital and metropolitan areas										Non-metropolitan areas								
	All	Capital area			Metropolitian and special self-governing cities						All	Provinces					Special provinces		
Years	All	Seoul	Incheon	Gyeong-gi	Busan	Daegu	Daejeon	Gwangju	Sejong[†]	Ulsan	All	Chung-buk	Chung-nam	Gyeong-buk	Gyeong-nam	Jeon-nam	Gang-won	Jeju	Jeon-buk
Panel A: Number of primary schools, teachers, and students																			
Number of primary schools																			
1970	1,309	206	50	613	99	81	74	50	32	105	4,652	372	510	890	731	881	607	108	553
1980	1,525	291	55	676	137	86	79	54	34	113	4,962	397	546	948	782	954	618	114	603
1990	1,881	463	103	684	221	118	79	83	29	101	4,454	337	536	890	701	821	499	115	555
2000	2,312	532	174	835	267	178	110	109	22	85	2,955	247	410	492	449	462	367	106	422
2010	2,893	587	226	1,145	298	214	138	145	22	118	2,961	259	408	494	495	433	353	106	413
2020	3,164	607	253	1,298	304	230	148	155	49	120	2,956	258	410	473	505	429	347	113	421
Number of primary school teachers (1000s)																			
1970	37.4	10.6	2.0	8.4	4.1	3.9	2.6	2.4	0.6	2.7	63.7	6.0	7.1	11.5	8.8	12.4	7.1	1.2	9.4
1980	51.5	17.9	2.5	10.6	7.4	4.2	2.8	2.7	0.6	2.8	67.5	6.2	7.4	12.5	9.0	13.5	7.5	1.6	9.8
1990	72.5	25.4	4.5	16.7	10.4	5.7	2.9	3.2	0.5	3.1	64.3	5.4	7.5	12.0	10.2	11.6	7.4	1.8	8.4
2000	86.7	25.3	7.2	26.5	9.8	6.5	3.9	3.8	0.4	3.3	53.3	4.9	6.5	9.5	9.9	8.1	5.7	1.9	6.9
2010	114.8	29.3	9.5	40.4	11.0	8.7	5.6	5.6	0.5	4.2	62.0	5.9	8.0	10.4	12.6	8.3	6.5	2.4	7.9
2020	123.1	28.6	10.1	46.8	10.1	8.9	6.0	6.0	2.1	4.3	66.2	6.7	9.3	10.3	13.8	8.3	6.6	2.9	8.3
Number of primary school students (1000s)																			
1970	2,531	770	136	469	287	282	192	191	32	172	3,218	310	349	570	428	630	371	64	494
1980	3,005	1,169	148	510	446	243	154	163	26	146	2,653	222	280	491	364	538	292	76	389
1990	3,109	1,142	208	656	457	255	120	134	12	124	1,759	153	205	318	309	290	188	56	240
2000	2,773	759	246	889	295	216	126	127	8	107	1,247	124	143	218	269	164	123	47	160
2010	2,277	566	183	848	197	168	109	116	8	82	1,022	105	131	164	228	124	100	44	127
2020	1,867	410	157	762	154	123	80	86	29	67	826	85	120	129	191	92	73	41	95
Panel B: Percentage changes in the number of primary schools, teachers, and students																			
Percentage change in primary schools																			
2020 vs 1970	142%	195%	406%	112%	207%	184%	100%	210%	53%	14%	-36%	-31%	-20%	-47%	-31%	-51%	-43%	5%	-24%
2020 vs 1980	107%	109%	360%	92%	122%	167%	87%	187%	44%	6%	-40%	-35%	-25%	-50%	-35%	-55%	-44%	-1%	-30%
2020 vs 1990	68%	31%	146%	90%	38%	95%	87%	87%	69%	19%	-34%	-23%	-24%	-47%	-28%	-48%	-30%	-2%	-24%
2020 vs 2000	37%	14%	45%	55%	14%	29%	35%	42%	123%	41%	0%	4%	0%	-4%	12%	-7%	-5%	7%	0%
2020 vs 2010	9%	3%	12%	13%	2%	7%	7%	7%	123%	2%	0%	0%	0%	-4%	2%	-1%	-2%	7%	2%

Continued on next page

Table A.6: Korea: schools, teachers, and students

	Capital and metropolitan areas										Non-metropolitan areas								
	All	Capital area			Metropolitian and special self-governing cities						All	Provinces					Special provinces		
Years	All	Seoul	Incheon	Gyeong-gi	Busan	Daegu	Daejeon	Gwangju	Sejong†	Ulsan	All	Chung-buk	Chung-nam	Gyeong-buk	Gyeong-nam	Jeon-nam	Gang-won	Jeju	Jeon-buk
Percentage change in primary school teachers																			
2020 vs 1970	229%	171%	400%	456%	146%	129%	129%	147%	251%	59%	4%	11%	31%	-11%	57%	-33%	-7%	130%	-12%
2020 vs 1980	139%	60%	295%	340%	37%	112%	119%	128%	235%	56%	-2%	8%	25%	-17%	54%	-39%	-12%	83%	-16%
2020 vs 1990	70%	13%	123%	180%	-3%	56%	105%	88%	357%	37%	3%	26%	24%	-14%	35%	-29%	-10%	61%	-2%
2020 vs 2000	42%	13%	41%	77%	4%	36%	55%	58%	426%	29%	24%	37%	43%	9%	40%	2%	16%	55%	20%
2020 vs 2010	7%	-2%	6%	16%	-7%	2%	9%	8%	328%	3%	7%	14%	16%	0%	10%	0%	2%	21%	4%
Percentage change in students																			
2020 vs 1970	-26%	-47%	15%	62%	-47%	-57%	-58%	-55%	-8%	-61%	-74%	-73%	-66%	-77%	-55%	-85%	-80%	-37%	-81%
2020 vs 1980	-38%	-65%	6%	49%	-66%	-50%	-48%	-47%	15%	-54%	-69%	-62%	-57%	-74%	-48%	-83%	-75%	-47%	-76%
2020 vs 1990	-40%	-64%	-25%	16%	-66%	-52%	-34%	-36%	144%	-46%	-53%	-44%	-41%	-59%	-38%	-68%	-61%	-28%	-61%
2020 vs 2000	-33%	-46%	-36%	-14%	-48%	-43%	-37%	-32%	249%	-37%	-34%	-31%	-16%	-41%	-29%	-44%	-40%	-13%	-41%
2020 vs 2010	-18%	-28%	-14%	-10%	-22%	-27%	-27%	-25%	282%	-17%	-19%	-19%	-8%	-21%	-16%	-25%	-26%	-8%	-25%
Panel C: Primary school student and school and teacher ratios																			
Ratio (Primary school students)/(Primary school)																			
1970	1,934	3,739	2,724	766	2,900	3,487	2,594	3,811	998	1,635	692	834	685	641	586	715	611	594	894
1980	1,970	4,016	2,692	755	3,257	2,830	1,945	3,016	752	1,292	535	560	512	518	466	564	473	668	644
1990	1,653	2,466	2,022	959	2,068	2,162	1,523	1,620	417	1,228	395	455	382	357	441	353	377	487	432
2000	1,199	1,428	1,412	1,065	1,105	1,216	1,143	1,163	384	1,254	422	503	349	442	599	354	334	441	378
2010	787	964	811	741	662	783	790	799	350	692	345	406	320	332	460	286	283	415	307
2020	590	675	620	587	505	533	539	558	602	562	280	330	293	273	378	215	212	359	225
Ratio (Primary school students/Primary school teachers)																			
1970	68	73	68	56	70	73	73	78	52	64	51	51	49	49	48	51	52	52	52
1980	58	65	58	48	60	58	56	61	40	53	39	36	38	39	40	40	39	49	40
1990	43	45	46	39	44	45	41	42	26	40	27	29	27	26	30	25	26	31	29
2000	32	30	34	34	30	33	32	33	21	32	23	25	22	23	27	20	22	25	23
2010	20	19	19	21	18	19	20	21	15	19	17	18	16	16	18	15	15	19	16
2020	15	14	16	16	15	14	13	14	14	16	12	13	13	13	14	11	11	14	11

Note: The data source is Korean Educational Statistics Service (KESS). For details on the data source, see Appendix B.

† Sejong is the only special self-governing city, similar to Washington D.C. in the United States. Percentage changes in the table are computed as: $\frac{\text{Outcome}_{2020,\text{region}} - \text{Outcome}_{\text{year,region}}}{\text{Outcome}_{\text{year,region}}} \times 100$.

Aggregate national statistics for Korea are provided in Appendix Tables A.3, A.4 and A.4.

B Data sources by Country, Teachers, Schools, and Students

Data and statistical programs used by the paper is available at our project website.

B.1 Global

B.1.1 World Bank

Our primary source for global data is World Bank Indicators (2023). We specifically extract annual data on the child population aged 0 to 14, the number of students and teachers in primary education, and fertility rates spanning the years 1960 to 2021. In our global level analysis, we focus our analysis on variations over time by seven World Bank analytical groupings. The seven analytical groupings are visualized on this map: World Bank Analytic Groupings (World Bank 2017). While population data calculations may be subject to inconsistencies (Murray et al. 2018), and the reported number of teachers might not fully capture local situations such as teacher absenteeism (Bold et al. 2017), we adhere to our sources as our focus is on the overall trend rather than exact population estimation. The downloaded data files are named *Data_Extract_From_World_Development_ Indicators_including_ratio.xls* and *world_bank_global_fertility.xls* in the replication package.

Primary school age differs across countries. We use the population between ages 0 to 14 as a uniform demographic unit to ease international comparisons. The UNESCO Institute for Statistics (UNESCO Institute for Statistics 2022) defines school age population as the number of persons at the age defined in a country's regulations or laws to attend a given grade or level of education in that country. Given variations in definitions for primary school grades across countries and the availability of global population data between ages 0 and 14, we consider shifts over time in the population size for this broad group of children as capturing shifts in the primary school age population.

Regarding the countries included in Figure 2, out of the 211 countries and economies for which we possess data, 77 countries have information on either population or teachers, while 134 countries provide data on both. Specifically, 36 out of 75 East Asia & Pacific and European & Central Asian countries, 24 out of 64 American and South Asian countries, and 17 out of 72 African countries are not included due to the absence of relevant data. Germany is not included for example, due to the changes in data from the reunification. For the full list of countries, see Table A.1.

B.2 East Asia

Our compilation of education resource statistics in East Asia and Western Europe is based on official statistics from each economy, which may lead to variations in resource definitions. For example, Korean statistics include branch schools, whereas Japanese statistics do not. However, as discussed in A.4, the trend over time remains consistent regardless of whether branch schools are included. Given our main focus on longitudinal trends, this consistency alleviates concerns about differences in school resource definitions across economies.

B.2.1 China

Our source for Chinese data is Chinese National Bureau of Statistics (2023). We specifically extract annual data on the number of elementary schools, teachers, and students spanning the

years 1949 to 2021. Elementary schools include six grades. The downloaded data file is named *Data_China_School_Teachers_Students.xlsx* in the replication package.

Our Chinese school data considers the number of full primary schools. There are also teaching points and other types of incomplete primary schools, which also experienced reductions of similar scales (Ding and Zheng 2015; Hannum, Liu, and Wang 2021).

B.2.2 Korea

Our source for Korean data is Korean Educational Statistics Service (2023). We specifically extract annual data on the number of elementary schools, teachers, and students spanning the years 1965 to 2021. Elementary schools include six grades. The downloaded data file is named *Korean elementary school 1965-2021.xlsx* in the replication package.

During the period of analysis, multiple metropolitan cities gained independence from their respective provinces and were designated as metropolitan cities. For example, in 1982, Daegu became a metropolitan city separate from Gyeongbuk. The designation of a metropolitan city leads to a sudden increase in counts in the area from 0, and a corresponding decrease in the province from which it was originally a part. For instance of Daegu, the school count is 0 before 1982 and 86 in 1982. To account for this, we assign the count number from the metropolitan area in the year of independence to the years before the designation and subtract it from the original province after considering trends in the corresponding province.[B.1] The complete list of changes in metropolitan cities is as follows (year-city-province): 1982-Daegu-Gyeongbuk, 1982-Incheon-Gyeong-gi, 1986-Gwangju-Jeonnam, 1988-Daejeon-Chungnam, 1997-Ulsan-Gyeongnam, 2013-Sejong-Chungnam.

Branch campuses are not included in the school count. The number of teachers includes both regular and contract teachers. It also includes teachers on leave of absence.

B.2.3 Japan

Our source for Japanese data is Statistics of Japan (2023). We specifically extract annual data on the number of elementary schools, teachers, and students spanning the years 1948 to 2021. Elementary schools include six grades. The downloaded data files are named *japan_school_count_1948_2022.xlsx*, *japan_student_count_1948_2022.xlsx*, and *japan_teacher_count_1948_2022.xlsx* in the replication package.

The number of schools includes national, public, and private institutions. The number of schools is for the main campus and branch campuses combined. The number of teachers includes full-time teachers.

B.2.4 Taiwan

Our source for Taiwanese data is Taiwanese Ministry of Education (2023). We specifically extract annual data on the number of elementary schools, teachers, students, and enrollment ratio spanning the years 1976 to 2021. Elementary schools include six grades. The downloaded data files are named *taiwan_students_count_by_levels_1976_2021.csv*, *taiwan_teachers_count_by_levels_1976_2021.csv*, *taiwan_schools_count_by_levels_1976_2021.csv*, and *taiwan_gross_enrollment_ratio_by_levels_1976_2021.csv* in the replication package.

[B.1] For instance, the number of schools in Gyeongbuk province in 1965 is 84% of the number of schools in 1982. The number of schools in Daegu in 1965 will be assigned 84% of the number of schools in 1982.

B.3 Europe

According to the "Standard Country or Area Codes for Statistical Use" published by the United Nations, the countries in Western Europe include Austria, France, Germany, Liechtenstein, Luxembourg, Monaco, the Netherlands, and Switzerland. We focus on countries with a population of at least one million people with the exception of Belgium, where national education statistics are not available.

B.3.1 Germany

Our source for German data is German Federal Statistical Office (2023a, 2023b). We specifically extract annual data on the number of elementary schools and teachers from 1992 to 2020, and the number of students from 1998 to 2021. Elementary schools include four grades. The downloaded data files are named *germany_schools_classes_bystates_30years.xlsx* (tab 2.1 for the number of schools and tab 7.1 for the number of teachers) and *germany_students_total_24years.xlsx* in the replication package.

Teachers include full-time employed (Vollzeitbeschäftigte), part-time (Teilzeitbeschäftigte) employed, and hourly employed (Stundenweise beschäftigte) teachers.

B.3.2 Austria

Our source for Austrian data is Statistics Austria (2023). We specifically extract annual data on the number of elementary schools, teachers, and students spanning the years 1923 to 2020. Elementary schools include four grades. The downloaded data files are named *austria_school_count_1923_2020.ods*, *austria_students_count_1923_2020.ods*, and *austria_teachers_count_1923_2020.ods* in the replication package.

When it comes to school data, there is a discontinuity in the time series between 2002/03 and 2003/04 due to changes in school counting methodology. Starting from 2006/07, the data includes schools with foreign curricula. Additionally, from 2003/04 onwards, it encompasses institutions managed by private school providers. Regarding student data, complete data is not available from 2003/04 to 2005/06, and values for this period were partially estimated. From 2006/07 onwards, the data includes schools with a foreign curriculum. Since 2003/04, it also includes facilities operated by private school owners. As for teacher data, due to allocations in assigning teachers to school types, there may be rounding differences to the school type total. Notably, teaching staff at federal sports academies and schools and academies of health sciences are excluded. From 2006/07 onwards, the data includes schools with a foreign curriculum.

B.3.3 France

Our source for French data is French Ministry of National Education and Youth (2019) and French Directorate of Evaluation, Forecasting and Performance Monitoring (2023). We specifically extract annual data on the number of elementary schools, teachers, and students spanning the years 1984 to 2022. Primary education comprises three years of pre-elementary levels and five years of elementary levels. The downloaded data files are named *1984-2022 rers.pdf*, *france_students_count_1960_2019.xlsx*, *france_teachers_rers2021_2008_2020.xlsx*, and *france_teachers_rers2022_2015_2021.xlsx* in the replication package.

We use public primary education data including both elementary and pre-elementary levels. There are multiple reasons for this. First, pre-elementary education has been free since 1883 and

the enrollment rate of 3-year-old children was 90% and that of 4-year-olds was virtually 100% in the 1970s (Dumas and Lefranc 2010). Second, data availability is limited if we only focus on elementary education. However, our analysis shows the qualitatively same results even if we focus on elementary education.

Over the period of yearbooks, the coverage regions change. Yearly statistics include overseas departments (Guadeloupe, Guyane, Martinique, and La Réunion) since year 1999 and also include Mayotte since 2011. Also, there are slight data inconsistencies across yearbooks when it comes to the number of teachers in the years 1992 and 1987. Those changes and inconsistencies make jumps between years. To handle this issue, we remove the gap between years by subtracting the gaps from previous years.

B.3.4 Netherlands

Our source for Dutch data is Statistics Netherlands (2023a, 2023b). We specifically extract annual data on the number of elementary schools and students from 2003 to 2017 and the number of teachers from 2003-2017. Elementary schools include eight grades. The downloaded data files are named *netherlands_student_school_count_1990_2021.xlsx* and *netherlands_teachers-in-primary-education_2003_2017.xlsx* in the replication package.

B.3.5 Switzerland

Our source for Swiss data is Historical Statistics of Switzerland (HSSO) (2023) and Federal Statistical Office Switzerland (2023a, 2023b). We specifically extract data on the number of elementary students from 1864 to 1999 with intervals of 4 to 8 years, and the number of teachers from 1864 to 1961 with intervals of 4 to 8 years and from 2010 to 2020 annually. We also extract annual data on the number of elementary schools from 2010 to 2020. Elementary schools include four to six grades depending on the canton. The downloaded data file is named *swiss_data_students_teachers_schools.xlsx* in the replication package.

C Methods

C.1 Data Interpolation and Extrapolation

After data collection, we interpolate and extrapolate when there are gaps in years in the data. For each country or location and across all variables, we compute year-by-year percentage changes, as well as changes over 5, 10, 15, and 20-year intervals. This process involves both interpolation to derive values within existing data points and extrapolation to estimate values up to 5 years beyond, aligning with the nearest decade breakpoints. In instances such as Afghanistan, where there are data gaps for specific years (1983, 1987, and 1992), we use interpolation to fill these gaps and extrapolate to determine values for 2020 based on the changes observed between 2018 and 2019. Meanwhile, for Austria, where historical data is not available on an annual basis, we apply interpolation techniques to generate more frequent, annualized predictions for earlier decades.[C.1]

C.1.1 Interpolation

We calculate percentage changes by taking the difference between consecutive data points and dividing it by the prior level. This approach allows us to estimate potential percentage changes across multiple years even when there are gaps with missing data. Our methodology assumes a constant growth rate between years, enabling us to compute annualized percentage changes. The formula for our annual percentage change is outlined below:

$$annualPercentChange_{(from\ t'\ to\ t'+1)} = \left(\left(\frac{schoolTeacherOrStudent_{t+\tau}}{schoolTeacherOrStudent_t} \right)^{\frac{1}{\tau}} - 1 \right), \quad \text{(C.1)}$$

where the percentage change is for all $t \leq t' \leq t + \tau - 1$.

The annual percentage change is exact where we know the level of schools, teachers, or students in the current year and the year immediately after. But it is based on growth trend "linear" interpolation when we have years of missing data in between. We use the interpolated annual percentage changes to fill in gaps in levels.

C.1.2 Extrapolation

We extrapolate before the start and after the end of the data timeframes. The extrapolation does not exceed going 5 years forward and going 5 years backward. Moreover, extrapolation only happens within years in which there is at least one variable, among variables for the country, that has non-missing values. Extrapolation is meant to help with situations, for instance, where we have data up to 2019, but for consistency of comparison, it would be useful to extend the data to 2020 by extrapolating 1 year forward.

In instances where a country's data is accessible only from 1980 onwards, we permit extrapolation back to 1980 for a maximum of 5 years. Specifically, because we generally have population data from 1960 to 2020 for all countries, we will not be extrapolating prior to 1960 or after 2020. In the case of Korea, where data starts in 1965, we do not extrapolate to any years before 1965, but if one of the Korean variables has data starting from 1970, we extrapolate between 1965 and 1970. For Germany, unification happened in 1992. We do not have data in

[C.1] We also construct a public website that outlines the data preparation process, including details on interpolation and extrapolation procedures.

1990, preventing us from computing change from 1990 to 2000. We extrapolate from 1992 back 5 years to 1987, generating a value for 1990.

We take the difference between consecutive data points at both ends of the available data and divide it by the prior level to get percentage changes. We assume a constant growth rate in extrapolation. Given these, our formula when extrapolating forward is shown below:

$$extrapolatedValue_{t-1} = value_t \times \frac{1}{1 + changeRate_{from\ t\ to\ t+1}} \ . \tag{C.2}$$

In the same manner, we can extrapolate forward.

C.2 Percentage change

To maintain consistency in data presentation, we establish the year 2020 as our baseline for calculating percentage changes in Figures 1, 3, and 4. The base year 2020 percentage changes, Y_t, is computed for each data point X_t using the following formula:

$$Y_t = (X_t - X_{2020})/X_{2020} \ . \tag{C.3}$$

To facilitate discussions, we also compute percentage changes from year t to year 2020, using year t as the base year. When we describe percentage changes in the main text and appendix Tables, we compute base year t percentage changes, Z_t, which is equal to:

$$Z_t = (X_{2020} - X_t)/X_t \ . \tag{C.4}$$

The base year 2020 and base year t percentage changes are related via the following relationship:

$$Z_t = (-Y_t)/(Y_t + 1) \ . \tag{C.5}$$

C.3 Pupil to Teacher Ratio, and Elasticity

Let C_t, P_t, T_t, and S_t represent the number of children, students, teachers, and schools at time t in a particular region, country and subnational administrative unit. The children and pupil to teacher and children and pupil to school ratio at time t are defined as $\frac{C_t}{T_t}$, $\frac{P_t}{T_t}$, $\frac{C_t}{S_t}$, and $\frac{P_t}{S_t}$, respectively. We present and discuss these statistics through out the text.

In addition to these ratios, we also construct and discuss elasticities of teacher count with respect to the number of children (ages 0-14) in the main text and Appendix Table A.2. The elasticity of teachers with respect to children (teacher-children elasticity) in year t is defined as:

$$elasticity_{t,t+\tau} = \frac{\%\Delta T_{t,t+\tau}}{\%\Delta C_{t,t+\tau}} \ , \tag{C.6}$$

where $\Delta T_{t,t+\tau}$ is the change number of teachers between time t and $t+\tau$, and $\Delta C_{t,t+\tau}$ is the change in the number of children between time t and $t+\tau$. The % symbol means we convert changes in levels to percentage changes in teachers and children. Thus, the teacher-children elasticity quantifies the responsiveness of teachers to changes in the school-age population over time, expressed as the percentage change in teachers relative to percentage changes in child population between years t and $t+\tau$. An elasticity that is equal to 1 indicates that shifts in the number of teachers are keeping pace with population changes, preserving the existing children to teacher ratio, despite population dynamics.