

Supplementary data

Supplementary Table 1. Average achievement and sample size for PISA domains and cycles

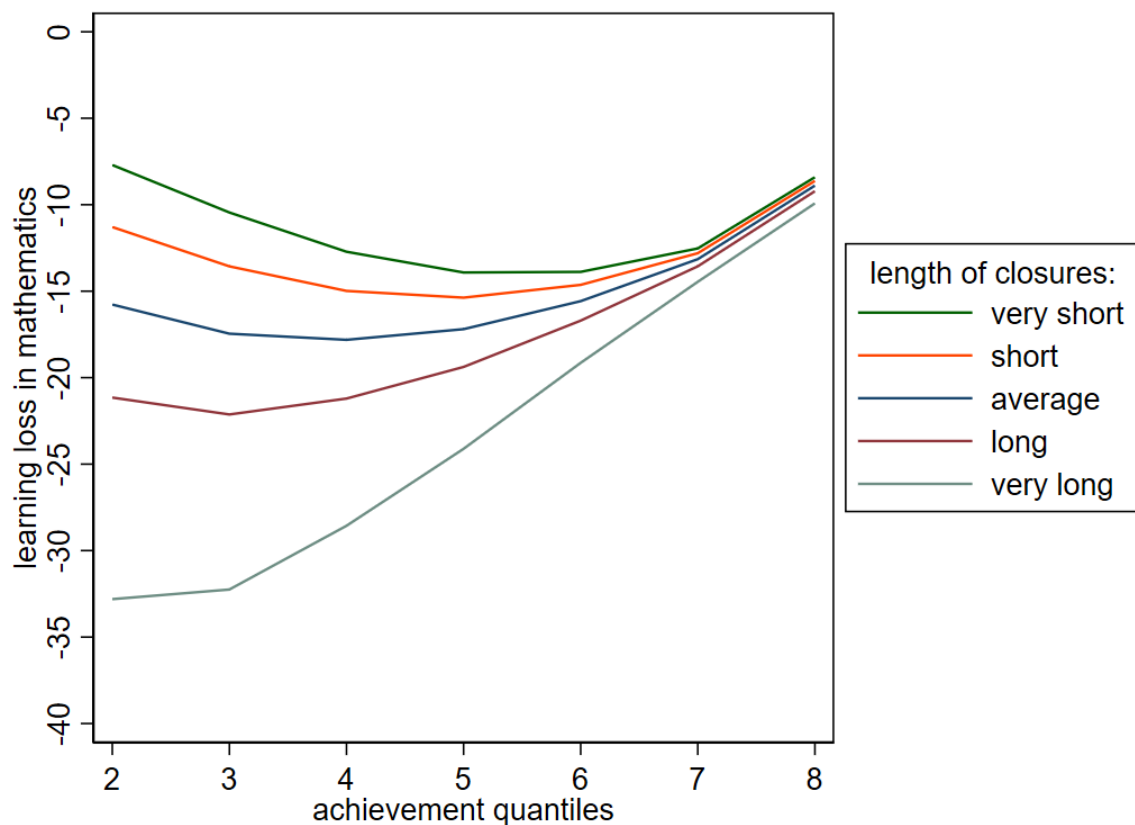
Year	Mathematics		Reading		Science	
	score	N	score	N	score	N
2000			474.0	218241		
2003	489.5	256810	485.6	256810		
2006	473.2	367519	467.1	361908	479.2	367519
2009	472.2	425564	470.9	425564	477.9	425564
2012	471.9	453363	473.4	453363	478.3	453363
2015	465.0	439102	466.1	439102	470.0	439102
2018	457.7	550004	453.3	520059	457.3	550004
2022	446.5	561540	443.7	565420	455.5	561540

Source: Own analysis of PISA microdata.

Supplementary Table 2. School closure duration for each country

Country	UNESCO		PISA country average	
	Full	Full and partial closures	Student-provided length of closures	Principal-provided length of closures
ALB	11	29	21.1	11.3
ARE	18	66	37.8	15.5
ARG	22	82	40.0	27.2
AUS	0	46	18.5	9.8
AUT	15	39	18.2	10.2
BEL	9	29	17.4	7.5
BGR	18	48	17.8	12.8
BRA	38	79	46.5	36.3
BRN	24	37	20.0	21.2
CAN	13	52	21.9	12.4
CHE	6	6	10.6	6.7
CHL	14	69	33.0	26.7
COL	23	77	43.0	36.1
CRI	43	82	44.6	19.2
CZE	20	46	28.7	24.5
DEU	14	38	25.8	13.1
DNK	8	35	-	-
DOM	33	55	30.0	26.5
ESP	10	15	16.4	8.7
EST	15	26	18.6	12.5
FIN	8	33	12.4	5.4
FRA	7	12	12.7	7.7
GBR	16	27	27.5	13.0
GEO	19	35	25.3	14.6
GRC	18	37	24.6	16.9
HKG	9	30	21.5	10.6
HRV	8	10	11.7	11.4
HUN	20	39	17.5	20.7
IDN	20	92	37.9	35.8
IRL	22	26	30.3	11.9
ISL	0	6	6.4	0.5
ISR	16	33	19.9	10.0
ITA	13	38	24.5	17.5
JOR	44	54	38.8	28.5
JPN	3	11	7.5	5.0
KAZ	9	52	28.0	18.4
KOR	11	79	9.0	4.2
KSV	28	28	17.8	8.2
LTU	10	38	16.1	8.4
LVA	16	49	34.2	17.8
MAC	9	30	13.8	13.9
MAR	17	37	20.7	12.4
MDA	16	16	14.6	11.6
MEX	53	81	41.5	45.9
MKD	20	54	34.4	21.7
MLT	18	21	20.6	9.8
MNE	19	55	22.0	12.6
MYS	42	69	31.7	18.3
NLD	12	31	22.4	7.1
NOR	5	29	-	-
NZL	8	27	14.5	8.3
PAN	55	87	39.4	39.3
PER	34	77	41.7	43.8
PHL	75	76	37.7	32.9
POL	26	44	24.5	19.8
PRT	12	24	15.7	12.8
QAT	25	60	27.0	10.7
QAZ	29	49	33.6	23.7
ROU	22	36	21.6	20.1
SAU	50	68	33.5	19.6
SGP	4	16	-	-
SRB	28	49	13.5	9.7
SVK	10	38	23.4	24.6
SVN	21	47	19.6	19.5
SWE	0	24	7.1	1.3
TAP	9	30	5.5	5.7
THA	16	69	19.6	21.1
TUR	28	49	35.5	28.8
URY	10	40	20.3	14.1
USA	0	77	29.5	11.9
VNM	7	46	15.4	15.7

Supplementary Figure 1. Learning loss estimates depending on student achievement quantiles and the length of closures



Unconditional quantile regression estimates for countries with short or average school closure lengths (top and middle lines) show that low-, average-, and high-achieving students suffer similar learning loss. In countries with long and very long closures (bottom lines), the learning loss among the best students is identical to that in countries with short closures. Still, in countries with lengthy closures, the learning loss is more extensive among the average students and even more considerable among the lowest achievers.

Supplementary Table 3. Impact of Pandemic on Student Mathematics Achievement

	(1)	(2)	(3)	(4)	(5)
Departure from a linear trend in 2022	-12.20*** (0.43)	-5.27*** (0.79)	-8.70*** (1.03)	-4.74*** (1.14)	-7.50*** (0.88)
UNESCO: number of weeks with full closures		-0.44*** (0.04)			
UNESCO: number of weeks with full or partial closures			-0.08*** (0.02)		
PISA: country's average student-provided number of weeks of closures				-0.32*** (0.04)	
PISA: country's average principal-provided number of weeks of closures					-0.21*** (0.03)
<i>Additional controls</i>					
Individual level: gender, immigrant background, SES	Yes	Yes	Yes	Yes	Yes
Country average: gender, immigrant background, SES	Yes	Yes	Yes	Yes	Yes
Country fixed effects	Yes	Yes	Yes	Yes	Yes
Country*time	Yes	Yes	Yes	Yes	Yes
N	2,896,916	2,896,916	2,896,916	2,791,234	2,791,234

Standard errors in parentheses. * p<0.05; ** p<0.01; *** p<0.001.

Supplementary Table 4. Impact of Pandemic on Student Mathematics Achievement by gender and socioeconomic status

	Overall impact	Impact by length of full school closures (UNESCO)
Departure from a linear trend in 2022	-14.20***	-10.00***
Departure from a linear trend in 2022 for boys (girls=baseline)	4.18***	6.83***
Departure from a linear trend in 2022 for immigrant students (natives=baseline)	4.98***	8.00***
Departure from a linear trend in 2022 for the slope of ESCS	2.62***	3.78***
Change in the departure from linear trend in 2022 by:		
- Length of closures (in weeks)		-0.29***
- Length of closures*Boys		-0.17**
- Length of closures*Immigrant		-0.33***
- Length of closures*ESCS slope		-0.12***
<i>Additional controls</i>		
Individual level: gender, immigrant background, SES	Yes	Yes
Country average: gender, immigrant background, SES	Yes	Yes
Country fixed effects	Yes	Yes
Country*time	Yes	Yes
Country*time*boys	Yes	Yes
Country*time*immigrant	Yes	Yes
Country*time*ESCS	Yes	Yes
N	2,896,916	2,896,916

* p<0.05; ** p<0.01; *** p<0.001.

Supplementary Table 5. Impact of Pandemic on Student Science and Reading

Achievement

	Reading (2000 to 2022)			Science (2006 to 2022)		
	(1)	(2)	(3)	(4)	(5)	(6)
Departure from a linear trend in 2022	-12.10*** (0.43)	-6.96*** (0.75)	-8.43*** (1.10)	-0.78 (0.46)	6.16*** (0.84)	8.13*** (1.15)
UNESCO: number of weeks with full closures		-0.33*** (0.04)			-0.44*** (0.04)	
PISA: country's average student-provided number of weeks of closures			-0.14*** (0.04)			-0.38*** (0.04)
<i>Additional controls</i>						
Individual level: gender, immigrant background, SES	Yes	Yes	Yes	Yes	Yes	Yes
Country average: gender, immigrant background, SES	Yes	Yes	Yes	Yes	Yes	Yes
Country fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Country*time	Yes	Yes	Yes	Yes	Yes	Yes
N	3,080,007	3,080,007	2,966,140	2,663,094	2,663,094	2,565,541

Standard errors in parentheses. * p<0.05; ** p<0.01; *** p<0.001.

Supplementary Table 6. Results for robustness checks

<i>Different regression specifications</i>	No controls	Individual controls only	Quadratic time trend	Total population weights
Departure from a linear trend in 2022	-14.64*** (0.49)	-10.40*** (0.41)	-12.02*** (1.00)	-11.55*** (0.85)
Quadratic time trend	No	No	Yes	No
Survey weights representing the global population of 15-year-olds instead of country averages	No	No	No	Yes
<i>Additional controls</i>				
Individual level: gender, immigrant background, SES	No	Yes	Yes	Yes
Country average: gender, immigrant background, SES	No	No	Yes	Yes
Country fixed effects	Yes	Yes	Yes	Yes
Country*time	Yes	Yes	Yes	Yes
N	3,053,902	2,896,916	2,896,916	2,896,916
<i>Different time periods</i>				
	2006-2022	2009-2022	2012-2022	2015-2022
Departure from a linear trend in 2022	-12.27 (0.43)	-12.50 (0.46)	-12.94 (0.59)	-16.13 (0.81)
<i>Additional controls</i>				
Individual level: gender, immigrant background, SES	Yes	Yes	Yes	Yes
Country average: gender, immigrant background, SES	Yes	Yes	Yes	Yes
Country fixed effects	Yes	Yes	Yes	Yes
Country*time	Yes	Yes	Yes	Yes
N	2,648,214	2,291,150	1,876,969	1,443,203

Standard errors in parentheses. * p<0.05; ** p<0.01; *** p<0.001.

Stata code to reproduce main estimates

```
clear all

* loading a file with appended public data from PISA 2003 2006 2009 2012 2015 2018
and 2022
* student survey probability weight is named "final_weight"
* replicate weights are renamed to repw_1-repw_80
* stu_closures is student-provided information on COVID-related school closures
* sch_closures is principal-provided information on weeks of COVID-related school
closures

use PISA2003to2022_trends, clear

* dummy variable denoting 2022 data
gen after=0
replace after=1 if year==2022

* dummy denoting females
recode female (1=0) (0=1), gen(boys)

* time=0 for 2003
gen time=year-2003

* set of dummies denoting countries
encode cnt, gen(kraj)

* merging with public UNESCO data
* variables are renamed to:
* UNESCO_partially (weeks of partial closures)
* UNESCO_fully (weeks of full closures)

merge m:1 cnt using closures_forPISA_NOV2023
keep if _merge==3
drop _merge

* UNESCO full closures + UNESCO partial closures = UNESCO total which we use to
test for different definitions of school closures
egen UNESCO_total=rowtotal(UNESCO_fully UNESCO_partially)

* recoding student-provided information on school closures into average weeks of
closures
recode stu_closures (1=0) (2=2.1725) (3=8.69) (4=19.5525) (5=39.105) (6=78.21)

* taking weighted country averages of PISA-derived school closures
egen PISA_cntclosures=wtmean(stu_closures), weight(final_weight) by(cnt)
egen PISA_schclosures=wtmean(sch_closures), weight(final_weight) by(cnt)
* replacing school days into weeks of school closures
replace PISA_schclosures=PISA_schclosures/5

* creating senate weights, which give an equal weight to each country in a
regression
egen cnt_year=group(cnt year)
egen temp=total(final_weight), by(cnt_year)
gen senate_weight=final_weight/temp*5000
```

```

* creating another set of BRR replicate weights, which are standardized as senate
weights to estimate proper standard errors
forvalues i=1(1)80 {
    cap drop temp
    egen temp=total(repwt_`i'), by(cnt_year)
    gen sreptwt_`i'=repwt_`i'/temp*5000
}

* country averages of gender, immigrant background and socioeconomic status (ESCS)
by country and year
egen xboys=wtmean(boys), by(cnt year) weight(senate_weight)
egen xmigrant=wtmean(migrant), by(cnt year) weight(senate_weight)
egen xescs=wtmean(escs), by(cnt year) weight(senate_weight)

* checking distributions of school closures variables to compare effects across
groups of countries with different length of closures (main results in Figure 1
are calculated by these values, which are also provided in Table 1 in Methods)
tabstat UNESCO_fully UNESCO_total PISA_cntclosures PISA_schclosures
[aw=senate_weight], stat(p10 p25 p50 p75 p90)

* estimating main regressions
* reg1 and reg2 are the main COVID-related time trend departure effects; reg2
controlling for background variables
* reg3-reg6 are regressions estimating the effect of the length of school closures
in weeks using different school closures definitions from UNESCO and PISA
global reg1 = "c.time##i.kraj i.after"
global reg2 = "c.time##i.kraj i.after boys migrant escs"
global reg3 = "c.time##i.kraj i.after##c.UNESCO_fully boys migrant escs"
global reg4 = "c.time##i.kraj i.after##c.UNESCO_total boys migrant escs"
global reg5 = "c.time##i.kraj i.after##c.PISA_cntclosures boys migrant escs"
global reg6 = "c.time##i.kraj i.after##c.PISA_schclosures boys migrant escs"

* estimating the above regression models over different specifications:
* a) with normal survey weights giving the total student population estimates
* b) the same as (a) but controlling for country-average changes across years in
gender, migrant and socioeconomic status distributions
* c) the same but with senate weights which give the same weight to each country

foreach pv in math {
    forvalues i = 6(1)6 {
        local temp="reg`i'"

        pv, pv(pv*`pv') weight(final_weight) brr rw(repwt_*) fays(0.5): ///
        reg @pv $`temp' [aw=@w]
        est sto r`i'_`pv'

        pv, pv(pv*`pv') weight(final_weight) brr rw(repwt_*) fays(0.5): ///
        reg @pv $`temp' xescs xboys xmigrant [aw=@w]
        est sto rx`i'_`pv'

        pv, pv(pv*`pv') weight(senate_weight) brr rw(sreptwt_*) fays(0.5): ///
        reg @pv $`temp' xescs xboys xmigrant [aw=@w]
        est sto sx`i'_`pv'

    }
}

* tabulating all regression estimates
est tab *_math, b(%9.2f) star varwidth(32) stat(N) drop(i.kraj kraj#c.time)

```