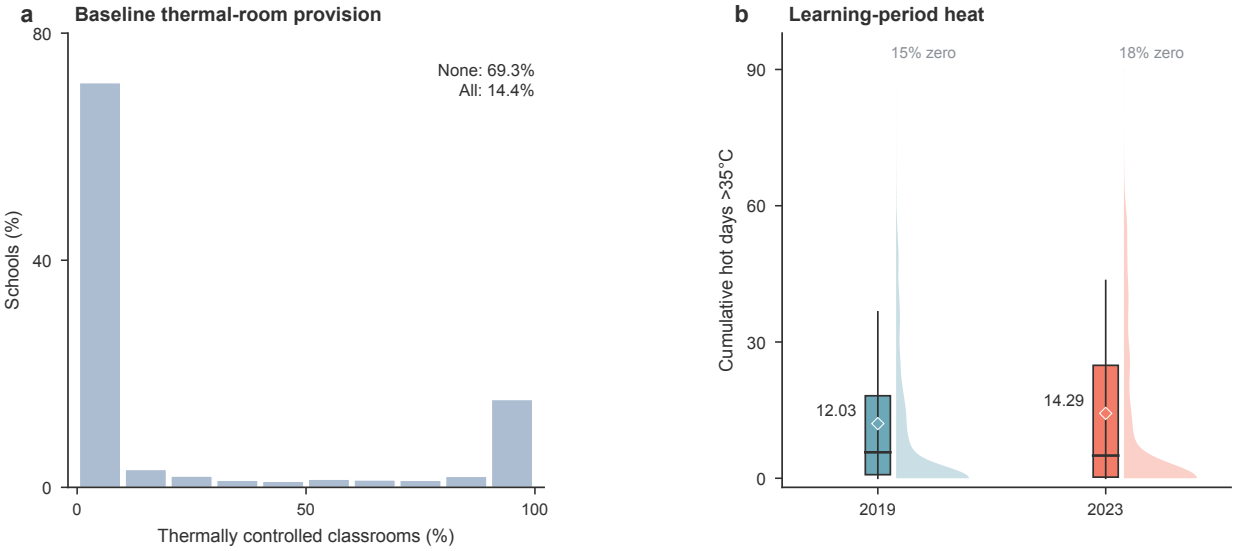
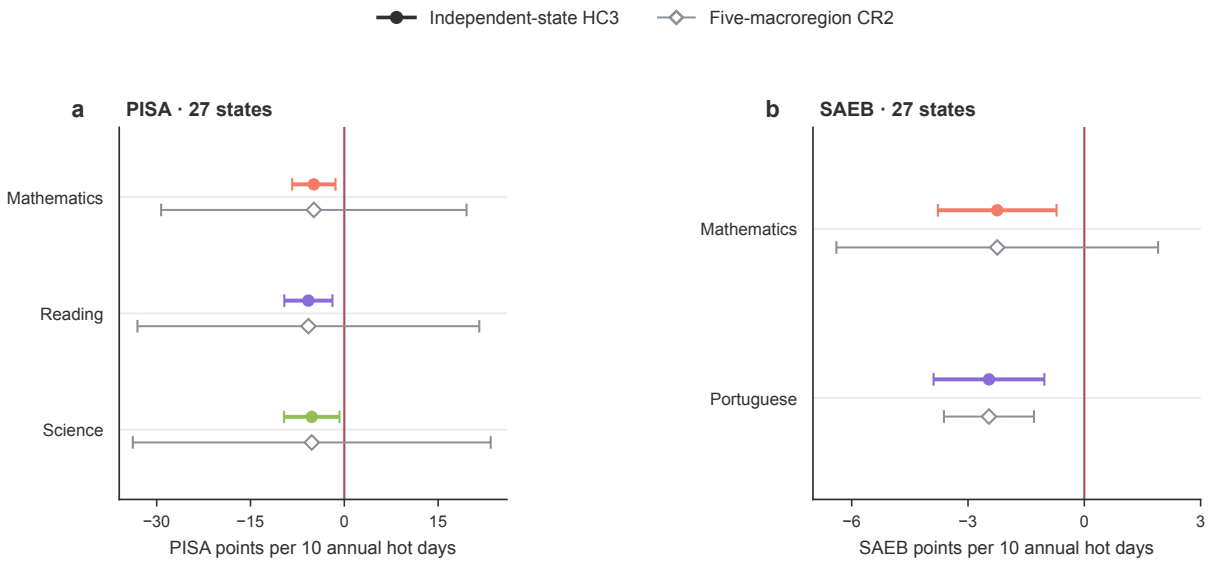
Supplementary Figure 1 School thermal provision and learning-period heat

a Baseline 2019 thermal-room provision in the school panel. Bins span ten percentage points. The first includes 0% and the last includes 100%. Thermal control includes cooling, heating and other temperature-control equipment. b School-weighted distributions of cumulative nominal learning-period hot days, calculated from municipal area-weighted BR-DWGD weather, in 2019 and 2023. Half-violins show kernel densities reflected at zero and calculated from all 15,724 school records per cycle. Widths are normalized separately within each cycle. Boxes show the interquartile range, horizontal lines the median, whiskers the 10th–90th percentiles and diamonds the arithmetic mean. Labels give the mean and percentage of schools with zero exposure. The state annual-average and school cumulative measures represent different exposure windows and populations.



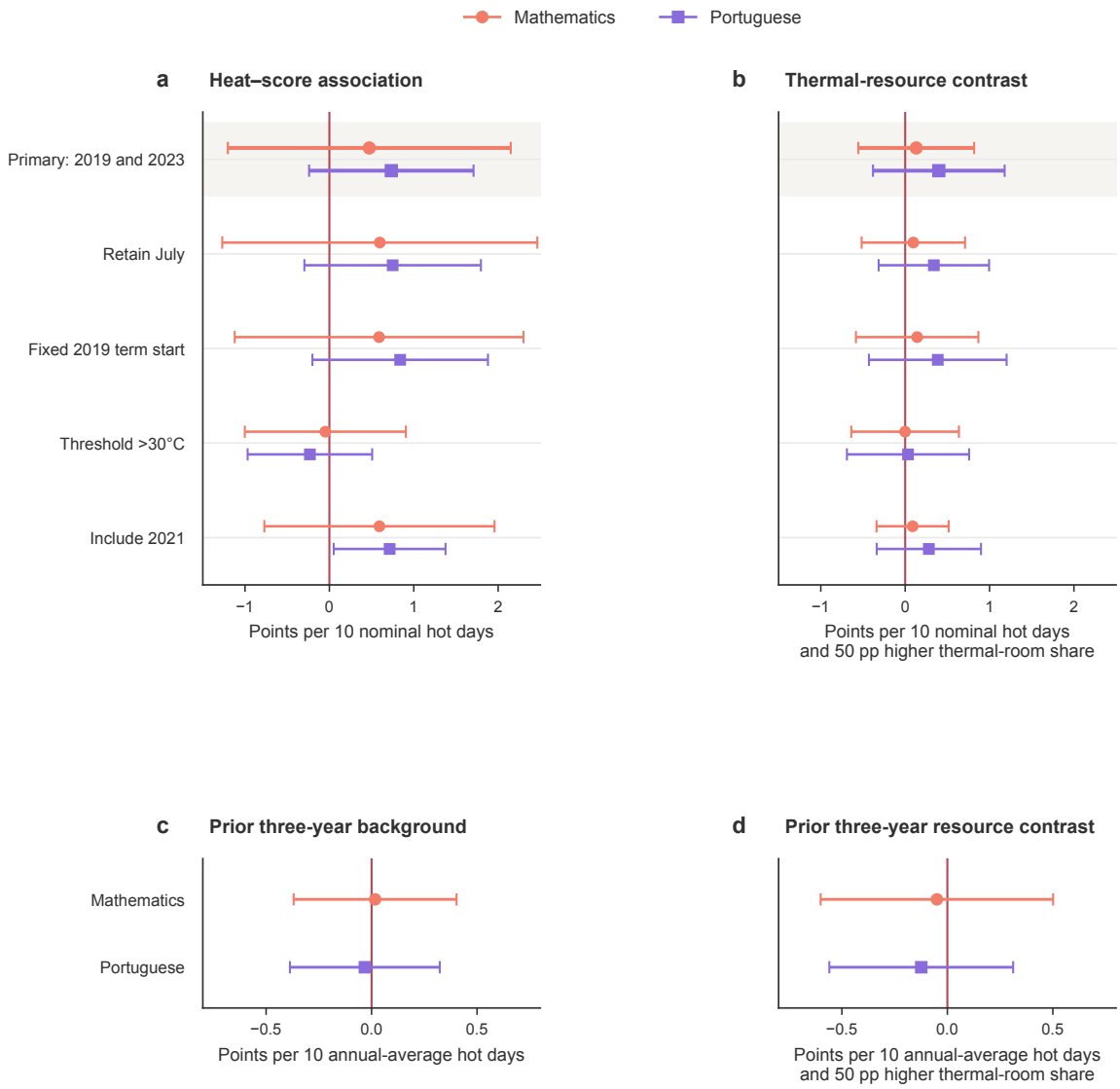
Supplementary Figure 2 State slopes and confidence intervals

a PISA slopes for mathematics, reading and science. b SAEB slopes for mathematics and Portuguese using the 24,344 paired schools. Both panels use the same 27 state exposure contrasts. Filled circles and coloured bars show point estimates and marginal 95% intervals from independent-state HC3 inference. Open diamonds and grey bars show five-macroregion CR2 intervals. PISA intervals incorporate plausible-value pooling with approximate finite-sample degrees of freedom. SAEB HC3 uses 25 residual degrees of freedom and SAEB macroregion CR2 uses approximately 1.78 Satterthwaite degrees of freedom. Each assessment retains its native score units.



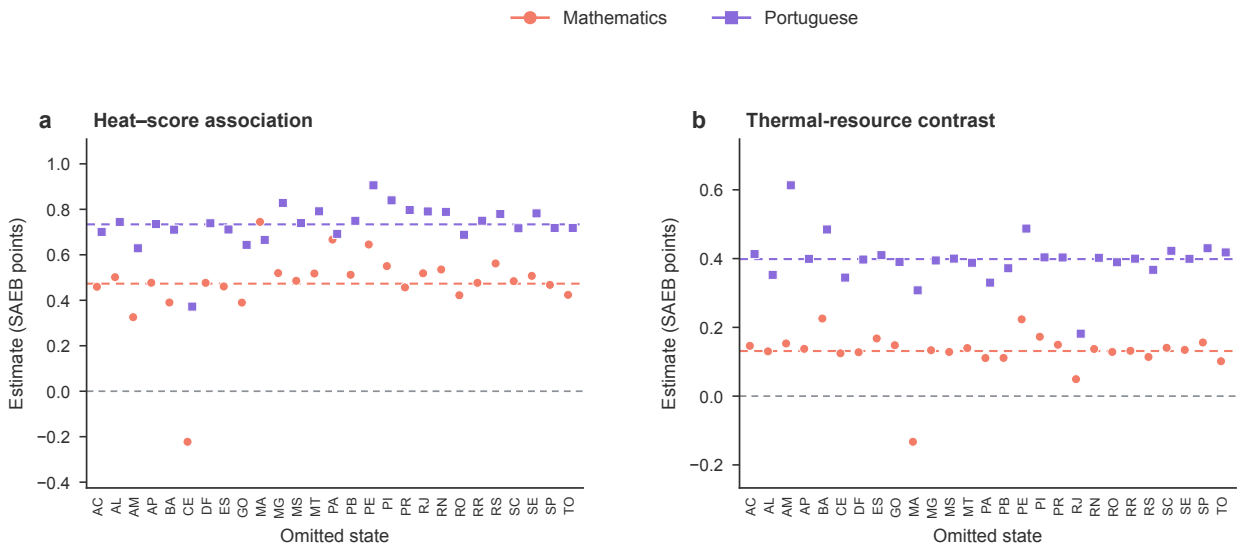
Supplementary Figure 3 Fixed sensitivity analyses

a,b The primary 2019–2023 models and four fixed current-year sensitivities: retaining July, fixing term starts to 2019, using a 30°C threshold and including 2021. a Overall heat–score associations per ten cumulative nominal learning-period hot days. b Heat-slope differences for a 50-percentage-point higher 2019 thermal-room share. The primary row is shaded. Circles denote mathematics and squares Portuguese. Bars are marginal 95% state-clustered CR2 confidence intervals. The primary cohort contains 15,724 schools. The 2021-inclusive analysis contains 15,209 schools observed across three cycles. Including 2021 yields a positive Portuguese association of 0.71 points (95% CI 0.05 to 1.38). c,d The earlier three-year background exposure specification, expressed per ten annual-average hot days in the preceding three years, with the same distinction between overall and resource contrasts. These panels use a separate numerical scale and a different exposure dose from a,b. All 24 state-clustered contrasts across six specifications are displayed. Four additional primary macroregion-clustered contrasts and the complete model definitions remain in Supplementary Table 3. The source table reports Holm-adjusted p values for the four primary tests.



Supplementary Figure 4 State omission estimates

a Heat–score association and b thermal-resource contrast after omitting each state in turn. Coloured dashed lines give the corresponding full-sample point estimates. Circles denote mathematics and squares Portuguese. The unit in a is SAEB points per ten cumulative nominal learning-period hot days. The unit in b also incorporates a 50-percentage-point higher baseline thermal-room share. State order is alphabetical. Supplementary Table 8 records the information shares for the full-sample contrasts.



Supplementary Table 1 SAEB publication coverage across states

state abbreviation	available2015	available2025	paired schools	retained fraction2015	retained fraction2025
AC	116	154	95	0.818966	0.616883
AL	471	520	377	0.800425	0.725
AM	560	747	443	0.791071	0.593039
AP	116	153	102	0.87931	0.666667
BA	2246	2411	1618	0.720392	0.671091
CE	1391	1799	1000	0.718907	0.555864
DF	175	156	137	0.782857	0.878205
ES	618	676	500	0.809061	0.739645
GO	985	1014	791	0.803046	0.780079
MA	1442	1917	1136	0.787795	0.592593
MG	3552	3629	3140	0.884009	0.865252
MS	440	449	334	0.759091	0.743875
MT	584	526	375	0.642123	0.712928
PA	1330	1955	1142	0.858647	0.584143
PB	661	800	486	0.73525	0.6075
PE	1278	1394	998	0.780908	0.715925
PI	727	885	532	0.731774	0.60113
PR	1471	1663	1394	0.947655	0.838244
RJ	1690	1657	1325	0.784024	0.799638
RN	547	633	418	0.764168	0.660348
RO	281	310	217	0.772242	0.7
RR	79	90	48	0.607595	0.533333
RS	1818	2694	1548	0.851485	0.57461
SC	1285	1410	1093	0.850584	0.775177
SE	392	476	310	0.790816	0.651261
SP	5042	4953	4523	0.897065	0.913184
TO	323	383	262	0.811146	0.684073

Supplementary Table 2 Common-period SAEB slopes and dependence sensitivity

Model standard errors, degrees of freedom and marginal 95% confidence intervals are shown where applicable. CSV files in the analysis package retain full numerical precision.

sample	outcome	interval	Estimate	SE	df	P	States	schools2015	schools2025	95% CI
paired schools	math	independent state HC3	−2.24634	0.743159	25	0.00571739	27	24344	24344	−3.777 to −0.716
paired schools	portuguese	independent state HC3	−2.46009	0.693763	25	0.00157283	27	24344	24344	−3.889 to −1.031
all available schools	math	independent state HC3	−2.81851	0.639624	25	0.000173521	27	29620	33454	−4.136 to −1.501
all available schools	portuguese	independent state HC3	−3.05522	0.842792	25	0.00128843	27	29620	33454	−4.791 to −1.319
paired schools	math	5 macroregion CR2	−2.24634	0.852018	1.77517	0.134085	27	24344	24344	−6.395 to 1.903
paired schools	portuguese	5 macroregion CR2	−2.46009	0.238423	1.77517	0.0136738	27	24344	24344	−3.621 to −1.299
all available schools	math	5 macroregion CR2	−2.81851	0.341762	1.77517	0.0202304	27	29620	33454	−4.483 to −1.154
all available schools	portuguese	5 macroregion CR2	−3.05522	0.612597	1.77517	0.0480247	27	29620	33454	−6.038 to −0.072

Supplementary Table 3 School-level estimates across all fixed specifications

Model standard errors, degrees of freedom and marginal 95% confidence intervals are shown where applicable. CSV files in the analysis package retain full numerical precision.

specification	design	outcome	cluster	Estimate	SE	df	P	schools	rows	Holm P	95% CI
main	overall	math	State	0.473065	0.775686	12.9772	0.55248	15724	31448	1	−1.203 to 2.149
main	overall	math	Macroregion	0.473065	0.143755	2.69077	0.0538445	15724	31448	0.215378	−0.016 to 0.962
main	overall	portuguese	State	0.73388	0.45101	12.9772	0.12772	15724	31448	0.510882	−0.241 to 1.708
main	overall	portuguese	Macroregion	0.73388	0.299385	2.69077	0.10137	15724	31448	0.215378	−0.284 to 1.752
main	resource	math	State	0.131194	0.288707	6.82734	0.663623	15724	31448	1	−0.555 to 0.817
main	resource	math	Macroregion	0.131194	0.0384825	2.25591	0.0643386	15724	31448	0.215378	−0.018 to 0.280
main	resource	portuguese	State	0.398562	0.328191	6.82734	0.264916	15724	31448	0.794747	−0.381 to 1.179
main	resource	portuguese	Macroregion	0.398562	0.276227	2.25591	0.272344	15724	31448	0.272344	−0.670 to 1.467
include july	overall	math	State	0.597352	0.861927	12.6819	0.500778	15724	31448	–	−1.269 to 2.464
include july	overall	portuguese	State	0.749833	0.48304	12.6819	0.145175	15724	31448	–	−0.296 to 1.796
include july	resource	math	State	0.0968268	0.26381	7.66943	0.723514	15724	31448	–	−0.516 to 0.710
include july	resource	portuguese	State	0.339929	0.281635	7.66943	0.263343	15724	31448	–	−0.314 to 0.994
fixed2019 start	overall	math	State	0.588904	0.79022	12.7225	0.469671	15724	31448	–	−1.122 to 2.300
fixed2019 start	overall	portuguese	State	0.838775	0.480511	12.7225	0.104967	15724	31448	–	−0.202 to 1.879
fixed2019 start	resource	math	State	0.142019	0.303639	6.65968	0.6549	15724	31448	–	−0.583 to 0.868
fixed2019 start	resource	portuguese	State	0.386408	0.341396	6.65968	0.296802	15724	31448	–	−0.429 to 1.202
threshold30	overall	math	State	−0.0477604	0.390526	6.03151	0.906637	15724	31448	–	−1.002 to 0.907
threshold30	overall	portuguese	State	−0.23078	0.302012	6.03151	0.473605	15724	31448	–	−0.969 to 0.507
threshold30	resource	math	State	−0.000859172	0.284384	9.52808	0.997652	15724	31448	–	−0.639 to 0.637

Supplementary Table 3 School-level estimates across all fixed specifications (continued)

Model standard errors, degrees of freedom and marginal 95% confidence intervals are shown where applicable. CSV files in the analysis package retain full numerical precision.

specification	design	outcome	cluster	Estimate	SE	df	P	schools	rows	Holm P	95% CI
threshold30	resource	portuguese	State	0.0336932	0.32275	9.52808	0.919021	15724	31448	–	−0.690 to 0.758
old 3year window	overall	math	State	0.0166951	0.175577	11.0784	0.925944	15724	31448	–	−0.369 to 0.403
old 3year window	overall	portuguese	State	−0.0318725	0.161483	11.0784	0.84711	15724	31448	–	−0.387 to 0.323
old 3year window	resource	math	State	−0.0495896	0.219326	5.41542	0.829412	15724	31448	–	−0.601 to 0.501
old 3year window	resource	portuguese	State	−0.123839	0.173405	5.41542	0.504726	15724	31448	–	−0.559 to 0.312
add2021	overall	math	State	0.593113	0.626102	12.0254	0.362129	15209	45627	–	−0.771 to 1.957
add2021	overall	portuguese	State	0.713849	0.304063	12.0254	0.0368255	15209	45627	–	0.052 to 1.376
add2021	resource	math	State	0.0884131	0.184497	7.76141	0.644999	15209	45627	–	−0.339 to 0.516
add2021	resource	portuguese	State	0.28065	0.266553	7.76141	0.324064	15209	45627	–	−0.337 to 0.899

Supplementary Table 4 PISA coefficients with HC3 and plausible-value pooling

Model standard errors, degrees of freedom and marginal 95% confidence intervals are shown where applicable. CSV files in the analysis package retain full numerical precision.

outcome	specification	term	Estimate	SE	df	P	States	PVs	95% CI
science	primary	intercept	2.05161	3.32553	21.9196	0.543639	27	10	−4.847 to 8.950
science	primary	heat per10	−5.20572	2.14665	23.0797	0.0235353	27	10	−9.646 to −0.766
science	previous year	intercept	5.57601	3.58589	22.1373	0.134131	27	10	−1.858 to 13.010
science	previous year	heat per10	−4.44157	1.07368	22.078	0.00042938	27	10	−6.668 to −2.215
science	area heat	intercept	2.39092	3.33863	21.7981	0.48151	27	10	−4.537 to 9.319
science	area heat	heat per10	−5.02764	2.34516	22.8713	0.0429102	27	10	−9.880 to −0.175
science	composition adjusted	intercept	12.5714	5.1315	19.8021	0.0237258	27	10	1.860 to 23.282
science	composition adjusted	heat per10	−7.18594	3.03049	20.0405	0.027863	27	10	−13.507 to −0.865
science	composition adjusted	age change	265.021	108.14	19.3741	0.0239071	27	10	38.976 to 491.066
science	composition adjusted	female change10	31.1434	14.9132	19.8782	0.0498478	27	10	0.023 to 62.264
science	composition adjusted	immigrant change10	−10.3572	13.758	19.8821	0.460383	27	10	−39.067 to 18.352
science	macroregion FE	intercept	1.63432	5.28313	18.2515	0.760562	27	10	−9.454 to 12.723
science	macroregion FE	heat per10	−4.12049	2.7172	19.1067	0.145778	27	10	−9.806 to 1.565
science	macroregion FE	macroregion N	−6.43073	8.38224	18.5157	0.452644	27	10	−24.006 to 11.145
science	macroregion FE	macroregion NE	−3.51629	6.45721	18.6111	0.592527	27	10	−17.051 to 10.018
science	macroregion FE	macroregion S	14.974	14.7754	19.0567	0.323545	27	10	−15.945 to 45.893
science	macroregion FE	macroregion SE	6.60419	13.0032	18.9413	0.617395	27	10	−20.618 to 33.826
math	primary	intercept	−3.67697	2.80103	16.7822	0.206946	27	10	−9.592 to 2.239
math	primary	heat per10	−4.87358	1.66701	21.4586	0.00800085	27	10	−8.336 to −1.411

Supplementary Table 4 PISA coefficients with HC3 and plausible-value pooling (continued)

Model standard errors, degrees of freedom and marginal 95% confidence intervals are shown where applicable. CSV files in the analysis package retain full numerical precision.

outcome	specification	term	Estimate	SE	df	P	States	PVs	95% CI
math	previous year	intercept	−1.12787	2.92489	18.7614	0.704122	27	10	−7.255 to 4.999
math	previous year	heat per10	−3.64317	0.941566	18.5953	0.00106791	27	10	−5.617 to −1.670
math	area heat	intercept	−3.4037	2.85175	16.8202	0.249218	27	10	−9.425 to 2.618
math	area heat	heat per10	−4.63897	2.04817	21.8423	0.0337874	27	10	−8.888 to −0.390
math	composition adjusted	intercept	3.71061	3.93626	18.733	0.357847	27	10	−4.536 to 11.957
math	composition adjusted	heat per10	−6.15473	2.49756	19.3119	0.0232659	27	10	−11.376 to −0.933
math	composition adjusted	age change	229.058	114.079	18.1629	0.0597658	27	10	−10.459 to 468.574
math	composition adjusted	female change10	16.1575	12.2757	17.5429	0.205041	27	10	−9.681 to 41.996
math	composition adjusted	immigrant change10	−5.66322	14.2912	19.5234	0.696201	27	10	−35.521 to 24.194
math	macroregion FE	intercept	−1.13137	4.7935	15.6915	0.816469	27	10	−11.309 to 9.047
math	macroregion FE	heat per10	−4.56366	2.16923	17.3695	0.0502525	27	10	−9.133 to 0.006
math	macroregion FE	macroregion N	−6.13289	7.22825	17.3145	0.407758	27	10	−21.362 to 9.096
math	macroregion FE	macroregion NE	−5.32031	6.19258	13.9514	0.404782	27	10	−18.606 to 7.966
math	macroregion FE	macroregion S	3.55886	11.45	18.0293	0.759504	27	10	−20.494 to 27.612
math	macroregion FE	macroregion SE	1.66688	10.602	18.1001	0.876809	27	10	−20.598 to 23.932
reading	primary	intercept	−2.22592	3.07154	18.5657	0.477675	27	10	−8.665 to 4.213
reading	primary	heat per10	−5.74827	1.85585	22.2217	0.00521608	27	10	−9.595 to −1.902
reading	previous year	intercept	1.27039	3.22302	17.4097	0.698248	27	10	−5.517 to 8.058
reading	previous year	heat per10	−4.63312	0.955894	19.5182	0.0001043	27	10	−6.630 to −2.636

Supplementary Table 4 PISA coefficients with HC3 and plausible-value pooling (continued)

Model standard errors, degrees of freedom and marginal 95% confidence intervals are shown where applicable. CSV files in the analysis package retain full numerical precision.

outcome	specification	term	Estimate	SE	df	P	States	PVs	95% CI
reading	area heat	intercept	−1.72522	3.08499	18.5274	0.582702	27	10	−8.193 to 4.743
reading	area heat	heat per10	−5.74442	2.14207	22.0206	0.0136192	27	10	−10.187 to −1.302
reading	composition adjusted	intercept	5.16	4.73276	18.4977	0.289592	27	10	−4.764 to 15.084
reading	composition adjusted	heat per10	−7.26413	2.75491	19.3573	0.0160914	27	10	−13.023 to −1.505
reading	composition adjusted	age change	165.782	118.441	18.64	0.178026	27	10	−82.442 to 414.006
reading	composition adjusted	female change10	24.8025	15.0393	19.0163	0.115532	27	10	−6.673 to 56.278
reading	composition adjusted	immigrant change10	−7.33072	30.1109	20.0906	0.81012	27	10	−70.123 to 55.461
reading	macroregion FE	intercept	−2.77339	5.55989	11.8031	0.627072	27	10	−14.910 to 9.363
reading	macroregion FE	heat per10	−4.85778	2.24096	17.9871	0.0438423	27	10	−9.566 to −0.149
reading	macroregion FE	macroregion N	−4.85885	7.23028	17.3699	0.510415	27	10	−20.089 to 10.371
reading	macroregion FE	macroregion NE	−2.66244	7.05366	12.5422	0.712145	27	10	−17.958 to 12.633
reading	macroregion FE	macroregion S	16.2881	10.5345	16.2049	0.14137	27	10	−6.021 to 38.597
reading	macroregion FE	macroregion SE	2.56958	10.6369	18.1884	0.811814	27	10	−19.761 to 24.900
science minus math read	primary	intercept	5.00306	1.687	7.87315	0.0183145	27	10	1.102 to 8.904
science minus math read	primary	heat per10	0.105204	0.720258	13.7202	0.885995	27	10	−1.443 to 1.653
science minus math read	previous year	intercept	5.50475	1.83025	10.8841	0.012047	27	10	1.471 to 9.538
science minus math read	previous year	heat per10	−0.303429	0.576035	12.045	0.607929	27	10	−1.558 to 0.951
science minus math read	area heat	intercept	4.95537	1.74093	8.24701	0.0209431	27	10	0.962 to 8.949
science minus math read	area heat	heat per10	0.164054	0.782798	11.0572	0.837812	27	10	−1.558 to 1.886

Supplementary Table 4 PISA coefficients with HC3 and plausible-value pooling (continued)

Model standard errors, degrees of freedom and marginal 95% confidence intervals are shown where applicable. CSV files in the analysis package retain full numerical precision.

outcome	specification	term	Estimate	SE	df	P	States	PVs	95% CI
science minus math read	composition adjusted	intercept	8.13606	2.02757	13.3005	0.00141358	27	10	3.766 to 12.506
science minus math read	composition adjusted	heat per10	−0.476507	0.896544	10.0916	0.606578	27	10	−2.472 to 1.519
science minus math read	composition adjusted	age change	67.601	61.078	11.7243	0.290573	27	10	−65.824 to 201.026
science minus math read	composition adjusted	female change10	10.6634	6.23969	15.1109	0.10791	27	10	−2.628 to 23.954
science minus math read	composition adjusted	immigrant change10	−3.86025	13.9733	19.7722	0.785216	27	10	−33.030 to 25.309
science minus math read	macroregion FE	intercept	3.5867	3.18762	8.53935	0.291136	27	10	−3.684 to 10.857
science minus math read	macroregion FE	heat per10	0.59023	1.11728	14.4711	0.605316	27	10	−1.799 to 2.979
science minus math read	macroregion FE	macroregion N	−0.934862	3.64223	9.98604	0.802642	27	10	−9.052 to 7.182
science minus math read	macroregion FE	macroregion NE	0.475085	4.48687	9.34001	0.917914	27	10	−9.619 to 10.569
science minus math read	macroregion FE	macroregion S	5.05049	6.12859	15.2007	0.422633	27	10	−7.997 to 18.098
science minus math read	macroregion FE	macroregion SE	4.48596	4.93645	15.6087	0.377305	27	10	−6.000 to 14.972
ghg minus other4	primary	intercept	−2.43525	0.846156	25	0.00807822	27	1	−4.178 to −0.693
ghg minus other4	primary	heat per10	0.456648	0.488422	25	0.35876	27	1	−0.549 to 1.463
ghg minus other4	previous year	intercept	−2.3776	1.00628	25	0.0262291	27	1	−4.450 to −0.305
ghg minus other4	previous year	heat per10	0.137876	0.365272	25	0.709017	27	1	−0.614 to 0.890
ghg minus other4	area heat	intercept	−2.60711	0.802774	25	0.00330579	27	1	−4.260 to −0.954
ghg minus other4	area heat	heat per10	0.658384	0.667693	25	0.333553	27	1	−0.717 to 2.034
ghg minus other4	composition adjusted	intercept	−0.916835	1.31894	22	0.494251	27	1	−3.652 to 1.818
ghg minus other4	composition adjusted	heat per10	0.352955	0.760048	22	0.646935	27	1	−1.223 to 1.929

Supplementary Table 4 PISA coefficients with HC3 and plausible-value pooling (continued)

Model standard errors, degrees of freedom and marginal 95% confidence intervals are shown where applicable. CSV files in the analysis package retain full numerical precision.

outcome	specification	term	Estimate	SE	df	P	States	PVs	95% CI
ghg minus other4	composition adjusted	age change	56.425	53.7953	22	0.305619	27	1	–55.140 to 167.990
ghg minus other4	composition adjusted	female change10	1.64081	3.4406	22	0.638138	27	1	–5.495 to 8.776
ghg minus other4	composition adjusted	immigrant change10	–2.10457	14.4355	22	0.885414	27	1	–32.042 to 27.833
ghg minus other4	macroregion FE	intercept	1.67788	2.37675	21	0.487976	27	1	–3.265 to 6.621
ghg minus other4	macroregion FE	heat per10	0.428803	0.70752	21	0.550968	27	1	–1.043 to 1.900
ghg minus other4	macroregion FE	macroregion N	–6.35925	2.59033	21	0.0228929	27	1	–11.746 to –0.972
ghg minus other4	macroregion FE	macroregion NE	–6.28858	3.26442	21	0.0676972	27	1	–13.077 to 0.500
ghg minus other4	macroregion FE	macroregion S	–2.70204	3.00487	21	0.378731	27	1	–8.951 to 3.547
ghg minus other4	macroregion FE	macroregion SE	–0.352699	2.75243	21	0.899257	27	1	–6.077 to 5.371

Supplementary Table 5 PISA slopes with five-macroregion CR2 and plausible-value pooling

Model standard errors, degrees of freedom and marginal 95% confidence intervals are shown where applicable. CSV files in the analysis package retain full numerical precision.

outcome	specification	Estimate	SE	df	P	States	PVs	Holm P	95% CI
ghg minus other4	area heat	0.658384	1.15446	1.97568	0.626624	27	1	–	−4.368 to 5.685
ghg minus other4	composition adjusted	0.352955	0.845088	2.41612	0.710457	27	1	–	−2.744 to 3.450
ghg minus other4	macroregion FE	0.428803	0.812087	1.73776	0.657066	27	1	–	−3.623 to 4.480
ghg minus other4	previous year	0.137876	0.620468	1.65047	0.848537	27	1	–	−3.154 to 3.430
ghg minus other4	primary	0.456648	0.830027	1.77517	0.643482	27	1	1	−3.585 to 4.498
math	area heat	−4.63897	1.42484	1.05139	0.179875	27	10	–	−20.781 to 11.503
math	composition adjusted	−6.15473	1.85746	1.40639	0.126331	27	10	–	−18.434 to 6.125
math	macroregion FE	−4.56366	1.36161	0.784487	0.236447	27	10	–	−38.348 to 29.220
math	previous year	−3.64317	0.457674	0.313307	0.361891	27	10	–	−2025.491 to 2018.205
math	primary	−4.87358	1.79905	0.972917	0.230692	27	10	–	−29.293 to 19.545
reading	area heat	−5.74442	1.54339	1.07492	0.153324	27	10	–	−22.402 to 10.914
reading	composition adjusted	−7.26413	2.3643	1.43993	0.135525	27	10	–	−22.351 to 7.823
reading	macroregion FE	−4.85778	1.34431	0.837304	0.208857	27	10	–	−32.176 to 22.460
reading	previous year	−4.63312	0.860792	0.790259	0.163173	27	10	–	−25.500 to 16.234
reading	primary	−5.74827	2.16037	1.00179	0.228505	27	10	–	−33.083 to 21.586
science	area heat	−5.02764	1.3353	1.12928	0.142563	27	10	–	−18.027 to 7.972
science	composition adjusted	−7.18594	2.46804	1.5017	0.13884	27	10	–	−22.012 to 7.640
science	macroregion FE	−4.12049	1.1206	0.96072	0.177011	27	10	–	−19.811 to 11.570
science minus math read	area heat	0.164054	0.669767	0.519964	0.870103	27	10	–	−89.530 to 89.859

Supplementary Table 5 PISA slopes with five-macroregion CR2 and plausible-value pooling (continued)

Model standard errors, degrees of freedom and marginal 95% confidence intervals are shown where applicable. CSV files in the analysis package retain full numerical precision.

outcome	specification	Estimate	SE	df	P	States	PVs	Holm P	95% CI
science minus math read	composition adjusted	−0.476507	0.834405	0.81267	0.686309	27	10	–	−19.021 to 18.068
science minus math read	macroregion FE	0.59023	0.657596	0.424195	0.651755	27	10	–	−285.085 to 286.266
science minus math read	previous year	−0.303429	0.544726	0.548892	0.726687	27	10	–	−55.975 to 55.368
science minus math read	primary	0.105204	0.713315	0.701613	0.913794	27	10	1	−25.792 to 26.002
science	previous year	−4.44157	0.79229	0.863518	0.139804	27	10	–	−19.170 to 10.287
science	primary	−5.20572	2.39562	1.02693	0.269365	27	10	–	−33.822 to 23.410

Supplementary Table 6 Precision of the four school contrasts

Two-sided noncentral-t approximation at α = 0.05 with fitted standard errors and degrees of freedom held fixed. Effect sizes use the score units and exposure contrasts in the manuscript.

design	outcome	SE	df	95% CI half-width	80% detectable size	alpha	power
overall	math	0.775686	12.9772	1.67607	2.35168	0.05	0.8
overall	portuguese	0.45101	12.9772	0.974522	1.36734	0.05	0.8
resource	math	0.288707	6.82734	0.6862	0.948144	0.05	0.8
resource	portuguese	0.328191	6.82734	0.780045	1.07781	0.05	0.8

Supplementary Table 7 School point estimates with one state omitted

design	outcome	omitted state	Estimate
overall	math	AC	0.459427
overall	portuguese	AC	0.700647
overall	math	AL	0.50159
overall	portuguese	AL	0.744554
overall	math	AM	0.325607
overall	portuguese	AM	0.628776
overall	math	AP	0.477104
overall	portuguese	AP	0.735237
overall	math	BA	0.390201
overall	portuguese	BA	0.710482
overall	math	CE	−0.222335
overall	portuguese	CE	0.372167
overall	math	DF	0.476711
overall	portuguese	DF	0.738736
overall	math	ES	0.460763
overall	portuguese	ES	0.711389
overall	math	GO	0.389829
overall	portuguese	GO	0.64365
overall	math	MA	0.744774
overall	portuguese	MA	0.665513
overall	math	MG	0.519668
overall	portuguese	MG	0.828129
overall	math	MS	0.485756
overall	portuguese	MS	0.739611
overall	math	MT	0.51774
overall	portuguese	MT	0.79134
overall	math	PA	0.667017
overall	portuguese	PA	0.69205
overall	math	PB	0.512208
overall	portuguese	PB	0.749445
overall	math	PE	0.64526

Supplementary Table 7 School point estimates with one state omitted (continued)

design	outcome	omitted state	Estimate
overall	portuguese	PE	0.905633
overall	math	PI	0.550377
overall	portuguese	PI	0.839556
overall	math	PR	0.456631
overall	portuguese	PR	0.796978
overall	math	RJ	0.518676
overall	portuguese	RJ	0.790647
overall	math	RN	0.535367
overall	portuguese	RN	0.788742
overall	math	RO	0.422113
overall	portuguese	RO	0.688075
overall	math	RR	0.476825
overall	portuguese	RR	0.749866
overall	math	RS	0.561954
overall	portuguese	RS	0.779279
overall	math	SC	0.483937
overall	portuguese	SC	0.716758
overall	math	SE	0.507405
overall	portuguese	SE	0.782242
overall	math	SP	0.467719
overall	portuguese	SP	0.717967
overall	math	TO	0.423825
overall	portuguese	TO	0.717942
resource	math	AC	0.146262
resource	portuguese	AC	0.413128
resource	math	AL	0.130219
resource	portuguese	AL	0.352636
resource	math	AM	0.153125
resource	portuguese	AM	0.61311
resource	math	AP	0.137522
resource	portuguese	AP	0.399212

Supplementary Table 7 School point estimates with one state omitted (continued)

design	outcome	omitted state	Estimate
resource	math	BA	0.225622
resource	portuguese	BA	0.484655
resource	math	CE	0.124569
resource	portuguese	CE	0.344743
resource	math	DF	0.127604
resource	portuguese	DF	0.397196
resource	math	ES	0.167718
resource	portuguese	ES	0.410057
resource	math	GO	0.148057
resource	portuguese	GO	0.390257
resource	math	MA	–0.132756
resource	portuguese	MA	0.307682
resource	math	MG	0.133467
resource	portuguese	MG	0.394594
resource	math	MS	0.128464
resource	portuguese	MS	0.399916
resource	math	MT	0.139791
resource	portuguese	MT	0.387831
resource	math	PA	0.11081
resource	portuguese	PA	0.330092
resource	math	PB	0.111156
resource	portuguese	PB	0.371958
resource	math	PE	0.223321
resource	portuguese	PE	0.487273
resource	math	PI	0.172685
resource	portuguese	PI	0.403539
resource	math	PR	0.149426
resource	portuguese	PR	0.403241
resource	math	RJ	0.0493895
resource	portuguese	RJ	0.181668
resource	math	RN	0.137138

Supplementary Table 7 School point estimates with one state omitted (continued)

design	outcome	omitted state	Estimate
resource	portuguese	RN	0.402312
resource	math	RO	0.12849
resource	portuguese	RO	0.389338
resource	math	RR	0.131843
resource	portuguese	RR	0.399784
resource	math	RS	0.113928
resource	portuguese	RS	0.367317
resource	math	SC	0.140618
resource	portuguese	SC	0.422661
resource	math	SE	0.134483
resource	portuguese	SE	0.399344
resource	math	SP	0.15605
resource	portuguese	SP	0.430088
resource	math	TO	0.101503
resource	portuguese	TO	0.417927

Supplementary Table 8 State information shares for the school comparisons

design	state	Information share	rank	cumulative share	Effective count
overall	MA	0.130709	1	0.130709	14.0184
overall	SP	0.0987741	2	0.229484	14.0184
overall	PA	0.0956402	3	0.325124	14.0184
overall	AM	0.0838294	4	0.408953	14.0184
overall	BA	0.0804705	5	0.489424	14.0184
overall	RJ	0.0722293	6	0.561653	14.0184
overall	CE	0.0585904	7	0.620243	14.0184
overall	MG	0.0564624	8	0.676706	14.0184
overall	PE	0.0549233	9	0.731629	14.0184
overall	TO	0.0485074	10	0.780136	14.0184
overall	GO	0.0382145	11	0.818351	14.0184
overall	ES	0.0287809	12	0.847132	14.0184
overall	PR	0.0267064	13	0.873838	14.0184
overall	PI	0.017802	14	0.89164	14.0184
overall	MT	0.0166445	15	0.908285	14.0184
overall	RN	0.0162189	16	0.924504	14.0184
overall	RS	0.0149376	17	0.939441	14.0184
overall	AL	0.0145076	18	0.953949	14.0184
overall	RO	0.0107601	19	0.964709	14.0184
overall	PB	0.00965159	20	0.97436	14.0184
overall	AC	0.00730726	21	0.981668	14.0184
overall	SE	0.00657059	22	0.988238	14.0184
overall	SC	0.00428546	23	0.992524	14.0184
overall	MS	0.00303064	24	0.995554	14.0184
overall	RR	0.00282671	25	0.998381	14.0184
overall	AP	0.00156872	26	0.99995	14.0184
overall	DF	5.01445e−05	27	1	14.0184
resource	PA	0.25091	1	0.25091	7.84355
resource	MA	0.14886	2	0.399769	7.84355
resource	RJ	0.136066	3	0.535836	7.84355
resource	AM	0.107734	4	0.64357	7.84355

Supplementary Table 8 State information shares for the school comparisons (continued)

design	state	Information share	rank	cumulative share	Effective count
resource	GO	0.0776853	5	0.721255	7.84355
resource	BA	0.0399921	6	0.761247	7.84355
resource	PE	0.0379498	7	0.799197	7.84355
resource	CE	0.0299368	8	0.829133	7.84355
resource	RO	0.0212185	9	0.850352	7.84355
resource	TO	0.0180426	10	0.868395	7.84355
resource	PI	0.0173418	11	0.885736	7.84355
resource	AL	0.0172342	12	0.902971	7.84355
resource	PR	0.0133251	13	0.916296	7.84355
resource	AC	0.012826	14	0.929122	7.84355
resource	RS	0.0115949	15	0.940717	7.84355
resource	MT	0.0111193	16	0.951836	7.84355
resource	MG	0.00854254	17	0.960379	7.84355
resource	SP	0.00802594	18	0.968404	7.84355
resource	ES	0.00760789	19	0.976012	7.84355
resource	RN	0.0065198	20	0.982532	7.84355
resource	PB	0.0056915	21	0.988224	7.84355
resource	SC	0.0054744	22	0.993698	7.84355
resource	SE	0.00321448	23	0.996913	7.84355
resource	AP	0.001173	24	0.998086	7.84355
resource	DF	0.00104566	25	0.999131	7.84355
resource	MS	0.000597648	26	0.999729	7.84355
resource	RR	0.000271171	27	1	7.84355

Supplementary Table 9 State comparisons with macroregion indicators and region omissions

Model standard errors, degrees of freedom and marginal 95% confidence intervals are shown where applicable. CSV files in the analysis package retain full numerical precision.

assessment	domain	model	Omitted region	States	Estimate	SE	df	P	PVs	95% CI
PISA	math	unadjusted	None	27	−4.87358	1.66701	21.4586	0.00800085	10	−8.336 to −1.411
PISA	math	macroregion FE	None	27	−4.56366	2.16923	17.3695	0.0502525	10	−9.133 to 0.006
PISA	math	macroregion FE	CO	23	−4.05364	2.40371	14.9706	0.112438	10	−9.178 to 1.071
PISA	math	macroregion FE	N	20	−3.83631	3.34919	12.3531	0.273732	10	−11.111 to 3.438
PISA	math	macroregion FE	NE	18	−5.62927	3.0583	10.7541	0.0934033	10	−12.379 to 1.121
PISA	math	macroregion FE	S	24	−4.74875	2.21283	15.7628	0.0478011	10	−9.445 to −0.052
PISA	math	macroregion FE	SE	23	−4.55301	2.1678	14.7038	0.0533866	10	−9.182 to 0.076
PISA	reading	unadjusted	None	27	−5.74827	1.85585	22.2217	0.00521608	10	−9.595 to −1.902
PISA	reading	macroregion FE	None	27	−4.85778	2.24096	17.9871	0.0438423	10	−9.566 to −0.149
PISA	reading	macroregion FE	CO	23	−4.37522	2.57119	15.4386	0.108872	10	−9.842 to 1.092
PISA	reading	macroregion FE	N	20	−4.03099	2.98395	12.6876	0.200332	10	−10.494 to 2.432
PISA	reading	macroregion FE	NE	18	−6.0227	3.29442	11.0033	0.094741	10	−13.273 to 1.228
PISA	reading	macroregion FE	S	24	−5.01383	2.26589	16.253	0.0415576	10	−9.811 to −0.216
PISA	reading	macroregion FE	SE	23	−4.84831	2.23969	15.2277	0.0466878	10	−9.616 to −0.081
PISA	science	unadjusted	None	27	−5.20572	2.14665	23.0797	0.0235353	10	−9.646 to −0.766
PISA	science	macroregion FE	None	27	−4.12049	2.7172	19.1067	0.145778	10	−9.806 to 1.565
PISA	science	macroregion FE	CO	23	−3.6117	3.22956	16.1771	0.27976	10	−10.452 to 3.229
PISA	science	macroregion FE	N	20	−3.43464	3.23677	13.218	0.307634	10	−10.416 to 3.546
PISA	science	macroregion FE	NE	18	−5.06445	4.51635	11.2577	0.285485	10	−14.977 to 4.848

Supplementary Table 9 State comparisons with macroregion indicators and region omissions (continued)

Model standard errors, degrees of freedom and marginal 95% confidence intervals are shown where applicable. CSV files in the analysis package retain full numerical precision.

assessment	domain	model	Omitted region	States	Estimate	SE	df	P	PVs	95% CI
PISA	science	macroregion FE	S	24	−4.3788	2.76463	17.1426	0.131497	10	−10.208 to 1.450
PISA	science	macroregion FE	SE	23	−4.08734	2.71165	16.1606	0.151026	10	−9.831 to 1.656
SAEB	math	unadjusted	None	27	−2.24634	0.743159	25	0.00571739	1	−3.777 to −0.716
SAEB	math	macroregion FE	None	27	−0.528847	1.33395	21	0.695771	1	−3.303 to 2.245
SAEB	math	macroregion FE	CO	23	−0.459722	1.36725	18	0.740579	1	−3.332 to 2.413
SAEB	math	macroregion FE	N	20	−0.45983	2.71577	15	0.867809	1	−6.248 to 5.329
SAEB	math	macroregion FE	NE	18	−0.495758	1.48618	13	0.744016	1	−3.706 to 2.715
SAEB	math	macroregion FE	S	24	−0.670268	1.30842	19	0.614363	1	−3.409 to 2.068
SAEB	math	macroregion FE	SE	23	−0.504034	1.33825	18	0.710846	1	−3.316 to 2.308
SAEB	portuguese	unadjusted	None	27	−2.46009	0.693763	25	0.00157283	1	−3.889 to −1.031
SAEB	portuguese	macroregion FE	None	27	−0.862969	1.16194	21	0.465894	1	−3.279 to 1.553
SAEB	portuguese	macroregion FE	CO	23	−0.949442	1.11055	18	0.403824	1	−3.283 to 1.384
SAEB	portuguese	macroregion FE	N	20	−0.1614	1.89135	15	0.933123	1	−4.193 to 3.870
SAEB	portuguese	macroregion FE	NE	18	−1.27403	1.7422	13	0.477585	1	−5.038 to 2.490
SAEB	portuguese	macroregion FE	S	24	−0.951336	1.16159	19	0.422944	1	−3.383 to 1.480
SAEB	portuguese	macroregion FE	SE	23	−0.84549	1.1623	18	0.476319	1	−3.287 to 1.596

Supplementary Table 10 Within-macroregion variation in annual hot-day changes

Exposure is change in annual-average days above 35°C. Within-region SS shares partition the total residual sum of squares after removing macroregion means.

macroregion	States	mean days	sd days	Within-region SS share
CO	4	13.1342	13.405	0.175594
N	7	21.8323	14.9523	0.436942
NE	9	−6.43935	12.1442	0.384314
S	3	−0.196455	2.0734	0.00280061
SE	4	1.51282	0.598119	0.000349584