Online Appendix: Policy Spillover Effects on Student Achievement – Evidence from PISA*

Clara-Christina E. Gerstner† Emmanuel S. Tsyawo‡

1 GMM Estimation and Inference

Spatial econometric models are typically estimated using maximum likelihood (MLE) (e.g., Anselin (1988) and Elhorst (2005)), quasi-maximum likelihood (QMLE) (e.g., Lee and Yu (2010)), two-stage least squares (2SLS) (e.g., Kelejian and Prucha (1998)), and generalised method of moments (GMM) (e.g., Lee (2007) and Lee and Liu (2010)). GMM is our preferred estimator because of its robustness to violations of distributional assumptions. Also, the GMM tends to be asymptotically more efficient than 2SLS, and it allows us to verify model specification using over-identifying restrictions tests (J-tests). The GMM estimator is given by

$$\hat{\boldsymbol{\theta}}_n = \arg\min_{\boldsymbol{\theta}\in\boldsymbol{\Theta}} Q_n(\boldsymbol{\theta}) = (\check{\mathbf{x}}'\boldsymbol{z}_n\boldsymbol{M}\boldsymbol{z}_n'\check{\mathbf{x}})^{-1}\check{\mathbf{x}}'\boldsymbol{z}_n\boldsymbol{M}\boldsymbol{z}_n'\mathbf{y}_n \tag{1.1}$$

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†Graduate School of Education, University of Pennsylvania, 3700 Walnut St, Philadelphia PA 19104, clarag@upenn.edu

‡AIRESS & FGSES, Université Mohammed VI Polytechnique, Technopolis-Rabat, Morocco, emmanuel.tsyawo@um6p.ma

where $Q_n(\boldsymbol{\theta}) = \frac{1}{n} g_n(\boldsymbol{\theta})' \boldsymbol{M} g_n(\boldsymbol{\theta})$, $g_n(\boldsymbol{\theta}) = \boldsymbol{z}_n' \boldsymbol{\varepsilon}_n(\boldsymbol{\theta})$, the $n \times p_p$ matrix of instruments $\boldsymbol{z}_n$ denotes the linearly independent columns of $[\mathbf{x}_n, \boldsymbol{w}_n \mathbf{x}_n]$, $\boldsymbol{\varepsilon}_n(\boldsymbol{\theta}) = \mathbf{y}_n - \check{\mathbf{x}} \boldsymbol{\theta}$, $\check{\mathbf{x}} \equiv [\boldsymbol{w}_n \mathbf{y}_n, \mathbf{x}_n]$, $\boldsymbol{\Theta}$ is a compact parameter space, and $\boldsymbol{M}$ is a $p_p \times p_p$ positive definite matrix. The subscript n is used to emphasise dependence on data and also denote the total number of country-year observations $N \times T$.

Following the GMM literature (e.g., Hansen (1982) and Lee (2007)), the optimal weighting matrix is $\boldsymbol{M} = \boldsymbol{\Omega}_n^{-1}$ where $\boldsymbol{\Omega}_n \equiv \mathrm{var}(g_n(\boldsymbol{\theta}_o))$. Since disturbances may be heteroskedastic and arbitrarily correlated over time for each country, they are clustered at the country level, i.e., $\boldsymbol{\Omega}_n(\boldsymbol{\theta}_o) \equiv \mathrm{var}(g_n(\boldsymbol{\theta}_o)) = \mathrm{var}(\sum_{i=1}^N \sum_{t=1}^T \boldsymbol{z}_{it} \varepsilon_{it}) = \sum_{i=1}^N \mathrm{var}(\sum_{t=1}^T \boldsymbol{z}_{it} \varepsilon_{it}) = \sum_{i=1}^N \sum_{t=1}^T \sum_{t'=1}^T \mathbb{E}(\boldsymbol{z}_{it} \varepsilon_{it} \varepsilon_{it'} \boldsymbol{z}_{it'}')$.

Following standard arguments (e.g., Hansen (1982) and Lee (2007)), $\sqrt{n}(\hat{\boldsymbol{\theta}}_n - \boldsymbol{\theta}_o) \xrightarrow{d} \mathcal{N}(\mathbf{0}, \boldsymbol{V}_o)$ and $\boldsymbol{V}_o = \big[\lim_{n\to\infty} \check{\mathbf{x}}' \boldsymbol{z}_n \boldsymbol{\Omega}_n^{-1} \boldsymbol{z}_n' \check{\mathbf{x}}/n\big]^{-1}$. The covariance matrix is estimated using $\hat{\boldsymbol{V}}_n = \big[\check{\mathbf{x}}' \boldsymbol{z}_n \hat{\boldsymbol{\Omega}}_n^{-1} \boldsymbol{z}_n' \check{\mathbf{x}}/n\big]^{-1}$, where $\hat{\boldsymbol{\Omega}}_n = \sum_{i=1}^N \sum_{t=1}^T \sum_{t'=1}^T \boldsymbol{z}_{it} \hat{\varepsilon}_{it} \hat{\varepsilon}_{it'} \boldsymbol{z}_{it'}'$, $\hat{\varepsilon}_{it}$ is the residual corresponding to country i in year t, and $\mathrm{var}(\hat{\boldsymbol{\theta}}_n) = \hat{\boldsymbol{V}}_n/n$ is the covariance matrix of $\hat{\boldsymbol{\theta}}_n$. Recall p_p is the total number of moments. Let p_θ denote the length of the parameter vector $\boldsymbol{\theta}$. The test statistic for the over-identifying restrictions test is J-stat $= g_n(\hat{\boldsymbol{\theta}}_n)' \hat{\boldsymbol{\Omega}}_n^{-1} g_n(\hat{\boldsymbol{\theta}}_n) \xrightarrow{d} \chi^2(p_p - p_\theta)$ where $p_p - p_\theta$ is the degrees of freedom.

2 Descriptive Statistics

This section provides additional descriptive statistics at the country level and over time. Table 2.1 shows summary statistics by country for outcome variables viz. test scores in Reading, Mathematics, and Science, and covariates viz. school autonomy, private school share, external monitoring, shortage (none and large), GDP per capita, and OECD membership. As reading test scores and school autonomy are, respectively, the outcome variable and main covariate of interest, Table 2.2 provides their summary statistics by country and year.[1]

Trends of both reading scores and autonomy by country can be visualised in Figures 2.1 and 2.2. Both plots show that on average (see the thick black line) neither school autonomy or reading scores dramatically increase over time. Generally, there is no discernible pattern or trend. This alleviates concerns about the existence of trends that may lead to spurious correlations or co-integration. Moreover, such concerns are further alleviated by the inclusion of year dummies and other controls in the specifications. Taking this argument up a notch further, two considerations come to mind. One is diagnostic and the other is robust estimation. On diagnostics, the number of waves is insufficient to conduct any informative test of co-integration in panels as such tests often require $T \to \infty$. On robust estimation, we face two challenges in using an ARDL specification and its SAR extension, for example. First, we only have three waves of data thus at least one wave is lost due to time lagging. Second, an SAR-ARDL(1,1), for example, doubles the number of covariates, i.e., from $\boldsymbol{x}_{it}$ to $[\boldsymbol{x}_{it}, \boldsymbol{x}_{i(t-1)}]$ with a loss of N country observations due to lagging by one period. This, in our case, leads to a non-invertible covariance matrix of the GMM moment conditions.

[1] Table 2.2 is not replicated for other variables due to concerns of space.

Table 2.1: Summary Statistics by Country (averaged over all three waves)

	Test scores			School	Private	External	No	Large	GDP	OECD
	Reading	Math	Science	Autonomy	School Share	Monitoring	Shortage	Shortage	Per Capita	Member
ALB	394.68	394.98	405.10	0.62	0.11	0.81	0.48	0.09	4,462	0
ARE	435.55	427.55	440.97	0.49	0.57	0.91	0.60	0.08	42,482	0
ARG	423.19	410.93	427.22	0.69	0.42	0.66	0.36	0.14	12,047	0
AUS	509.87	504.13	519.58	0.93	0.47	0.87	0.59	0.01	41,485	1
AUT	481.59	499.40	498.38	0.81	0.14	0.45	0.47	0.05	55,198	1
BEL	504.36	512.26	504.48	0.86	0.58	0.49	0.50	0.04	49,058	1
BGR	432.31	436.00	443.84	0.50	0.03	0.84	0.40	0.06	20,925	0
BRA	408.54	383.80	402.57	0.59	0.19	0.84	0.40	0.08	9,985	0
CAN	524.68	520.18	527.28	0.79	0.13	0.88	0.49	0.02	36,931	1
CHE	500.58	528.71	512.46	0.73	0.15	0.39	0.61	0.01	70,599	0
CHL	449.78	422.12	446.45	0.69	0.51	0.79	0.31	0.09	37,331	1
COL	413.83	382.33	405.39	0.66	0.28	0.79	0.17	0.26	9,160	1
CRI	436.87	405.55	426.48	0.58	0.22	0.90	0.22	0.33	8,032	0
CZE	486.11	494.70	500.54	0.99	0.09	0.52	0.24	0.04	18,408	1
DEU	504.70	510.76	517.89	0.81	0.07	0.31	0.40	0.03	37,321	1
DNK	496.95	504.80	499.92	0.87	0.29	0.64	0.42	0.02	58,012	1
ESP	488.72	484.68	493.14	0.72	0.43	0.74	0.53	0.04	50,287	1
EST	512.13	517.39	534.47	0.97	0.07	0.76	0.21	0.06	32,799	1
FIN	528.77	523.44	543.39	0.89	0.05	0.41	0.35	0.01	44,699	1
GBR	497.16	492.94	512.35	0.99	0.43	0.84	0.53	0.02	46,529	1
GRC	475.67	457.57	463.89	0.16	0.04	0.62	0.39	0.12	33,642	1
HKG	534.81	554.57	542.42	0.99	0.93	0.70	0.54	0.01	38,028	0
HRV	482.39	465.04	484.37	0.62	0.09	0.83	0.23	0.11	17,556	1
HUN	484.05	481.35	491.23	0.77	0.16	0.49	0.36	0.06	23,428	0
IDN	398.36	377.51	389.19	0.90	0.61	0.76	0.13	0.27	6,470	0
IRL	513.21	497.45	510.85	0.90	0.56	0.54	0.44	0.06	42,459	1
ISL	488.11	495.83	482.33	0.95	0.02	0.75	0.38	0.01	35,806	1
ISR	479.58	461.00	463.82	0.93	0.16	0.80	0.30	0.08	39,577	1
ITA	486.85	485.99	487.64	0.86	0.16	0.26	0.34	0.03	44,540	1
JOR	404.05	384.17	411.14	0.15	0.20	0.85	0.46	0.19	14,996	0
JPN	524.62	532.61	541.52	0.96	0.25	0.09	0.57	0.07	41,009	1
KOR	530.83	541.37	530.53	0.92	0.30	0.84	0.31	0.02	16,859	1
LTU	472.72	477.93	487.51	0.86	0.02	0.69	0.36	0.07	22,482	1
LUX	480.47	488.23	485.99	0.73	0.22	0.61	0.34	0.00	86,435	1
LVA	486.80	484.94	495.43	0.83	0.04	0.54	0.23	0.02	15,627	1
MAC	501.43	535.74	520.06	0.89	0.92	0.45	0.39	0.07	75,355	0
MEX	424.03	413.27	415.51	0.35	0.20	0.87	0.17	0.22	11,978	1
MNE	418.85	410.03	407.56	0.49	0.02	0.92	0.12	0.04	36,158	0
NLD	507.53	520.35	517.62	0.99	0.64	0.71	0.56	0.03	40,911	1
NOR	506.79	496.35	497.63	0.79	0.06	0.75	0.23	0.02	68,308	1
NZL	514.11	504.76	520.32	0.98	0.15	0.91	0.43	0.02	40,853	1
PER	383.80	373.26	379.71	0.77	0.34	0.60	0.13	0.31	35,703	0
POL	508.12	505.59	511.78	0.92	0.07	0.79	0.48	0.01	24,143	1
PRT	491.74	488.53	494.44	0.56	0.17	0.81	0.45	0.02	18,236	1
QAT	387.04	382.32	393.57	0.45	0.41	0.91	0.79	0.03	61,573	0
ROU	431.89	438.53	433.94	0.67	0.01	0.68	0.24	0.03	9,859	0
RUS	476.39	481.35	483.74	0.71	0.01	0.99	0.28	0.13	13,347	0
SGP	534.41	566.56	549.59	0.78	0.13	0.97	0.86	0.00	50,487	0
SVK	464.24	484.52	474.08	0.95	0.12	0.80	0.13	0.12	18,571	1
SVN	489.87	504.17	512.92	0.86	0.01	0.65	0.41	0.02	25,598	1
SWE	493.65	488.81	491.11	0.89	0.27	0.84	0.53	0.00	58,976	1
THA	423.91	420.26	430.21	0.95	0.13	0.90	0.18	0.13	5,275	0
TUN	389.59	375.37	395.04	0.23	0.16	0.82	0.19	0.21	4,292	0
TUR	456.01	437.96	447.60	0.20	0.02	0.89	0.15	0.32	11,506	1
URY	424.58	418.00	426.14	0.51	0.23	0.68	0.46	0.05	13,387	0
USA	498.12	479.47	498.55	0.77	0.23	0.91	0.40	0.04	51,111	1

Table 2.2: Summary Statistics by Country by Year

	Reading test scores			School autonomy		
	2009	2012	2015	2009	2012	2015
ALB	384.82	393.96	405.26	0.63	0.61	0.61
ARE	431.42	441.7	433.54	0.47	0.49	0.5
ARG	398.26	395.98	502.9	0.73	0.6	0.92
AUS	514.9	511.8	484.87	0.95	0.93	0.83
AUT	470.28	489.61	498.52	0.83	0.76	0.86
BEL	505.95	508.62	431.72	0.86	0.86	0.48
BGR	429.08	436.13	407.35	0.52	0.49	0.59
BRA	411.75	406.53	526.67	0.6	0.56	0.8
CAN	524.24	523.12	492.2	0.82	0.75	0.71
CHE	500.5	509.04	458.57	0.76	0.71	0.69
CHL	449.37	441.4	424.91	0.73	0.65	0.7
COL	413.18	403.4	427.49	0.66	0.61	0.52
CRI	442.58	440.55	487.25	0.71	0.52	0.99
CZE	478.19	492.89	509.1	0.99	1	0.83
DEU	497.31	507.68	499.81	0.79	0.8	0.9
DNK	494.92	496.13	519.14	0.87	0.84	0.99
ESP	481.04	487.94	526.42	0.76	0.68	0.9
EST	500.96	516.29	497.97	0.96	0.96	0.99
FIN	535.88	524.02	467.04	0.94	0.84	0.17
GBR	494.18	499.32	526.68	0.99	0.99	0.99
GRC	482.78	477.2	486.86	0.13	0.16	0.64
HKG	533.15	544.6	469.52	0.99	1	0.69
HRV	475.75	484.57	397.26	0.65	0.59	0.9
HUN	494.18	488.46	520.81	0.8	0.81	0.91
IDN	401.71	396.12	481.53	0.86	0.93	0.95
IRL	495.64	523.17	478.96	0.89	0.9	0.93
ISL	500.28	482.52	484.76	0.94	0.95	0.85
ISR	473.99	485.8	408.1	0.94	0.92	0.16
ITA	486.05	489.75	515.96	0.86	0.87	0.95
JOR	405.01	399.03	517.44	0.14	0.16	0.94
JPN	519.86	538.05	472.41	0.98	0.95	0.87
KOR	539.27	535.79	481.44	0.91	0.92	0.77
LTU	468.44	477.31	487.76	0.84	0.88	0.85
LUX	472.17	487.81	508.69	0.7	0.71	0.92
LVA	483.96	488.69	423.28	0.8	0.83	0.32
MAC	486.64	508.95	426.88	0.9	0.87	0.54
MEX	425.27	423.55	502.96	0.36	0.36	0.99
MNE	407.55	422.11	513.19	0.57	0.35	0.88
NLD	508.4	511.23	509.27	0.99	0.98	0.98
NOR	503.23	503.94	397.54	0.77	0.7	0.76
NZL	520.88	512.19	505.7	0.98	0.97	0.92
PER	369.7	384.15	498.13	0.77	0.76	0.62
POL	500.48	518.19	475.33	0.93	0.92	0.74
PRT	489.33	487.76	401.89	0.48	0.59	0.44
QAT	371.72	387.5	497.19	0.44	0.47	0.71
ROU	424.46	437.6	433.62	0.69	0.58	0.75
RUS	459.4	475.15	494.63	0.73	0.71	0.69
SGP	525.9	542.22	535.1	0.84	0.82	0.68
SVK	477.44	462.77	452.51	0.95	0.95	0.95
SVN	483.08	481.32	505.22	0.92	0.86	0.79
SWE	497.45	483.34	500.16	0.92	0.86	0.89
THA	421.37	441.22	409.13	0.92	0.96	0.96
TUN	403.63	404.08	361.06	0.18	0.39	0.13
TUR	464.19	475.49	428.34	0.3	0.16	0.13
URY	425.81	411.35	436.57	0.47	0.51	0.54
USA	499.83	497.58	496.94	0.8	0.71	0.8

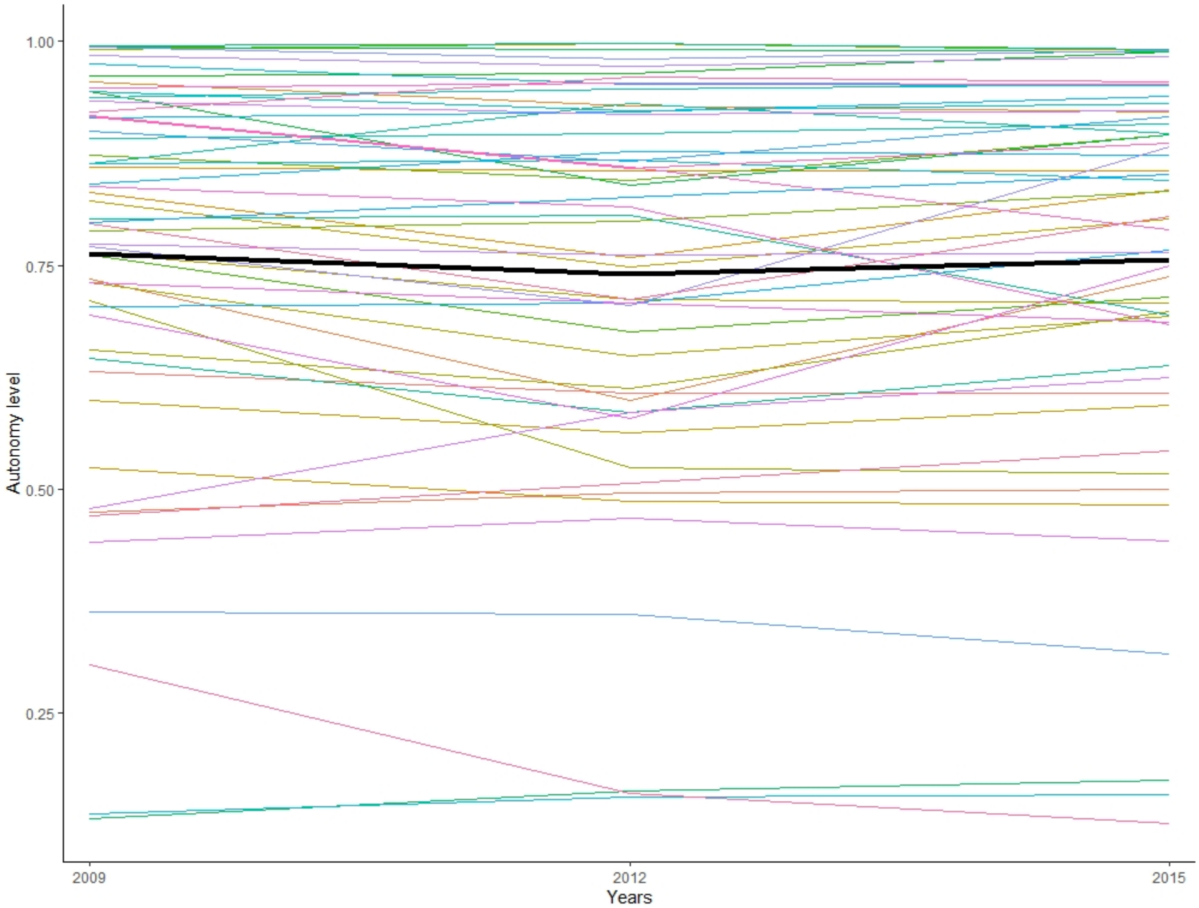

Figure 2.1: Trend in School Autonomy by Year

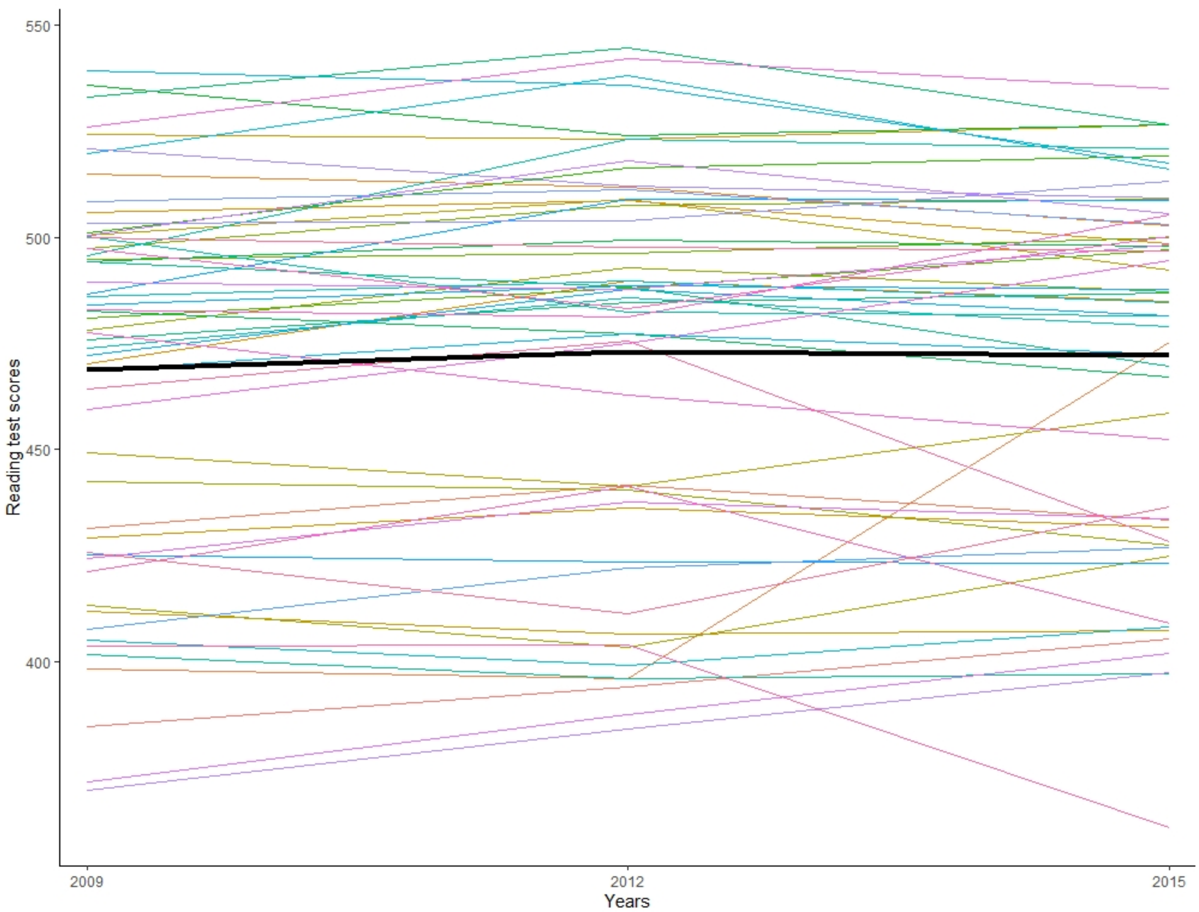

Figure 2.2: Trend in Reading Test Scores by Year

3 Additional Empirical Results

Additional empirical results are shown and discussed in this section. We replicate the results by subdomain (Table 4.3 in the main text) and the robustness analyses (Table 4.4 in the main text) for Mathematics and Science here. For Tables 3.1 and 3.2, we see that all specifications have significant spatial coefficients and spillover effects, albeit larger than the effects reported in the main text for Reading. For Tables 3.3 and 3.4, we again show that dropping imputed values does not alter our results, that the spatial coefficient for OECD countries only is insignificant and that there are large spillover effects for the European sample. Including country-fixed effects for Mathematics reduces the size of the spillover effects but they are still positive and significant. For Science, this specification could not be computed due to challenges in inverting the covariance matrix of moments.

Finally, Table 3.5 displays three specifications with alternative spatial matrices all related to economic distance or similarity between countries, namely, closeness in GDP per capita, OECD membership, and World Bank income categories.[2] The spillover effect with the spatial matrix based on GDP per capita (column (1) of Table 3.5) is not interpreted as the spatial coefficient is unreasonably large; it falls outside the natural bound $\rho \in (-1, 1)$ for a row-normalised spatial matrix. Moreover, the J-statistic suggests the model is not supported by the data at the 5% level. For the other two specifications, the spillover effects are, respectively, larger and smaller than the comparable spillover effect reported in the main text. Although the spillover effects in Table 3.5 (columns (2) and (3)) appear different from the one reported in the main text (see Table 4.2 column (1) of the main text), the respective confidence intervals, however, do not exclude the estimate in the main text. The local effects are, however, very similar to those reported in the main text. Thus, these findings suggest that the choice of the spatial matrix does not significantly (in the statistical sense) alter the spillover effects. In addition, the local effect does not vary in any meaningful way across

[2] A spatial matrix based on common language or linguistic similarity could not be considered as it led to the isolation and thus loss of several countries.

Table 3.1: SAR Results by Subdomains for Mathematics

	School				Personnel	Budget
	Assessments	Textbooks	Content	Course choice		
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A	Coefficients					
Autonomy	79.588***	56.951***	47.650***	65.669***	42.679***	67.446***
	(16.249)	(13.496)	(12.524)	(11.560)	(14.330)	(14.061)
ρ	0.653***	0.787***	0.750***	0.655***	0.693***	0.627***
	(0.183)	(0.163)	(0.157)	(0.147)	(0.166)	(0.190)
Panel B	Partial effects					
Local	83.246	62.051	51.151	68.712	45.042	70.187
	[53.8;122]	[35.6;113.1]	[27.0;86.8]	[46.2;96.5]	[17.0;79.0]	[44.7;101.9]
Spillover	146.251	205.463	139.356	121.588	93.801	110.602
	[34.3;1334.2]	[45.9;2684.7]	[34.6;1487.7]	[35.5;735.8]	[20.0;804.8]	[24.0;921.6]
Total	229.498	267.515	190.507	190.3	138.843	180.789
	[108.9;1435.8]	[93.4;2785.1]	[72.2;1562.5]	[92.7;809.4]	[45.9;866.7]	[87.3;1010.0]
Panel C	Goodness of fit					
J-stat (df)	7.62 (8)	7.38 (8)	7.55 (8)	6.41 (8)	8.96 (8)	7.08 (8)
p-value	0.47	0.5	0.48	0.6	0.35	0.53
R^2	0.6	0.55	0.58	0.63	0.53	0.59

Notes: Dependent variable: PISA mathematics score. Robust standard errors adjusted for clustering at the country level are in parentheses. The 95% confidence intervals provided in brackets are constructed from 10,000 simulations of partial effects. All specifications control for year fixed effects, income category, private school share, external monitoring, shortage of instruction materials, and GDP per capita. *Significance levels*: *** 1%, ** 5%, * 10%.

Table 3.2: SAR Results by Subdomains for Science

	School				Personnel	Budget
	Assessments	Textbooks	Content	Course choice		
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A	Coefficients					
Autonomy	68.259***	49.64***	41.289***	58.549***	32.745**	55.885***
	(14.758)	(10.339)	(10.835)	(10.648)	(12.653)	(12.649)
ρ	0.607***	0.705***	0.665***	0.620***	0.650***	0.563***
	(0.181)	(0.164)	(0.168)	(0.151)	(0.166)	(0.188)
Panel B	Partial effects					
Local	70.791	52.562	43.299	60.856	34.231	57.566
	[43.3;103.3]	[32.6;81.4]	[22.8;68.2]	[40.2;85.0]	[9.3;62.4]	[33.7;84.8]
Spillover	103.086	115.875	80.097	93.346	59.431	70.291
	[23.5;719.9]	[28.6;1094.1]	[20.0;590.9]	[26.7;496.0]	[10.2;420.6]	[13.7;461.2]
Total	173.877	168.437	123.395	154.202	93.662	127.857
	[84.0;804.5]	[70.7;1164.8]	[52.9;642.6]	[77.5;567.7]	[24.7;469.8]	[62.0;524.7]
Panel C	Goodness of fit					
J-stat (df)	5.59 (8)	6.64 (8)	5.90 (8)	5.31 (8)	8.97 (8)	6.63 (8)
p-value	0.69	0.58	0.66	0.72	0.34	0.58
R^2	0.61	0.57	0.58	0.64	0.55	0.61

Notes: Dependent variable: PISA science score. Robust standard errors adjusted for clustering at the country level are in parentheses. The 95% confidence intervals provided in brackets are constructed from 10,000 simulations of partial effects. All specifications control for year fixed effects, income category, private school share, external monitoring, shortage of instruction materials, and GDP per capita. *Significance levels*: *** 1%, ** 5%, * 10%.

Table 3.3: Robustness Analyses for Mathematics

	Drop Missing (1)	OECD only (2)	Europe only (3)	Country-fixed effects (4)
Panel A		Coefficients		
Autonomy	81.606***	62.571***	69.41***	43.434***
	(14.198)	(11.667)	(15.620)	(8.521)
ρ	0.758***	0.472	0.760**	0.158***
	(0.166)	(0.430)	(0.354)	(0.030)
Panel B		Partial effects		
Local	87.997	63.798	75.936	43.51
	[60.9;144.8]	[46.0;97.7]	[50.0;175.9]	[51.4;84.5]
Spillover	249.904	54.665	213.488	8.103
	[61.3;2813.1]	[-21.9;1130.1]	[1.3;3049.9]	[6.8;20.1]
Total	337.901	118.463	289.424	51.614
	[137.6;2948.3]	[49.8;1218.3]	[78.2;3226.5]	[60.5;102.1]
Panel C		Goodness of fit		
J-stat (df)	3.57 (8)	10.90 (7)	14.48 (7)	276.30 (8)
p-value	0.89	0.14	0.04	0.00
N (Countries)	56	35	31	56
R^2	0.64	0.65	0.55	0.98

Notes: Dependent variable: PISA mathematics score. Robust standard errors adjusted for clustering at the country level are in parentheses. The 95% confidence intervals provided in brackets are constructed from 10,000 simulations of partial effects. Standard errors in specification (4) are only heteroskedasticity-robust because the cluster-robust covariance matrix is not invertible. All specifications control for year fixed effects, income categories, private school share, external monitoring, shortage of instruction materials, and GDP per capita. *Significance levels*: *** 1%, ** 5%, * 10%.

Table 3.4: Robustness Analyses for Science

	Drop Missing (1)	OECD only (2)	Europe only (3)
Panel A		Coefficients	
Autonomy	78.795***	62.134***	60.804***
	(11.769)	(10.981)	(13.969)
ρ	0.702***	0.353	0.894***
	(0.166)	(0.461)	(0.343)
Panel B		Partial effects	
Local	83.445	62.737	77.059
	[61.0;121.1]	[44.8;92.0]	[-22.1;149.0]
Spillover	181.314	33.315	498.302
	[46.7;1733]	[-26.8;794.7]	[-2405.5;2513.8]
Total	264.760	96.051	575.361
	[120.1;1853.4]	[41.9;884.6]	[-2404.6;2653.1]
Panel C		Goodness of fit	
J-stat (df)	3.50 (8)	5.93 (7)	12.21 (7)
p-value	0.90	0.55	0.09
N (Countries)	56	35	31
R^2	0.66	0.66	0.52

Notes: Dependent variable: PISA science score. Robust standard errors adjusted for clustering at the country level are in parentheses. The 95% confidence intervals provided in brackets are constructed from 10,000 simulations of partial effects. All specifications control for year fixed effects, income categories, private school share, external monitoring, shortage of instruction materials, and GDP per capita. *Significance levels*: *** 1%, ** 5%, * 10%.

Table 3.5: SAR Results for Alternative Spatial Matrices

	GDP per capita (1)	OECD membership (2)	Income categories (3)
Autonomy	52.847***	77.899***	79.948***
	(10.227)	(15.076)	(18.862)
ρ	-8.655	0.601***	0.260
	(1.952)	(0.161)	(0.216)
Panel B		Partial effects	
Local	65.499	80.462	80.379
	[41.7;96.2]	[53.9;113.8]	[45;118]
Spillover	-60.026	114.933	27.685
	[-90.2;-37.9]	[33.8;579.7]	[-13;146.1]
Total	5.473	195.394	108.064
	[2.8;10.8]	[108.4;672.5]	[58.4;233.0]
Panel C		Goodness of fit	
J-stat (df)	13.73 (8)	9.48 (8)	8.93 (8)
p-value	0.06	0.22	0.18

Notes: Outcome variable: Reading Scores. Total number of country-year observations is 168. Robust standard errors adjusted for clustering at the country level are in parentheses. The 95% confidence intervals for partial effects provided in brackets are constructed from 10,000 simulations – see Lesage and Pace (2009) and Fischer et al. (2009). Spatial matrices in columns (2) and (3) are based on a binary OECD membership and World Bank income categories (1=high income, 2=upper-middle income, 3=lower-middle income). *Significance levels*: *** 1%, ** 5%, * 10%.

spatial matrix. The spatial matrix based on geographic distance appears to be the most viable as models based on other spatial matrices are either rejected by the data (GDP per capita) or the spatial matrix has too little variation (e.g., only two categories used in the construction of the OECD spatial matrix).

References

[1] Anselin, Luc. *Spatial Econometrics: Methods and Models*. Springer Science, 1988.

[2] Elhorst, J Paul. "Unconditional maximum likelihood estimation of linear and log-linear dynamic models for spatial panels". *Geographical Analysis* 37.1 (2005), pp. 85–106.

[3] Fischer, Manfred M, Monika Bartkowska, Aleksandra Riedl, Sascha Sardadvar, and Andrea Kunnert. “The impact of human capital on regional labor productivity in Europe”. *Letters in Spatial and Resource Sciences* 2.2-3 (2009), pp. 97–108.

[4] Hansen, Lars Peter. “Large sample properties of generalized method of moments estimators”. *Econometrica: Journal of the Econometric Society* (1982), pp. 1029–1054.

[5] Kelejian, Harry H and Ingmar R Prucha. “A generalized spatial two-stage least squares procedure for estimating a spatial autoregressive model with autoregressive disturbances”. *The Journal of Real Estate Finance and Economics* 17.1 (1998), pp. 99–121.

[6] Lee, Lung-Fei. “GMM and 2SLS estimation of mixed regressive, spatial autoregressive models”. *Journal of Econometrics* 137.2 (2007), pp. 489–514.

[7] Lee, Lung-Fei and Xiaodong Liu. “Efficient GMM estimation of high order spatial autoregressive models with autoregressive disturbances”. *Econometric Theory* 26.1 (2010), pp. 187–230.

[8] Lee, Lung-Fei and Jihai Yu. “Estimation of spatial autoregressive panel data models with fixed effects”. *Journal of Econometrics* 154.2 (2010), pp. 165–185.

[9] Lesage, James P and R Kelley Pace. *Introduction to Spatial Econometrics*. CRC Press, 2009.