SHOCKS AND THE SPATIAL DISTRIBUTION OF ECONOMIC ACTIVITY: THE ROLE OF INSTITUTIONS
Supplemental Material

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For Online Publication

Abstract

This supplement reports (i) summary statistics, (ii) robustness checks and other supplemental exercises, (iii) additional figures, (iv) a detailed data appendix, and (v) additional theoretical discussion. See the Replication Files .zip file for (i) a full dataset, (ii) replication files for Stata, (iii) instructions for replication, and (iv) a description of all data files.

Table A.1: Summary Statistics

Variable	Observations	Mean	Std. Dev.	Min.	Max.
Agricultural country	83700	.553	.497	0	1
% City growth	83700	3.418	3.265	-94.460	138.267
Democracy$_{t-1}$	83508	.461	.498	0	1
Earthquake$_{t-1}$	83700	.008	.091	0	1
Earthquake risk area	83700	.481	.500	0	1
Income level	83700	.382	.486	0	1
Nearest city (km)	83700	82.561	108.672	1.237	2577.282
Ln nearest city	83700	0	.917	-3.203	3.847
Quake depth$_{t-1}$ (km)	83700	55.033	103.693	0	678
Ln quake depth$_{t-1}$	83700	0	1.067	-3.288	3.233
Richter$_{t-1}$	83700	5.345	.390	5	9.1
Ln Richter$_{t-1}$	83700	0	.249	-.262	1.367
Stable democracy	83565	.291	.454	0	1
Stable nondemocracy	83565	.292	.455	0	1
Stable high control of corruption	83700	.209	.407	0	1
Stable strong rule of law	83700	.239	.427	0	1
Unstable polity	83565	.416	.493	0	1
Urban country	83700	.463	.499	0	1
Region	5	–	–	–	–
Country	153	–	–	–	–
City	1860	–	–	–	–
Year	45	–	–	1974	2018

Notes: For variable descriptions, see the end of these supplementary materials.

Table A.2: Main Effects (Additional Lags)

	(1)	(2)	(3)	(4)
Earthquake$_{t-1}$	-.439	-.512	-.468	-.499
	(.160)***	(.217)**	(.227)**	(.229)**
Earthquake$_{t-2}$	-.491	-.560	-.529	-.521
	(.159)***	(.201)***	(.205)***	(.213)**
Earthquake$_{t-3}$	-.547	-.618	-.589	-.533
	(.169)***	(.214)***	(.208)***	(.211)**
Earthquake$_{t-4}$	-.521	-.676	-.655	-.530
	(.171)***	(.216)***	(.213)***	(.216)**
Earthquake$_{t-5}$	-.858	-1.058	-1.049	-.531
	(.296)***	(.321)***	(.319)***	(.195)***
Earthquake$_{t-6}$	-1.106	-1.482	-1.502	-.695
	(.366)***	(.421)***	(.426)***	(.198)***
Cumulative effect	-3.962	-4.906	-4.794	-3.308
	(.735)***	(.857)***	(.865)***	(.814)***
Earthquake$_{t-1}$×Stable democracy	–	.118	.205	.149
		(.313)	(.329)	(.357)
Earthquake$_{t-2}$×Stable democracy	–	.213	.345	.244
		(.305)	(.320)	(.354)
Earthquake$_{t-3}$×Stable democracy	–	.172	.301	.460
		(.307)	(.315)	(.378)
Earthquake$_{t-4}$×Stable democracy	–	.477	.565	.898
		(.313)	(.316)*	(.218)***
Earthquake$_{t-5}$×Stable democracy	–	.792	.807	.887
		(.413)*	(.421)*	(.254)***
Earthquake$_{t-6}$×Stable democracy	–	1.348	1.343	1.508
		(.377)***	(.495)***	(.149)***
Cum. interaction×Stable democracy	–	3.120	3.565	4.146
		(1.065)***	(1.075)***	(.972)***
Earthquake$_{t-1}$×Earthquake risk	.333	.439	.420	.451
	(.176)*	(.234)*	(.240)*	(.246)*
Earthquake$_{t-2}$×Earthquake risk	.441	.533	.534	.526
	(.174)**	(.217)**	(.220)**	(.230)**
Earthquake$_{t-3}$×Earthquake risk	.537	.636	.637	.580
	(.185)***	(.231)***	(.224)***	(.230)**
Earthquake$_{t-4}$×Earthquake risk	.548	.749	.747	.619
	(.187)***	(.233)***	(.229)***	(.234)***
Earthquake$_{t-5}$×Earthquake risk	.882	1.113	1.109	.583
	(.305)***	(.332)***	(.329)***	(.214)***
Earthquake$_{t-6}$×Earthquake risk	1.081	1.454	1.467	.647
	(.373)***	(.429)***	(.434)***	(.217)***
Cum. interaction×Earthquake risk	3.823	4.923	4.913	3.406
	(.758)***	(.883)***	(.887)***	(.848)***
Adj. R^2	.148	.148	.148	.148
Observations	74400	74280	74280	74280
Income level interaction?	No	No	Yes	Yes
Income×risk interaction?	No	No	No	Yes

Notes: Standard errors are robust to spatial correlation up to a distance of 300 km, according to a uniform spatial weighting kernel, with ***, **, and * denoting significance at the 1%, 5%, and 10% levels, respectively. All specifications include city, year×income level, and year×earthquake risk fixed effects. An earthquake is considered to have hit a city if it struck within 25 km of that city's centroid in the previous year. "Earthquake risk" is a dummy that equals 1 if there is at least a 10% probability of a city experiencing an MMI event greater than V in the next 50 years at any point within 50 km of its centroid. "Stable democracy" is a dummy that equals 1 if the country in which a city resides was consistently a democracy during the sample period. "Income level" is a dummy that equals 1 if the country in which a city resides was classified as high or upper-middle income in 1990. Regressions also include three-way interactions of the treatment, "stable democracy," and "earthquake risk." Baseline effects represent effects with dummies set to 0.

Table A.3: Main Effects (Alternative Standard Errors)

	No lag	3 lags	No lag	3 lags	No lag	3 lags	No lag	3 lags
	(1a)	(1b)	(2a)	(2b)	(3a)	(3b)	(4a)	(4b)
Earthquake$_{t-1}$	-1.484 (.452)***	-.569 (.205)***	-1.484 (.637)**	-.569 (.195)***	-1.484 (.468)***	-.569 (.224)**	-1.484 (.474)***	-.569 (.248)**
Earthquake$_{t-2}$	–	-.599 (.172)***	–	-.599 (.291)**	–	-.599 (.199)***	–	-.599 (.250)**
Earthquake$_{t-3}$	–	-1.007 (.196)***	–	-1.007 (.254)***	–	-1.007 (.316)***	–	-1.007 (.335)***
Earthquake$_{t-4}$	–	-1.492 (.379)***	–	-1.492 (.526)***	–	-1.492 (.438)***	–	-1.492 (.443)***
Cumulative effect	–	-3.667 (.743)***	–	-3.667 (.957)***	–	-3.667 (.678)***	–	-3.667 (.740)***
Earthquake$_{t-1}$ ×Stable dem.	1.096 (.471)**	.113 (.264)	1.096 (.657)*	.113 (.193)	1.096 (.511)**	.113 (.308)	1.096 (.525)**	.113 (.343)
Earthquake$_{t-2}$ ×Stable dem.	–	.172 (.244)	–	.172 (.246)	–	.172 (.289)	–	.172 (.343)
Earthquake$_{t-3}$ ×Stable dem.	–	.564 (.262)**	–	.564 (.260)**	–	.564 (.383)	–	.564 (.411)
Earthquake$_{t-4}$ ×Stable dem.	–	1.324 (.425)***	–	1.324 (.558)**	–	1.324 (.486)***	–	1.324 (.498)***
Cum. interaction ×Stable dem.	–	2.172 (.961)**	–	2.172 (.984)**	–	2.172 (.837)***	–	2.172 (.899)**
Earthquake$_{t-1}$ ×Earthquake risk	1.396 (.459)***	.508 (.221)**	1.396 (.630)**	.508 (.212)**	1.396 (.475)***	.508 (.239)**	1.396 (.481)***	.508 (.263)*
Earthquake$_{t-2}$ ×Earthquake risk	–	.558 (.196)***	–	.558 (.335)*	–	.558 (.215)***	–	.558 (.265)**
Earthquake$_{t-3}$ ×Earthquake risk	–	.994 (.218)***	–	.994 (.278)***	–	.994 (.327)***	–	.994 (.347)***
Earthquake$_{t-4}$ ×Earthquake risk	–	1.528 (.391)***	–	1.528 (.525)***	–	1.528 (.446)***	–	1.528 (.451)***
Cum. interaction ×Earthquake risk	–	3.588 (.818)***	–	3.588 (1.048)***	–	3.588 (.698)***	–	3.588 (.763)***
Adj. R^2	.134	.146	.134	.146	.134	.146	.134	.146
Observations	83565	77994	83565	77994	83565	77994	83565	77994
Clustering by	City	City	Country	Country	–	–	–	–
Conley S.E. cutoff	–	–	–	–	300 km	300 km	1000 km	1000 km

Notes: Standard errors are clustered by city in columns (1), country in columns (2), and otherwise robust to spatial correlation up to the distance specified, according to a uniform spatial weighting kernel, with ***, **, and * denoting significance at the 1%, 5%, and 10% levels, respectively. All specifications include city, year×income level, and year×earthquake risk fixed effects. An earthquake is considered to have hit a city if it struck within 25 km of that city's centroid in the previous year. "Earthquake risk" is a dummy that equals 1 if there is at least a 10% probability of a city experiencing an MMI event greater than V in the next 50 years at any point within 50 km of its centroid. "Stable democracy" is a dummy that equals 1 if the country in which a city resides was consistently a democracy during the sample period. Regressions also include three-ways interaction of the treatment, "stable democracy," and "earthquake risk." Baseline effects represent effects with dummies set to 0.

Table A.4: Main Effects (With Additional Controls)

	No lag	3 lags	No lag	3 lags	No lag	3 lags	No lag	3 lags
	(1a)	(1b)	(2a)	(2b)	(3a)	(3b)	(4a)	(4b)
Earthquake_{t-1}	-1.135 (.368)***	-.529 (.168)***	-1.101 (.396)***	-.440 (.183)**	-1.463 (.466)***	-.564 (.225)**	-1.485 (.491)***	-.525 (.232)**
Earthquake_{t-2}	–	-.592 (.219)***	–	-.514 (.162)***	–	-.623 (.205)***	–	-.584 (.204)***
Earthquake_{t-3}	–	-.881 (.336)***	–	-.860 (.276)***	–	-1.018 (.299)***	–	-1.024 (.316)***
Earthquake_{t-4}	–	-1.042 (.438)***	–	-1.050 (.357)***	–	-1.452 (.414)***	–	-1.473 (.422)***
Cumulative effect	–	-3.044 (.589)***	–	-2.864 (.616)***	–	-3.657 (.657)***	–	-3.606 (.683)***
Earthquake_{t-1} ×Stable democracy	–	–	–	–	1.068 (.512)**	.084 (.307)	1.272 (.539)**	.250 (.324)
Earthquake_{t-2} ×Stable democracy	–	–	–	–	–	.198 (.295)	–	.327 (.300)
Earthquake_{t-3} ×Stable democracy	–	–	–	–	–	.601 (.371)	–	.704 (.389)*
Earthquake_{t-4} ×Stable democracy	–	–	–	–	–	1.309 (.464)***	–	1.388 (.474)***
Cum. interaction ×Stable democracy	–	–	–	–	–	2.191 (.818)***	–	2.668 (.850)***
Earthquake_{t-1} ×Earthquake risk	1.018 (.376)***	.407 (.186)**	1.006 (.399)***	.347 (.193)*	1.344 (.477)***	.460 (.247)*	1.412 (.501)***	.477 (.252)*
Earthquake_{t-2} ×Earthquake risk	–	.521 (.171)***	–	.466 (.175)***	–	.571 (.226)**	–	.578 (.224)***
Earthquake_{t-3} ×Earthquake risk	–	.876 (.271)***	–	.867 (.285)***	–	1.023 (.316)***	–	1.056 (.332)***
Earthquake_{t-4} ×Earthquake risk	–	1.067 (.358)***	–	1.075 (.446)***	–	1.511 (.426)***	–	1.546 (.433)***
Cum. interaction ×Earthquake risk	–	2.871 (.612)***	–	2.755 (.631)***	–	3.564 (.687)***	–	3.657 (.711)***
Adj. R^2	.134	.147	.134	.147	.134	.147	.134	.147
Observations	83700	78120	83700	78120	83565	77994	83565	77994
Ln Richter control	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Ln depth control	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Ln nearest city control	No	No	Yes	Yes	No	No	Yes	Yes

Notes: Standard errors are robust to spatial correlation up to a distance of 300 km, according to a uniform spatial weighting kernel, with ***, **, and * denoting significance at the 1%, 5%, and 10% levels, respectively. All specifications include city, year×income level, and year×earthquake risk fixed effects. All earthquake-city controls are separately interacted with the Earthquake_{t-s} dummy for each lag s, and all controls are mean-normalized. An earthquake is considered to have hit a city if it struck within 25 km of that city's centroid in the previous year. "Earthquake risk" is a dummy that equals 1 if there is at least a 10% probability of a city experiencing an MMI event greater than V in the next 50 years at any point within 50 km of its centroid. "Stable democracy" is a dummy that equals 1 if the country in which a city resides was consistently a democracy during the sample period. Regressions also include three-way interactions of the treatment, "stable democracy," and "earthquake risk" where applicable. Baseline effects represent effects with dummies set to 0.

Table A.5: Main Effects (Alternative Fixed Effects)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Earthquake$_{t-1}$	-.427	-.569	-.421	-.569	-.458	-.574	-.217	-.225
	(.211)*	(.208)***	(.217)***	(.224)**	(.198)**	(.194)***	(.198)	(.198)
Earthquake$_{t-2}$	-.453	-.594	-.444	-.599	-.528	-.635	-.295	-.323
	(.203)**	(.189)***	(.200)**	(.199)***	(.181)***	(.184)***	(.204)	(.204)
Earthquake$_{t-3}$	-.857	-1.013	-.843	-1.007	-.936	-1.123	-.769	-.772
	(.320)***	(.326)***	(.311)***	(.316)***	(.323)***	(.382)***	(.369)**	(.363)**
Earthquake$_{t-4}$	-1.314	-1.493	-1.304	-1.492	-1.462	-1.705	-1.235	-1.268
	(.434)***	(.452)***	(.424)***	(.438)***	(.449)***	(.527)***	(.465)***	(.457)***
Cumulative effect	-3.051	-3.668	-3.012	-3.667	-3.383	-4.037	-2.516	-2.588
	(.664)***	(.681)***	(.658)***	(.678)***	(.667)***	(.760)***	(.746)***	(.734)***
Earthquake$_{t-1}$	.081	.117	.082	.113	.298	.231	-.241	-.034
×Stable democracy	(.309)	(.292)	(.313)	(.308)	(.249)	(.233)	(.398)	(.306)
Earthquake$_{t-2}$	.097	.177	.091	.172	.330	.286	-.205	-.017
×Stable democracy	(.311)	(.276)	(.309)	(.289)	(.242)	(.286)	(.424)	(.341)
Earthquake$_{t-3}$	.434	.603	.404	.564	.695	.776	.130	.297
×Stable democracy	(.416)	(.387)	(.412)	(.383)	(.364)*	(.399)*	(.560)	(.473)
Earthquake$_{t-4}$	1.056	1.335	1.042	1.324	1.246	1.500	.850	.897
×Stable democracy	(.511)**	(.503)***	(.502)**	(.486)***	(.476)***	(.547)***	(.619)	(.541)*
Cum. interaction	1.668	2.231	1.619	2.172	2.569	2.793	.533	1.143
×Stable democracy	(.880)*	(.832)***	(.877)*	(.837)***	(.760)***	(.825)***	(1.159)	(.952)
Earthquake$_{t-1}$	.362	.516	.348	.508	.377	.504	.133	.127
×Earthquake risk	(.226)	(.225)**	(.232)	(.239)**	(.215)*	(.212)**	(.215)	(.211)
Earthquake$_{t-2}$	.410	.562	.393	.558	.467	.584	.236	.248
×Earthquake risk	(.217)*	(.206)***	(.214)*	(.215)***	(.197)**	(.201)***	(.220)	(.219)
Earthquake$_{t-3}$	.842	1.010	.820	.994	.905	1.104	.743	.729
×Earthquake risk	(.330)**	(.336)***	(.322)**	(.327)***	(.333)***	(.391)***	(.379)**	(.373)*
Earthquake$_{t-4}$	1.352	1.544	1.328	1.528	1.488	1.743	1.252	1.270
×Earthquake risk	(.442)***	(.460)***	(.432)***	(.446)***	(.457)***	(.534)***	(.473)***	(.465)***
Cum. interaction	2.966	3.631	2.890	3.588	3.236	3.935	2.365	2.374
×Earthquake risk	(.683)***	(.702)***	(.677)***	(698)***	(.687)***	(.779)***	(.766)***	(.755)***
Adj. R^2	.122	.144	.123	.146	.140	.157	.164	.179
Observations	77994	77994	77994	77994	77994	77994	77994	77994
City fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year×income FE	No	Yes	No	Yes	No	Yes	No	No
Year×risk area FE	No	No	Yes	Yes	No	No	No	No
Year×institutions FE	No	No	No	No	Yes	Yes	No	Yes
Year×region FE	No	No	No	No	No	No	Yes	Yes

Notes: Standard errors are robust to spatial correlation up to a distance of 300 km, according to a uniform spatial weighting kernel, with ***, **, and * denoting significance at the 1%, 5%, and 10% levels, respectively. All specifications include city and year fixed effects, the latter with various interactions. An earthquake is considered to have hit a city if it struck within 25 km of that city's centroid in the previous year. "Earthquake risk" is a dummy that equals 1 if there is at least a 10% probability of a city experiencing an MMI event greater than V in the next 50 years at any point within 50 km of its centroid. "Stable democracy" is a dummy that equals 1 if the country in which a city resides was consistently a democracy during the sample period. Regions used are Africa, Asia, Oceania, Europe, and the Americas. Regressions also include three-way interactions of the treatment, "stable democracy," and "earthquake risk." Baseline effects represent effects with dummies set to 0.

Table A.6: Main Effects (Alternative Institutions Measures)

	No lag	3 lags	No lag	3 lags	No lag	3 lags	No lag	3 lags
	(1a)	(1b)	(2a)	(2b)	(3a)	(3b)	(4a)	(4b)
Earthquake$_{t-1}$	-.1.527 (.494)***	-.569 (.245)**	-1.486 (.469)***	-.571 (.223)**	-1.380 (.488)***	-.470 (.230)**	-1.348 (.462)***	-.480 (.212)**
Earthquake$_{t-2}$	–	-.605 (.219)***	–	-.602 (.299)***	–	-.553 (.200)***	–	-.553 (.185)***
Earthquake$_{t-3}$	–	-1.051 (.336)***	–	-1.010 (.317)***	–	-.975 (.332)***	–	-.943 (.313)***
Earthquake$_{t-4}$	–	-1.486 (.438)***	–	-1.495 (.438)***	–	-1.251 (.435)***	–	-1.254 (.436)***
Cumulative effect	–	-3.711 (.700)***	–	-3.677 (.678)***	–	-3.249 (.699)***	–	-3.230 (.679)***
Earthquake$_{t-1}$ ×Institutions	1.075 (.530)**	.096 (.310)	1.097 (.512)**	.110 (.308)	.762 (.536)	-.143 (.307)	.777 (.524)	-.143 (.312)
Earthquake$_{t-2}$ ×Institutions	–	.160 (.290)	–	.170 (.290)	–	.021 (.281)	–	.022 (.290)
Earthquake$_{t-3}$ ×Institutions	–	.593 (.388)	–	.562 (.384)	–	.427 (.391)	–	.391 (.392)
Earthquake$_{t-4}$ ×Institutions	–	1.316 (.486)***	–	1.324 (.488)***	–	.853 (.504)*	–	.857 (.505)*
Cum. interaction ×Institutions	–	2.164 (.838)***	–	2.165 (.838)***	–	1.158 (.871)	–	1.128 (.877)
Earthquake$_{t-1}$ ×Earthquake risk	1.441 (.500)***	.509 (.259)**	1.396 (.476)***	.506 (.239)**	1.295 (.495)***	.404 (.245)*	1.272 (.469)***	.421 (.228)*
Earthquake$_{t-2}$ ×Earthquake risk	–	.566 (.233)**	–	.559 (.215)***	–	.535 (.215)**	–	.542 (.201)***
Earthquake$_{t-3}$ ×Earthquake risk	–	1.041 (.346)***	–	.997 (.327)***	–	.986 (.342)***	–	.956 (.324)***
Earthquake$_{t-4}$ ×Earthquake risk	–	1.517 (.446)***	–	1.532 (.446)***	–	1.293 (.443)***	–	1.303 (.444)***
Cum. interaction ×Earthquake risk	–	3.634 (.720)***	–	3.594 (.699)***	–	3.219 (.720)***	–	3.221 (.700)**
Adj. R^2	.134	.146	.134	.146	.134	.146	.134	.146
Observations	83565	77994	83565	77994	83700	78120	83700	78120
Democracy if Polity>0	Yes	Yes	No	No	No	No	No	No
Democracy if Polity≥ 6	No	No	Yes	Yes	No	No	No	No
State change allowed?	No	No	Yes	Yes	No	No	No	No
Polity IV?	Yes	Yes	Yes	Yes	No	No	No	No
WGI rule of law?	No	No	No	No	Yes	Yes	No	No
WGI control of corrupt?	No	No	No	No	No	No	Yes	Yes

Notes: Standard errors are robust to spatial correlation up to a distance of 300 km, according to a uniform spatial weighting kernel, with ***, **, and * denoting significance at the 1%, 5%, and 10% levels, respectively. All specifications include city, year×income level, and year×earthquake risk fixed effects. An earthquake is considered to have hit a city if it struck within 25 km of that city's centroid in the previous year. "Earthquake risk" is a dummy that equals 1 if there is at least a 10% probability of a city experiencing an MMI event greater than V in the next 50 years at any point within 50 km of its centroid. Columns (1) use a "stable democracy" institutions measure, in which a city is given a 1 if its country had a positive Polity score for the entire sample. Columns (2) use a time-varying "stable democracy" institutions measure, in which a city's institution assignment from Polity can change if its state changes (e.g. Prague "left" Czechoslovak institutions and "joined" Czech ones). Columns (3) use a "stable strong rule of law" institutions measure, in which a city is given a 1 if its country had a positive standardized WGI rule of law score for the 1996-2017 period. Columns (4) use a "stable high control of corruption" institutions measure, in which a city is given a 1 if its country had a positive standardized WGI control of corruption score for 1996-2017. Regressions also include three-way interactions of the treatment, institutions, and "earthquake risk."

Table A.7.1: Short-run Effects (Various Sample Splits)

	All	Stable democracy		Not stable democracy		Unstable polity	
		Yes	No	Stable non-democracy	Unstable polity	Dem-ocracy$_{t-1}$	Not dem-ocracy$_{t-1}$
	(1)	(2a)	(2b)	(3a)	(3b)	(4a)	(4b)
Earthquake$_{t-1}$	-1.147	-.135	-1.798	-.571	-2.127	.814	-1.541
	(.370)***	(.164)	(.585)***	(.361)	(.722)***	(.241)***	(.551)***
Earthquake$_{t-1}$×Risk	1.060	.082	1.696	.901	1.984	-.901	1.330
	(.377)***	(.213)	(.590)***	(.460)**	(.726)***	(.252)***	(.566)**
Adj. R^2	.134	.054	.180	.293	.156	.228	.099
Observations	83700	24345	59220	24435	34785	14162	20566

Notes: Standard errors are robust to spatial correlation up to a distance of 300 km, according to a uniform spatial weighting kernel, with ***, **, and * denoting significance at the 1%, 5%, and 10% levels, respectively. All specifications include city, year×income level, and year×earthquake risk fixed effects. An earthquake is considered to have hit a city if it struck within 25 km of that city's centroid in the previous year. "Earthquake risk" is a dummy that equals 1 if there is at least a 10% probability of a city experiencing an MMI event greater than V in the next 50 years at any point within 50 km of its centroid. "Stable democracy" is a dummy that equals 1 if the country in which a city resides was consistently a democracy during the sample period. Further institutional splits defined below.

Table A.7.2: Dynamic Effects (Various Sample Splits)

	All	Stable democracy		Not stable democracy	
		Yes	No	Stable nondemocracy	Unstable polity
	(1)	(2a)	(2b)	(3a)	(3b)
Earthquake$_{t-1}$	-.521	-.089	-.652	-.609	-.427
	(.168)***	(.156)	(.234)***	(.363)*	(.209)**
Earthquake$_{t-2}$	-.579	-.127	-.754	-1.105	-.311
	(.149)**	(.167)	(.232)***	(.429)***	(.263)
Earthquake$_{t-3}$	-.885	-.192	-1.287	-1.112	-1.253
	(.267)***	(.173)	(.417)***	(.426)***	(.649)*
Earthquake$_{t-4}$	-1.075	-.180	-1.931	-1.174	-2.153
	(.364)**	(.164)	(.570)***	(.387)***	(.859)**
Cumulative effect	-3.060	-.588	-4.623	-4.001	-4.144
	(.606)***	(.367)	(.835)***	(1.080)***	(1.050)***
Earthquake$_{t-1}$×Earthquake risk	.434	-.022	.576	.934	.308
	(.183)**	(.056)	(.249)**	(.474)**	(.223)
Earthquake$_{t-2}$×Earthquake risk	.519	.051	.699	1.676	.189
	(.164)**	(.058)	(.245)***	(.539)***	(.272)
Earthquake$_{t-3}$×Earthquake risk	.864	.189	1.262	1.801	1.146
	(.277)***	(.117)	(.425)***	(.579)***	(.653)*
Earthquake$_{t-4}$×Earthquake risk	1.084	.155	1.959	1.834	2.092
	(.371)**	(.116)	(.576)***	(.554)***	(.862)**
Cum. interaction×Earthquake risk	2.900	.374	4.496	6.245	3.735
	(.624)***	(.459)	(.852)***	(1.282)***	(1.059)***
Adj. R^2	.146	.073	.187	.303	.160
Observations	78120	22722	55272	22806	32466

Notes: Standard errors are robust to spatial correlation up to a distance of 300 km, according to a uniform spatial weighting kernel, with ***, **, and * denoting significance at the 1%, 5%, and 10% levels, respectively. All specifications include city, year×income level, and year×earthquake risk fixed effects. An earthquake is considered to have hit a city if it struck within 25 km of that city's centroid in the previous year. "Earthquake risk" is a dummy that equals 1 if there is at least a 10% probability of a city experiencing an MMI event greater than V in the next 50 years at any point within 50 km of its centroid. "Stable democracy" is a dummy that equals 1 if the country in which a city resides was consistently a democracy during the sample period. Further institutional splits defined below.

Table A.8.1: Short-run Effects (Alternative Risk Measures)

	(1a)	(1b)	(1c)	(2a)	(2b)	(2c)
Earthquake_{t-1}	-1.353	-.925	-1.038	-1.484	-1.103	-1.103
	(.435)***	(.361)***	(.422)**	(.468)***	(.456)**	(.456)**
Earthquake_{t-1}×Stable democracy	–	–	–	1.084	.716	.703
				(.645)*	(.499)	(.636)
Earthquake_{t-1}×Earthquake risk	1.264	.837	.947	1.386	1.014	1.014
	(.441)***	(.367)**	(.309)**	(.475)***	(.461)**	(.461)**
Adj. R^2	.134	.134	.134	.134	.134	.134
Observations	83700	83700	83700	83565	83565	83565
Naha in risk area	Yes	No	Yes	Yes	No	Yes
Risk area bandwidth	50 km	10 km	10 km	50 km	10 km	10 km

Notes: Standard errors are robust to spatial correlation up to a distance of 300 km, according to a uniform spatial weighting kernel, with ***, **, and * denoting significance at the 1%, 5%, and 10% levels, respectively. All specifications include city, year×income level, and year×earthquake risk fixed effects. An earthquake is considered to have hit a city if it struck within 25 km of that city's centroid in the previous year. "Earthquake risk" is a dummy that equals 1 if there is at least a 10% probability of a city experiencing an MMI event greater than V in the next 50 years at any point within 10 or 50 km of its centroid, depending on the bandwidth chosen. In all columns (a) and (c), the city of Naha, Japan is reassigned to be in an earthquake risk area, despite not being derived as such. "Stable democracy" is a dummy that equals 1 if the country in which a city resides was consistently a democracy during the sample period. Regressions in columns (2) also include a three-way interaction of the treatment, "stable democracy," and "earthquake risk." Baseline effects represent effects with dummies set to 0.

Table A.8.2: Dynamic Effects (Alternative Risk Measures)

	(1a)	(1b)	(1c)	(2a)	(2b)	(2c)
Earthquake$_{t-1}$	-.535 (.202)***	-.408 (.239)*	-.394 (.293)	-.569 (.224)**	-.400 (.326)	-.400 (.326)
Earthquake$_{t-2}$	-.554 (.184)***	-.404 (.244)*	-.357 (.304)	-.599 (.199)***	-.359 (.342)	-.359 (.342)
Earthquake$_{t-3}$	-.944 (.313)***	-.680 (.302)**	-.698 (.357)*	-1.007 (.316)***	-.726 (.383)*	-.726 (.383)*
Earthquake$_{t-4}$	-1.255 (.436)***	-.841 (.358)**	-.935 (.422)**	-1.492 (.438)***	-1.074 (.445)**	-1.074 (.445)**
Cumulative effect	-3.287 (.672)***	-2.334 (.672)***	-2.385 (.767)***	-3.667 (.678)***	-2.559 (.824)***	-2.559 (.824)***
Earthquake$_{t-1}$×Stable democracy	–	–	–	.230 (.499)	-.056 (.388)	.061 (.552)
Earthquake$_{t-2}$×Stable democracy	–	–	–	.271 (.489)	-.068 (.401)	.032 (.562)
Earthquake$_{t-3}$×Stable democracy	–	–	–	.674 (.548)	.282 (.440)	.392 (.589)
Earthquake$_{t-4}$×Stable democracy	–	–	–	1.817 (.465)***	.906 (.493)*	1.400 (.472)***
Cum. interaction×Stable democracy	–	–	–	2.993 (1.124)***	1.065 (.960)	1.884 (1.218)
Earthquake$_{t-1}$×Earthquake risk	.445 (.214)**	.321 (.246)	.304 (.297)	.508 (.239)**	.338 (.332)	.338 (.332)
Earthquake$_{t-2}$×Earthquake risk	.491 (.197)**	.343 (.250)	.293 (.308)	.558 (.215)***	.317 (.346)	.317 (.346)
Earthquake$_{t-3}$×Earthquake risk	.919 (.321)***	.657 (.309)**	.673 (.363)*	.994 (.327)***	.711 (.390)*	.711 (.390)*
Earthquake$_{t-4}$×Earthquake risk	1.261 (.441)***	.850 (.364)**	.940 (.427)**	1.528 (.446)***	1.110 (.452)**	1.110 (.452)**
Cum. interaction×Earthquake risk	3.117 (.689)***	2.171 (.687)***	2.211 (.780)***	3.588 (.698)***	2.476 (.840)***	2.476 (.840)***
Adj. R^2	.146	.146	.146	.146	.146	.146
Observations	78120	78120	78120	77994	77994	77994
Naha in risk area	Yes	No	Yes	Yes	No	Yes
Risk area bandwidth	50 km	10 km	10 km	50 km	10 km	10 km

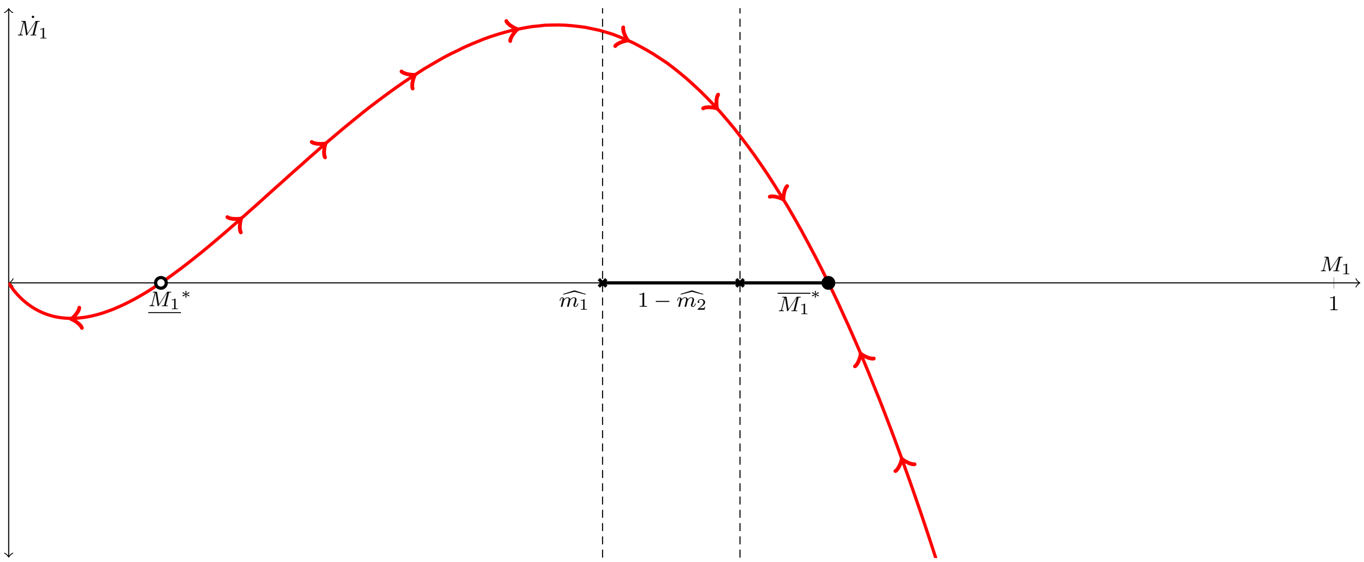
Notes: Standard errors are robust to spatial correlation up to a distance of 300 km, according to a uniform spatial weighting kernel, with ***, **, and * denoting significance at the 1%, 5%, and 10% levels, respectively. All specifications include city, year×income level, and year×earthquake risk fixed effects. An earthquake is considered to have hit a city if it struck within 25 km of that city's centroid in the previous year. "Earthquake risk" is a dummy that equals 1 if there is at least a 10% probability of a city experiencing an MMI event greater than V in the next 50 years at any point within 10 or 50 km of its centroid, depending on the bandwidth chosen. In all columns (a) and (c), the city of Naha, Japan is reassigned to be in an earthquake risk area, despite not being derived as such. "Stable democracy" is a dummy that equals 1 if the country in which a city resides was consistently a democracy during the sample period. Regressions in column (2) also include three-way interactions of the treatment, "stable democracy," and "earthquake risk." Baseline effects represent effects with dummies set to 0.

Table A.9: Agglomeration Economies

	(1a)	(1b)	(2a)	(2b)	(2c)	(2d)
Earthquake$_{t-1}$	-.497	-.270	-.519	-.519	-.524	-.524
	(.269)*	(.308)	(.239)**	(.239)**	(.218)**	(.218)**
Earthquake$_{t-2}$	-.698	-.485	-.525	-.526	-.527	-.527
	(.180)***	(.223)**	(.221)**	(.221)**	(.202)***	(.202)***
Earthquake$_{t-3}$	-1.169	-1.030	-.490	-.491	-.495	-.495
	(.314)***	(.338)***	(.220)**	(.220)**	(.202)**	(.202)**
Earthquake$_{t-4}$	-1.654	-1.516	-.363	-.364	-.364	-.364
	(.484)***	(.511)***	(.223)	(.224)	(.223)	(.223)
Cumulative effect	-4.018	-3.302	-1.898	-1.899	-1.910	-1.911
	(.707)***	(.760)***	(.585)***	(.585)***	(.550)***	(.550)***
Earthquake$_{t-1}$ ×Incentives to agglomerate	-.022	-.249	.022	.250	.030	.253
	(.360)	(.389)	(.360)	(.396)	(.375)	(.422)
Earthquake$_{t-2}$ ×Incentives to agglomerate	.173	-.041	-.173	.065	-.205	.032
	(.286)	(.314)	(.286)	(.319)	(.284)	(.333)
Earthquake$_{t-3}$ ×Incentives to agglomerate	.679	.540	-.679	-.486	-.752	-.562
	(.384)*	(.403)	(.384)*	(.405)	(.385)*	(.423)
Earthquake$_{t-4}$ ×Incentives to agglomerate	1.290	1.153	-1.290	-1.089	-1.283	-1.120
	(.533)**	(.558)**	(.533)**	(.561)*	(.533)**	(.562)**
Cum. interaction ×Incentives to agglomerate	2.121	1.403	-2.121	-1.259	-2.210	-1.397
	(.918)**	(.957)	(.918)**	(.962)	(.910)**	(.975)
Earthquake$_{t-1}$ ×Earthquake risk	.410	.309	.438	.443	.489	.494
	(.285)	(.306)	(.264)*	(.264)*	(.242)**	(.242)**
Earthquake$_{t-2}$ ×Earthquake risk	.610	.520	.482	.488	.532	.536
	(.201)***	(.220)**	(.250)*	(.250)*	(.229)**	(.230)**
Earthquake$_{t-3}$ ×Earthquake risk	1.105	1.041	.473	.477	.505	.509
	(.327)***	(.337)***	(.253)*	(.255)*	(.233)**	(.233)**
Earthquake$_{t-4}$ ×Earthquake risk	1.631	1.558	.355	.359	.395	.398
	(.493)***	(.509)***	(.255)	(.255)	(.251)	(.251)
Cum. interaction ×Earthquake risk	3.756	3.427	1.748	1.768	1.921	1.937
	(.731)***	(.757)***	(.634)***	(634)***	(.595)***	(.595)***
Adj. R^2	.146	.146	.146	.146	.146	.146
Observations	78120	78120	78120	78120	78120	78120
Measure=agricultural country	Yes	Yes	No	No	No	No
Measure=urban country	No	No	Yes	Yes	Yes	Yes
Midpoint or mean?	–	–	Mean	Mean	Midpoint	Midpoint
Income level interaction?	No	Yes	No	Yes	No	Yes

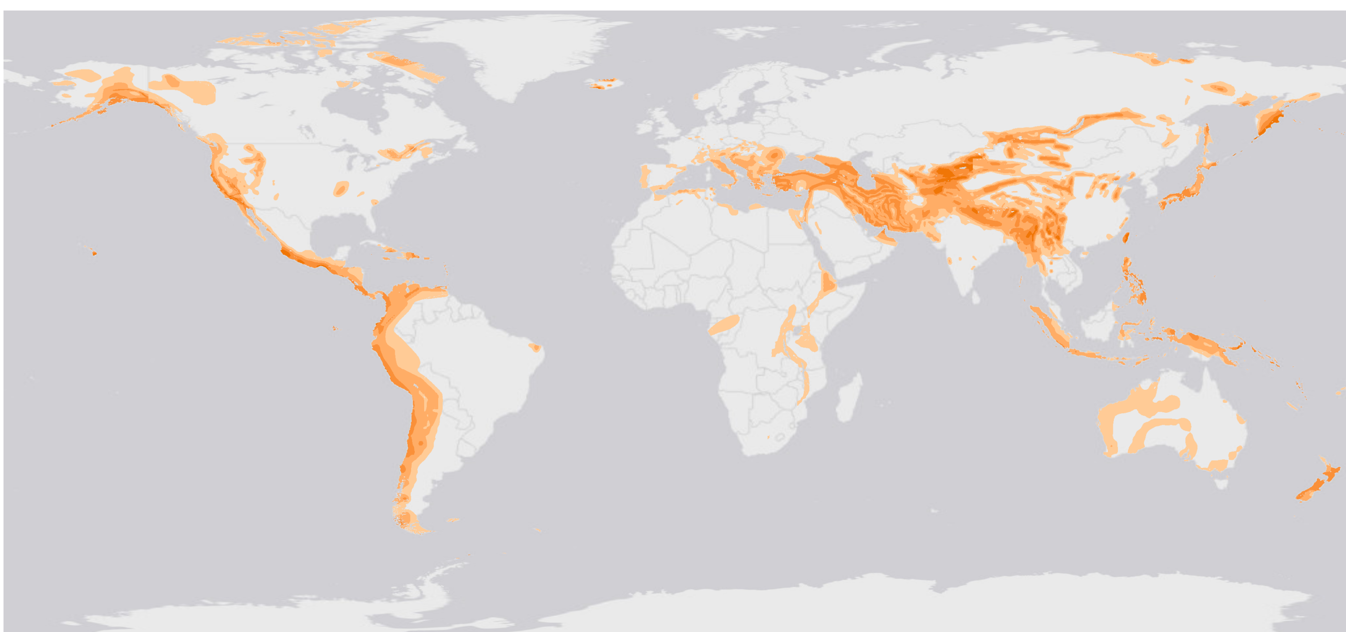
Notes: Standard errors are robust to spatial correlation up to a distance of 300 km, according to a uniform spatial weighting kernel, with ***, **, and * denoting significance at the 1%, 5%, and 10% levels, respectively. All specifications include city, year×income level, and year×earthquake risk fixed effects. An earthquake is considered to have hit a city if it struck within 25 km of that city's centroid in the previous year. "Earthquake risk" is a dummy that equals 1 if there is at least a 10% probability of a city experiencing an MMI event greater than V in the next 50 years at any point within 50 km of its centroid. "Agricultural country" is a dummy that equals 1 if the country in which a city resides was above-sample average agricultural (as % of employment) in 1991. "Urban country" is a dummy that equals 1 if the country in which a city resides was above-sample average in the percentage of its population living in urban areas, either in 1990 ("midpoint") or using the 1973-2017 mean ("mean"). "Income level" is a dummy that equals 1 if the country in which a city resides was classified as high or upper-middle income in 1990. Regressions also include three-way interactions of the treatment, the agglomeration measure, and "earthquake risk." Baseline effects represent effects with dummies set to 0.

Figure A.1: Asymmetric Long-run Equilibria, $\gamma > 1$



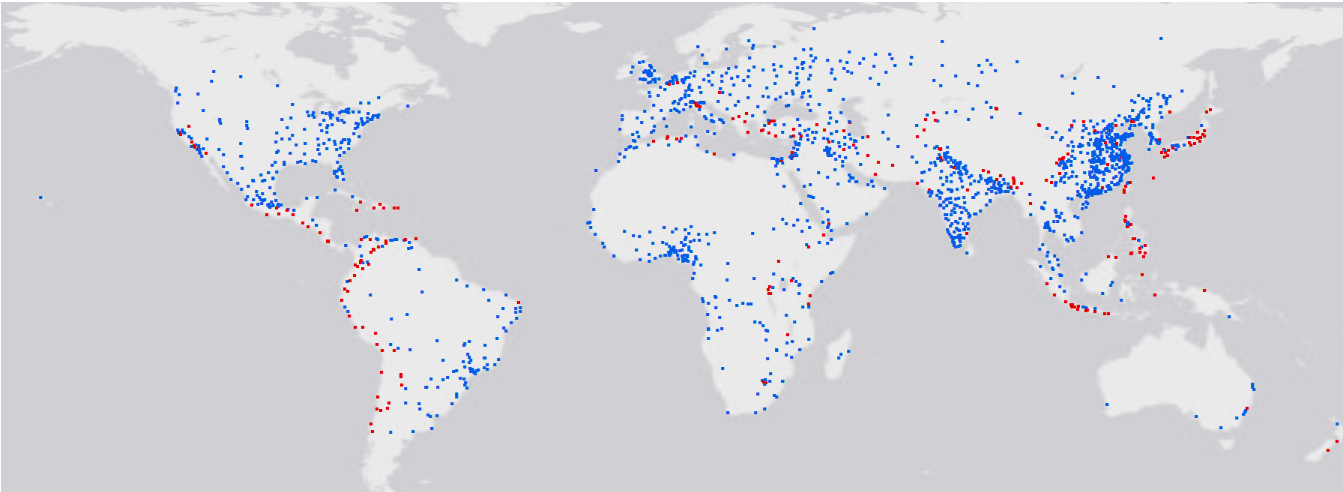
Notes: Asymmetric long-run equilibria for $\gamma = 3/2$, $\beta = 10/3$, $a_1 = a_2 = K = h = \lambda = 1$. See the corresponding Theory Discussion 2 below.

Figure A.2: Earthquake Risk Heatmap

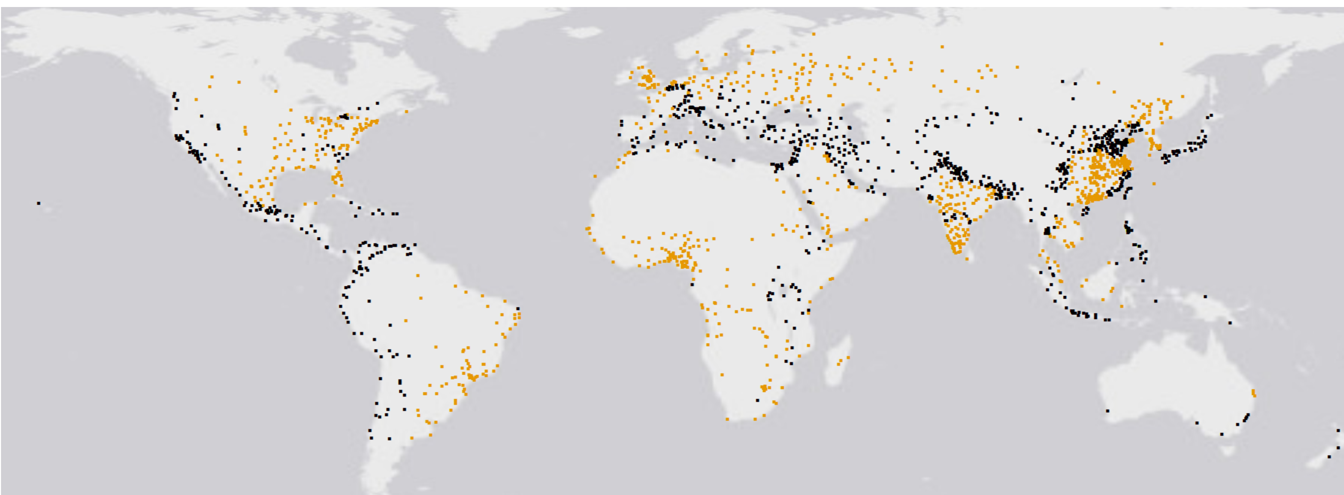


Notes: Earthquake risk heatmap, with darker orange corresponding to higher Modified Mercalli intensity scores with at least a 10% probability of being exceeded within the next 50 years. The four levels are >V, >VII, >VIII, and >IX. Recreated using raster data available at https://preview.grid.unep.ch.

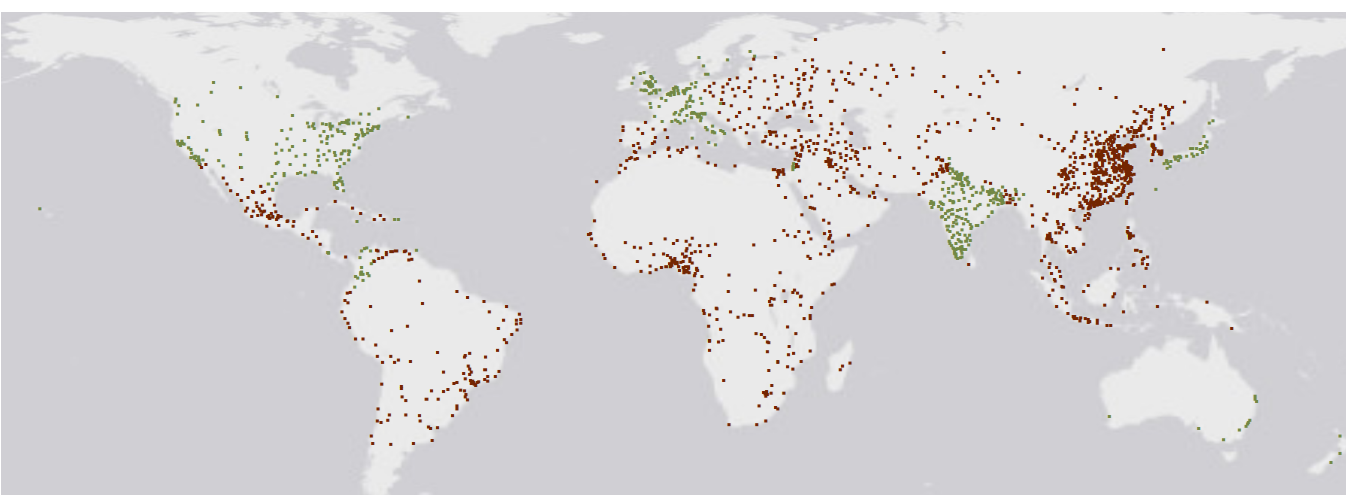
Figure A.3: Sample Cities by Subgroup



(a) Cities by exposure to major earthquake, 1973-2017 (0 = blue, 1 = red)



(b) Cities by earthquake risk (low = orange, high = black)



(c) Cities by stable democracy, 1973-2017 (0 = brown, 1 = green)

Notes: Maps show all 1860 cities in the sample as broken down by (i) exposure to a major earthquake between 1973 and 2017, (ii) earthquake risk, and (iii) stable democracy.

Variable descriptions

- **% City population growth**: the percentage change in a city's population from the previous year to the current year, based on mid-year counts. Calculated using data from 1973 to 2018 on the populations of the 1860 world urban agglomerations with at least 300,000 residents as of 2018, from the World Urbanization Prospects, as compiled by the UN's DESA/Population Division (2018).
- **Earthquake$_{t-1}$**: a city-year-level dummy variable, assigned a value of 1 if a major earthquake struck within 25 km of a city's centroid the previous year. Derived in ArcGIS using data on all 5+ Richter magnitude earthquakes that occurred from 1973 to 2017, including their coordinates, as made available by the U.S. Geological Survey (2018), in conjunction with city coordinate data from the UN DESA/Population Division World Urbanization Prospects (2018) database of world urban agglomerations. Projections used are equidistant cylindrical.
- **Earthquake risk area**: a city-level dummy variable, assigned a value of 1 if a city has at least a 10% probability of experiencing an earthquake event with a Modified Mercalli intensity greater than V (i.e. moderate strength) during the next 50 years at any point within 50 km of its centroid. Derived in ArcGIS using raster data on earthquake risk from UNEP/GRID-Geneva (2015), in conjunction with city coordinate data from the UN DESA/Population Division World Urbanization Prospects (2018) database. Raster data is transformed into an equidistant cylindrical polygon shapefile in ArcGIS.
- **Stable democracy**: a city-level dummy variable, assigned a value of 1 if the country in which a city resides has consistently had a score on Polity IV's (2019) POLITY index of 6 or greater for the entire 1973 to 2017 sample period. This factors in a city's entire institutional history under the sample period. Under this measure, for example, former West German cities are considered to be in stable democracies, while former East German cities are not. A second version allows for some time-variation if the state in which that city resided changed. Under this second measure, for example, former West German cities are considered to have been in a stable democracy for the entire sample, while East German cities (including the whole of Berlin, which is considered not to be stable democratic in the time-invariant version) are considered to not have been in a stable democracy prior to German reunification but *are* considered to have been in a stable democracy ever since. A third version is time-invariant but changes the POLITY cutoff to above zero.
- **Stable nondemocracy**: a city-level dummy variable, assigned a value of 1 if a city's country consistently had a POLITY score of less than 6 for the entire 1973 to 2017 sample period.
- **Unstable polity**: a city-level dummy variable, assigned a value of 1 if a city's country neither consistently had a POLITY score of 6 or greater for the entire 1973 to 2017 sample period nor a score of less than 6. It also includes "special polities" such as those under transition, interregnum, and foreign interruption, several former colonial countries that lack POLITY scores for some years (Angola, Djibouti, Guinea-Bissau, Mozambique, and Papua New Guinea) and the city of Berlin.
- **Democracy$_{t-1}$**: a city-year-level dummy variable, assigned a value of 1 if a city's country had a POLITY score of 6 or greater the previous year.
- **Stable strong rule of law**: a city-level dummy variable, assigned a value of 1 if the country in which a city resides has consistently had a positive standardized rule of law score in the World Governance Indicators (2020) index for their entire period from 1996 through 2017.
- **Stable high control of corruption**: a city-level dummy variable, assigned a value of 1 if the country in which a city resides has consistently had a positive standardized control of corruption score in the World Governance Indicators (2020) index for their entire period from 1996 through 2017.
- **Income level**: a country-level indicator of national income level, as determined by the World Bank and presented in their World Development Indicators (2019). Countries with gross national income (GNI) per capita in US dollars below $2465 in 1990 are considered low or lower-middle income, with the remainder of countries being upper-middle or high income. I refer to these groups simply as low and high income, respectively. As Palestine is not assigned a level until 1994 but is consistently considered lower-middle thereafter, I dummy it as such here.
- **Nearest city** (km): a world urban agglomeration's distance from the nearest world urban agglomeration, as derived in ArcGIS using coordinates provided by the UN DESA/Population Division World Urbanization Prospects (2018) database. Projection used is equidistant cylindrical. Control is logged and mean-normalized in all regressions used.

- **Richter magnitude**: an earthquake-city-level control interacted with the treatment dummy, also derived from the U.S. Geological Survey (2018) earthquake database. Control is logged and mean-normalized in all regressions used.
- **Earthquake depth** (km): an earthquake-city-level control interacted with the treatment dummy, also derived from the U.S. Geological Survey (2018) earthquake database. Control is logged and mean-normalized in all regressions used.
- **Urban country**: a country-level indicator for above-average urban, i.e. a binary function of the percentage of a city's country's population (at mid-year) residing in an urban agglomeration, as reported in the World Urbanization Prospects by the UN's DESA/Population Division (2018). Countries above the sample mean are given a value of 1 and all others a value of 0. I construct two measures: a "mid-sample" one which uses 1990 values, and one which uses the mean of all values from 1973 to 2017.
- **Agricultural country**: a country-level indicator for above-average agricultural, i.e. a binary function of a city's country's employment in agriculture (% of total employment, modeled ILO estimate) in 1991 (1990 not available), as reported in the World Bank's World Development Indicators (2020). Countries above the sample mean are given a value of 1 and all others a value of 0. As the World Bank considers Taiwan part of China, I assign Taiwan China's value.
- **City**: a city is considered a world urban agglomeration by the UN DESA/Population Division and is thus included in the sample if it had at least 300,000 residents as of 2018, for a total of 1860 cities.
- **Country**: the sample consists of 153 unique countries and territories. See below for a list.
- **Region**: the sample consists of five "regions": Africa, Asia, Oceania, Europe, and the Americas.
- **Year**: the sample consists of 44 years of earthquakes (1973-2017) as well as a 45th year (2018) of population measures.

Countries and territories

Afghanistan; Albania; Algeria; *Angola*; Argentina; Armenia; Australia; Austria; Azerbaijan; Bahrain; Bangladesh; Belarus; Belgium; Benin; Bolivia; Bosnia and Herzegovina; Brazil; Bulgaria; Burkina Faso; Burundi; Cambodia; Cameroon; Canada; Central African Republic; Chad; Chile; China; Colombia; Costa Rica; Croatia; Cuba; Czech Republic; Democratic Republic of the Congo; Denmark; *Djibouti*; Dominican Republic; Ecuador; Egypt; El Salvador; Equatorial Guinea; Eritrea; Estonia; Ethiopia; Finland; France; Gabon; Gambia; Georgia; *Germany*; Ghana; Greece; Guatemala; Guinea; *Guinea-Bissau*; Haiti; Honduras; **Hong Kong**; Hungary; India; Indonesia; Iran; Iraq; Ireland; Israel; Italy; Ivory Coast; Jamaica; Japan; Jordan; Kazakhstan; Kenya; Kuwait; Kyrgyzstan; Laos; Latvia; Lebanon; Liberia; Libya; Lithuania; **Macau**; Madagascar; Malawi; Malaysia; Mali; Mauritania; Mexico; Moldova; Mongolia; Morocco; *Mozambique*; Myanmar; Namibia; Nepal; Netherlands; New Zealand; Nicaragua; Niger; Nigeria; North Korea; North Macedonia; Norway; Oman; Pakistan; **Palestine**; Panama; *Papua New Guinea*; Paraguay; Peru; Philippines; Poland; Portugal; Qatar; Republic of Congo; Romania; Russia; Rwanda; Saudi Arabia; Senegal; Serbia; Sierra Leone; Singapore; Slovakia; Somalia; South Africa; South Korea; South Sudan; Spain; Sri Lanka; Sudan; Sweden; Switzerland; Syria; Taiwan; Tajikistan; Tanzania; Thailand; Togo; Trinidad and Tobago; Tunisia; Turkey; Turkmenistan; Uganda; Ukraine; United Arab Emirates; United Kingdom; United States (including Puerto Rico); Uruguay; Uzbekistan; Venezuela; Vietnam; Yemen; Zambia; Zimbabwe

*Countries or territories in which all years lack POLITY scores in **bold**.
**Countries or territories in which some years lack POLITY scores in *italics*.

Theory discussion 1: Endogenous β

Let $\beta(m_r, m_{-r})$ be a function such that $\beta'(\cdot) > 0$, i.e. a country's formal institutions are weakened as the relative prevalence of workers engaged in unproductive activities (e.g. corruption, property exploitation) increases.

An agent in region r prefers to engage in productive activities over unproductive ones if and only if

$$a_r \frac{K}{\lambda M_r} h^{1+\gamma} m_r^{\gamma} \geq \frac{K}{\beta(m_r, m_{-r}) M_r}.$$

Suppose

$$a_r \frac{K}{\lambda M_r} h^{1+\gamma} m_r^{\gamma} = \frac{K}{\beta(m_r, m_{-r}) M_r}.$$

Holding the total share of the population in each region, M_r, fixed, any arbitrarily small positive perturbation to m_r will in turn induce

$$a_r \frac{K}{\lambda M_r} h^{1+\gamma} m_r^{\gamma} > \frac{K}{\beta(m_r, m_{-r}) M_r},$$

such that the remainder of workers in region r also shift to production, until the total share of workers in r are all engaged in production and $m_r = M_r$. This is because the marginal benefit from engaging in productive activities is increasing in m_r:

$$\partial[a_r \frac{K}{\lambda M_r} h^{1+\gamma} m_r^{\gamma} - \frac{K}{\beta(m_r, m_{-r}) M_r}]/\partial m_r = \gamma(a_r \frac{K}{\lambda M_r} h^{1+\gamma} m_r^{\gamma-1}) + \frac{\beta'(\cdot) K}{\beta(\cdot)^2 M_r} > 0.$$

Note that this is rate of increase exceeds that from the basic model, in which the marginal benefit from engaging in productive activities increases at a rate of

$$\partial[a_r \frac{K}{\lambda M_r} h^{1+\gamma} m_r^{\gamma} - \frac{K}{\beta M_r}]/\partial m_r = \gamma(a_r \frac{K}{\lambda M_r} h^{1+\gamma} m_r^{\gamma-1}) > 0.$$

Hence, complicating the model so β is endogenous to local economic activity magnifies strategic complementaries in local worker behavior.

Theory discussion 2: Equilibria when $\gamma > 1$

Case 1: Symmetric high production long-run equilibria [HPLE]

Let $\gamma > 1$. Suppose $M_r > \widehat{m_r}$ and $m_r^* = M_r$ in all regions r, such that each is in a high production short-run equilibrium [HPSE]. Then by Proposition 3, there exists a steady state population share as part of a symmetric high production long-run equilibrium [HPLE] in which $\dot{M}_r = 0$. However, also by Proposition 3, it is always unstable in M_r, which brings me to case two.

Case 2: Asymmetric long-run equilibria [ALE]

Proposition A.1. *When agglomeration spillovers are sufficiently strong, specifically $\gamma > 1$, then:*

(i) There are at most two interior ALE, with productive region steady state population shares of $\underline{M_r}^*$ and $\overline{M_r}^* > \underline{M_r}^*$.

(ii) Only the more populated productive region steady state, $\overline{M_r}^*$, can be locally stable.

Proof. (i) Now suppose there is a sufficiently large negative population shock in one region, say $r = 2$ (without loss of generality), such that region 1 specializes in production while region 2 specializes in unproductive activities: $M_1 > \widehat{m_1}$, $m_1^* = M_r$, and $m_2^* = 0$. Then

$$\dot{M}_1 = M_1(1 - M_1)(V_1(h) - V_2(u)) = M_1(1 - M_1)\left(a_1 \frac{K}{\lambda} h^{1+\gamma} M_1^{\gamma-1} - \frac{K}{\beta(1 - M_1)}\right). \tag{1}$$

When if ever does $\dot{M}_r = 0$ for interior M_r?[1] First, note that $V_1(h) - V_2(u) \geq 0$ if and only if

$$M_1^{\gamma-1}(1 - M_1) - \frac{\lambda}{\beta a_1 h^{1+\gamma}} \geq 0, \tag{2}$$

where if there exist roots M_1 which solve (2) with equality, the same roots must solve $V_1(h) - V_2(u) = 0$, and vice versa.

Second, note that $M_1^{\gamma-1}(1 - M_1) - \frac{\lambda}{\beta a_1 h^{1+\gamma}} \ngeq 0$ as $M_1 \to 0$ or as $M_1 \to 1$.

Lastly, note that the left hand side of (2) has one extreme point in M_1, which one can derive by differentiating with respect to M_1 and setting equal to zero:

$$(\gamma - 1)M_1^{\gamma-2}(1 - M_1) - M_1^{\gamma-1} = 0 \Leftrightarrow M_1 = \frac{\gamma - 1}{\gamma} \in (0, 1),$$

where (2) is increasing (decreasing) in M_1 if and only if $M_1 < \frac{\gamma-1}{\gamma}$ ($> \frac{\gamma-1}{\gamma}$). A second derivative test will confirm that $M_1 = \frac{\gamma-1}{\gamma}$ constitutes a maximum point, with (2) being locally concave in M_1 at $M_1 = \frac{\gamma-1}{\gamma}$. Evaluating the second derivative of (2) with respect to M_1,

$$(\gamma - 2)(\gamma - 1)M_1^{\gamma-3}(1 - M_1) - 2(\gamma - 1)M_1^{\gamma-2} \Leftrightarrow (\gamma - 1)M_1^{\gamma-3}[(\gamma - 2)(1 - M_1) - 2M_1],$$

and plugging in $M_1 = \frac{\gamma-1}{\gamma}$,

$$(\gamma - 1)\left(\frac{\gamma - 1}{\gamma}\right)^{\gamma-3}\left[\frac{\gamma - 2}{\gamma} - \frac{2\gamma - 2}{\gamma}\right]$$

is by inspection negative for $\gamma > 1$.

Hence, there exist at most two interior M_1 such that (2) and therefore (1) hold with equality. In particular, if (2) is positive when evaluated at $M_1 = \frac{\gamma-1}{\gamma}$, or

$$\frac{1}{\gamma}\left(\frac{\gamma - 1}{\gamma}\right)^{\gamma-1} - \frac{\lambda}{\beta a_1 h^{1+\gamma}} > 0,$$

then there exists one $M_1 \equiv \underline{M_1}^* < \frac{\gamma-1}{\gamma}$ that solves (2) and therefore (1) with equality, and another $M_1 \equiv \overline{M_1}^* > \frac{\gamma-1}{\gamma}$ that solves (2) and therefore (1) with equality.

(ii) Note that the left hand side of (2) is increasing in M_1 from the origin through $\underline{M_1}^*$ to $M_1 = \frac{\gamma-1}{\gamma}$ and then decreasing from $M_1 = \frac{\gamma-1}{\gamma}$ through $\overline{M_1}^*$ to 1. It is straightforward to show that if $M_1^{\gamma-1}(1 - M_1) - \frac{\lambda}{\beta a_1 h^{1+\gamma}}$ is increasing (decreasing) through one of its roots, $a_1 \frac{K}{\lambda} h^{1+\gamma} M_1^{\gamma-1} - \frac{K}{\beta(1-M_1)}$ and in turn $\dot{M}_1$ must be increasing (decreasing) through that same root.

To show this, I evaluate the more general claim that if $f(x) - q(x)$ is increasing (decreasing) in x at the x^* that solves $f(x^*) = q(x^*)$, then $g(x)[f(x) - q(x)]$ must also be increasing (decreasing) in x at x^* for all continuously differentiable $f(x)$, $q(x)$, and $g(x) > 0$. The derivative of $f(x) - q(x)$ with respect to x at $x = x^*$ is

$$[f'(x) - q'(x)]|_{x=x^*}. \tag{3}$$

[1] A black hole equilibrium in which M_1 goes to 1 still does not exist here, since the related limit of $\dot{M}_1$ is $-K/\beta$.

The derivative of $g(x)[f(x) - q(x)]$ with respect to x at $x = x^*$ is

$$(g'(x)[f(x) - q(x)] + g(x)[f'(x) - q'(x)])|_{x=x^*} = g(x)[f'(x) - q'(x)]|_{x=x^*},$$

which has the same sign as (3) for all $g(x) > 0$. Let $x = M_1$, $f(\cdot) = a_1 \frac{K}{\lambda} h^{1+\gamma} M_1^{\gamma-1}$, $q(\cdot) = \frac{K}{\beta(1-M_1)}$ and $g(\cdot) = \frac{\lambda(1-M_1)}{a_1 h^{1+\gamma} K}$. Hence, $\frac{\partial \dot{M}_1}{\partial M_1}|_{M_1=\underline{M_1}^*} > 0$ and $\frac{\partial \dot{M}_1}{\partial M_1}|_{M_1=\overline{M_1}^*} < 0$. □

See Figure A.1 above for a graphical representation of this case.