Online Appendix: Technological Change and the International System

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Contents

1 Proofs

1.1 Proof of Proposition 1

It is straightforward to check that *escalate* is the unique best response to *back down* for both countries. The home country's unique best response to *escalate* is *escalate* if $\Phi^{-1}(s-\lambda) > c$ and *back down* if the inequality is reversed. The adversary's unique best response to *escalate* is *escalate* if $\Phi^{-1}(s-\lambda) < 1-c$ and *back down* if the inequality is reversed. Because $\Phi(\cdot)$ is strictly increasing and $-\Phi^{-1}(c) = \Phi^{-1}(1-c) = \Delta > 0$, these conditions can be expressed as $-(s-\lambda) < \Delta$ for the home country and $(s-\lambda) < \Delta$ for the adversary. Thus if $|s-\lambda| < \Delta$, *escalate* is a strictly dominant strategy for both countries and the unique equilibrium is for both to *escalate*. If $|s-\lambda| > \Delta$, then either $-(s-\lambda) < \Delta < (s-\lambda)$ or $(s-\lambda) < \Delta < -(s-\lambda)$. In the first (second) case, the home country (adversary) is stronger and *escalate* is its strictly dominant strategy. The adversary's (home country's) unique best response to escalate is *back down*. Therefore if $|s-\lambda| > \Delta$, the unique equilibrium is for the stronger country to *escalate* and the weaker country to *back down*. □

2 List of Technologies

1. Agricultural Tractors
2. ATMs
3. Aviation Passengers × kilometer
4. Aviation Tons × kilometer
5. Cars
6. Cellphones
7. Commercial Trucks
8. Communication Radios
9. Computers
10. Electricity production
11. Internet users
12. Rail Passengers × kilometers
13. Rail Tons × kilometers
14. Ships
15. Steel Tons from Blast Oxygen
16. Steel Tons from Electric-arc
17. Telegrams
18. Telephones
19. Transportation Rail Line kilometers
20. Televisions

Note: Technologies are measured in number of units, while technology adoption (which we use in our models) are the log of these numbers scaled by population. Our dataset extends the series recorded in Comin and Hobijn (2009), and follow its definitions. Additional information regarding the country and year temporal distribution can be made available upon request.

3 Reliability Check: Alternative System Concentration Measures

The first alternative measure is original, and looks at the number of great power coalitions possible at any time. It increases as the number of great powers grow or these become more equal in strength, and hence a larger number means less concentration, and thus us to expect more technology adoption.

Number of Viable Great Power Coalitions - The number of possible great power coalitions which satisfy two criteria: the coalition (1) controls at least 50 percent of great powers' resources (CINC), and (2) no member of the coalition is superfluous to doing so.[1]

Our next alternative measure is from the economics literature on competition among firms and industry concentration.

[1] We follow Correlates of War (2016) in our definition of great powers. These are: Austria/Austria-Hungary (1816-1918), China (1950-2016), France (1816-1940, 1945-2016), Prussia/Germany (1816-1918, 1925-1945, 1991-2016), Italy (1860-1943), Japan (1895-1945, 1991-2016), Russia/USSR (1816-1917, 1922-2016), The United Kingdom (1816-2016), The United States (1898-2016).

C4 index - Proportion of power resources (CINC) controlled by the top four countries. This measure is widely used in industrial economics to assess market concentration.

Table 1: Viable Great Power Coalitions / C4

	Dependent variable:			
	Change in Technology Adoption Level			
	(1)	(2)	(3)	(4)
Viable Great Power Coalitions	0.003***	0.003***		
	(0.000)	(0.000)		
C4			-0.206***	-0.206***
			(0.016)	(0.016)
Spatial Distance to Technology Adoption	-0.041***	-0.042***	-0.041***	-0.042***
	(0.001)	(0.002)	(0.002)	(0.002)
Log (GDP pc)		0.001		-0.002
		(0.001)		(0.001)
Polity2 score	0.000	0.000	0.001***	0.001***
	(0.000)	(0.000)	(0.000)	(0.000)
War (lagged one year)	-0.003	-0.003	0.005*	0.005**
	(0.003)	(0.003)	(0.003)	(0.003)
Civil War (lagged one year)	-0.003	-0.003	-0.008**	-0.009***
	(0.003)	(0.003)	(0.003)	(0.004)
Neighbors Mil. Spending		0.000**		0.001***
		(0.000)		(0.000)
Constant	-0.006***	-0.018*	0.119***	0.131***
	(0.002)	(0.010)	(0.008)	(0.014)
Observations	82567	77589	82567	77589
R^2	0.093	0.099	0.092	0.098
Adjusted R^2	0.093	0.099	0.092	0.098
Residual Std. Error	0.129	0.128	0.129	0.128
Note:	*p<0.1; **p<0.05; ***p<0.01			
	(Country-Technology-Clustered Standard Errors in Parentheses)			

3.1 Robustness Checks: Additional Models

Table 2: Systemic Analysis with Alternative IVs

	Dependent variable:					
	Δ Log (Tech. Adoption per capita), Worldwide					
	(1)	(2)	(3)	(4)	(5)	(6)
Syscon	-0.352***			-0.225***		
	(0.049)			(0.034)		
Viable Great Power Coalitions		0.002***			0.000	
		(0.000)			(0.000)	
C4			-0.206***			-0.141***
			(0.021)			(0.018)
Polity2 (World average)				0.005***	0.006***	0.004***
				(0.000)	(0.001)	(0.000)
Constant	0.132***	0.009***	0.144***	0.098***	0.028***	0.110***
	(0.016)	(0.002)	(0.013)	(0.011)	(0.002)	(0.011)
Observations	188	188	188	188	188	188
R^2	0.396	0.181	0.544	0.643	0.510	0.697
Adjusted R^2	0.393	0.176	0.541	0.639	0.505	0.694
Residual Std. Error	0.018	0.021	0.015	0.014	0.016	0.013
F Statistic	51.518***	23.614***	98.400***	101.016***	68.801***	119.648***
Note:						*p<0.1; **p<0.05; ***p<0.01 (Robust Standard Errors in Parentheses)

Table 3: Alternative System Concentration Variable Calculations

	Dependent variable: Δ Log(Tech. Adoption Level per capita)					
	Without Country *i*'s Contribution			Without Iron and Steel Production		
Syscon (Singer 1972)	-0.317*** (0.028)			-0.382*** (0.030)		
Viable Great Power Coalitions		0.003*** (0.000)			0.002*** (0.000)	
C4			-0.416*** (0.065)			-0.212*** (0.015)
Spatial Distance To Technology	-0.042*** (0.002)	-0.041*** (0.001)	-0.043*** (0.002)	-0.042*** (0.002)	-0.041*** (0.002)	-0.041*** (0.001)
Polity2 Score	0.001*** (0.000)	0.000** (0.000)	0.001*** (0.000)	0.001*** (0.000)	0.000*** (0.000)	0.000*** (0.000)
War (Lagged One Year)	0.000 (0.003)	0.000 (0.003)	-0.005** (0.003)	0.003 (0.003)	-0.004 (0.003)	0.004 (0.003)
Civil War (Lagged One Year)	-0.006* (0.003)	-0.003 (0.003)	-0.002 (0.003)	-0.007** (0.003)	-0.002 (0.003)	-0.008** (0.003)
Constant	0.102*** (0.008)	-0.006*** (0.002)	0.429*** (0.065)	0.116*** (0.008)	-0.000 (0.001)	0.121*** (0.008)
Observations	81402	82366	81402	82567	82567	82567
R^2	0.090	0.092	0.082	0.091	0.086	0.093
Adjusted R^2	0.090	0.092	0.082	0.091	0.086	0.093
Residual Std. Error	0.129	0.129	0.130	0.129	0.129	0.129
	In these regressions, the system concentration score for country *i* in year *t* was calculated using only data from other countries. For instance, system concentration for France in 1995 is the concentration of an international system composed of all countries except France in that year.			In these regressions, systemic variables were calculated using modified CINC scores which did not include iron and steel production nor energy consumption as components.		

*p<0.1; **p<0.05; ***p<0.01
(Country-Technology clustered standard errors in parentheses)

4 Validity Check: System Concentration as Measure of System Competitiveness

Table 4: Worldwide Military Spending / Wars / MIDs as Dependent Variable

	Dependent variable:			*Dependent variable:*			*Dependent variable:*			*Dependent variable:*		
	Worldwide Military spending, Logged			Worldwide Wars, Logged			Worldwide MIDs, Logged			% of States Entering MIDs		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Syscon	-54.097***			-6.607***			-13.216***			-0.310*		
	(7.101)			(1.424)			(1.647)			(0.174)		
Viable Great Power Coalitions		0.130**			0.009			0.039***			0.004**	
		(0.051)			(0.011)			(0.013)			(0.002)	
C4			-34.672***			-4.380***			-8.279***			-0.229***
			(2.062)			(0.555)			(0.574)			(0.079)
Constant	32.142***	14.325***	35.702***	4.089***	1.959***	4.610***	6.594***	2.193***	7.350***	0.326***	0.203***	0.364***
	(2.108)	(0.472)	(1.115)	(0.436)	(0.093)	(0.316)	(0.489)	(0.123)	(0.318)	(0.051)	(0.013)	(0.043)
Observations	189	189	189	189	189	189	189	189	189	189	189	189
R^2	0.356	0.030	0.587	0.125	0.003	0.221	0.309	0.039	0.487	0.013	0.031	0.029
Adjusted R^2	0.352	0.025	0.585	0.121	-0.002	0.217	0.305	0.034	0.485	0.008	0.026	0.024
Residual Std. Error	2.948	3.618	2.360	0.707	0.754	0.667	0.800	0.944	0.689	0.107	0.106	0.107
F Statistic (df = 1; 187)	58.041***	6.444**	282.822***	21.532***	0.720	62.364***	64.351***	9.258***	207.871***	3.173*	6.512**	8.383***

*p<0.1; **p<0.05; ***p<0.01
(Robust Standard Errors in Parentheses)

In this section, we test if our measure of system concentration (and two closely related alternatives we use for robustness checks) are statistically related to other plausible proxies for system competitiveness. Like many others, we argue that lower concentration can be related to a more competitive international system, or in the context of our theory, higher *p*.

Table 5: Conflict Links to Technology Adoption

	Dependent variable: ΔTech. Adoption Level			
Worldwide Military Spending (Logged)	0.006***			
	(0.001)			
Worldwide Wars (Logged)		0.011***		
		(0.002)		
Worldwide MIDs (Logged)			0.018***	
			(0.002)	
Proportion of Countries Entering MIDs				0.039***
				(0.007)
Spatial Distance to Technology Adoption	-0.042***	-0.043***	-0.043***	-0.043***
	(0.002)	(0.002)	(0.002)	(0.002)
Polity2 score	0.001***	0.001***	0.001***	0.001***
	(0.000)	(0.000)	(0.000)	(0.000)
War (lagged one year)	-0.002	-0.007***	-0.003	-0.006**
	(0.003)	(0.003)	(0.003)	(0.003)
Civil War (lagged one year)	-0.006*	-0.004	-0.005	-0.002
	(0.003)	(0.003)	(0.003)	(0.003)
Δ Neighboring Countries' Military Spending	0.001***	0.001***	0.001***	0.002***
	(0.000)	(0.000)	(0.000)	(0.000)
Constant	-0.100***	-0.013***	-0.045***	0.005***
	(0.011)	(0.004)	(0.006)	(0.002)
Observations	80591	80591	80591	80591
R^2	0.090	0.085	0.088	0.083
Adjusted R^2	0.090	0.085	0.088	0.083
Residual Std. Error	0.130	0.130	0.130	0.130

*p<0.1; **p<0.05; ***p<0.01
Country-Technology-Clustered Standard Errors in Parentheses

5 Robustness Check: Alternative Samples & Controls

Table 6: Main Specification With Alternative Samples

	Dependent variable: Δ Technology Adoption Level										
Sample:	Imputed Data	1900 - 2000	Minor Powers	Major Powers	European Countries	Non-European Countries	Without Rail Network & Passengers	Without Other Transportation Tech.	Without Communication Tech.	Without Industry Tech.	Without TV & ATM
Syscon	-0.262***	-0.270***	-0.345***	-0.267**	-0.291***	-0.336***	-0.239***	-0.465***	-0.209***	-0.349***	-0.404***
	(0.070)	(0.028)	(0.029)	(0.107)	(0.055)	(0.033)	(0.029)	(0.036)	(0.032)	(0.029)	(0.030)
Spatial Distance to Technology	-0.044***	-0.030***	-0.044***	-0.009*	-0.031***	-0.049***	-0.044***	-0.045***	-0.028***	-0.041***	-0.045***
	(0.003)	(0.001)	(0.002)	(0.005)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Polity2 Score	0.000	0.001***	0.001***	-0.000	0.000	0.001***	0.001***	0.001***	0.000***	0.001***	0.001***
	(0.000)	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
War (Lagged One Year)	0.003	0.003	0.005	-0.001	0.005	0.001	0.002	0.008**	0.003	0.004	0.005**
	(0.039)	(0.002)	(0.003)	(0.005)	(0.005)	(0.003)	(0.003)	(0.003)	(0.002)	(0.003)	(0.002)
Civil War (Lagged One Year)	0.007	-0.012***	-0.009***	0.042	0.009	-0.012***	-0.008**	-0.007	-0.009***	-0.008**	-0.007*
	(0.028)	(0.003)	(0.003)	(0.029)	(0.022)	(0.003)	(0.004)	(0.005)	(0.003)	(0.004)	(0.004)
Constant	0.083***	0.094***	0.108***	0.108***	0.097***	0.109***	0.084***	0.141***	0.071***	0.112***	0.125***
	(0.021)	(0.008)	(0.008)	(0.031)	(0.016)	(0.009)	(0.008)	(0.010)	(0.009)	(0.008)	(0.008)
Observations	240121	68615	75374	7193	25421	57146	73459	58488	58107	78110	77235
R^2		0.052	0.099	0.020	0.061	0.111	0.090	0.086	0.053	0.086	0.106
Adjusted R^2		0.052	0.099	0.019	0.060	0.111	0.090	0.086	0.053	0.086	0.106
Residual Std. Error		0.122	0.130	0.115	0.125	0.130	0.136	0.146	0.105	0.132	0.124

*p<0.1; **p<0.05; ***p<0.01
(Country-Technology clustered standard errors in parentheses)

Table 7: Main Specification With Alternative Controls

	Dependent variable: Δ Technology Adoption Level				
Syscon	-0.331***	-0.293***	-0.338***	-0.377***	-0.318***
	(0.029)	(0.029)	(0.029)	(0.030)	(0.031)
Spatial Distance to Technology	-0.042***	-0.041***	-0.041***	-0.041***	-0.041***
	(0.002)	(0.001)	(0.002)	(0.002)	(0.001)
Polity2 Score	0.001***	0.000**	0.001***	0.001***	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
War (Lagged One Year)	0.002	0.003	0.004	0.005**	0.002
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
Civil War (Lagged One Year)	-0.009**	-0.006*	-0.007**	-0.007**	-0.008**
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
Log(Population)	0.002***				0.002***
	(0.001)				(0.001)
Cold War (Indicator)		-0.018***			-0.017***
		(0.002)			(0.002)
Democracy (Indicator)			-0.004		-0.001
			(0.004)		(0.004)
Post World War (5-year interval)				0.024***	0.016***
				(0.003)	(0.003)
Constant	0.087***	0.106***	0.110***	0.118***	0.093***
	(0.011)	(0.008)	(0.008)	(0.008)	(0.012)
Observations	82567	82567	82567	82567	82567
R^2	0.089	0.093	0.089	0.090	0.094
Adjusted R^2	0.089	0.093	0.089	0.090	0.094
Residual Std. Error	0.129	0.129	0.129	0.129	0.129

*p<0.1; **p<0.05; ***p<0.01 – (Country-Tech. clustered standard errors in parentheses)

Table 8: New Systemic Controls: Inventions & Military Spending

	Dependent variable: Average Δ Tech. Adoption Level, Worldwide				
	Main Tech. Selection		**Expanded Tech. Selection**		**Military Spending**
Syscon	-0.202***	-0.182***	-0.108***	-0.094***	-0.193***
	(0.066)	(0.064)	(0.025)	(0.021)	(0.046)
Inventions (Yearly Average)	0.000***		0.000***		
	(0.000)		(0.000)		
Inventions (5-year Moving Average)		0.000***		0.000***	
		(0.000)		(0.000)	
Log(Global Military Spending)					0.003***
					(0.000)
Constant	0.087***	0.081***	0.046***	0.041***	0.038**
	(0.022)	(0.021)	(0.008)	(0.007)	(0.017)
Observations	188	185	188	185	188
R^2	0.330	0.398	0.488	0.597	0.542
Adjusted R^2	0.322	0.392	0.482	0.593	0.537
Residual Std. Error	0.021	0.018	0.010	0.008	0.015

*p<0.1; **p<0.05; ***p<0.01 – (Robust Standard Errors in Parentheses)

6 Additional Models with Lagged Dependent Variable

Although the use of the change in technology adoption as opposed to levels allows (to some extent) our analyses to take into account an over-time effect for a particular technology being in a country, to further attempt to delineate the shorter-term impact of system concentration on technology adoption, we have added models – at both the systemic level and technology-country-year level – with a lagged dependent variable, given in Tables 9a and 9b, respectively, yielding similar results.

Table 9: Lagged Dependent Variable Models

(a) Lagged Dependent Variable Analysis: Country-Technology Year

	Dependent variable: Change in Technology Adoption Level					
	(1)	(2)	(3)	(4)	(5)	(6)
Syscon (Singer 1972)	-0.195***			-0.193***		
	(0.018)			(0.018)		
Viable Great Power Coalitions		0.002***			0.002***	
		(0.000)			(0.000)	
C4			-0.121***			-0.121***
			(0.010)			(0.010)
Spatial Distance to Technology Adoption	-0.024***	-0.024***	-0.024***	-0.025***	-0.024***	-0.025***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Polity2 score	0.000***	0.000	0.000***	0.000***	0.000	0.000***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
War (lagged one year)	0.002	-0.002	0.003	0.002	-0.002	0.003
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Civil War (lagged one year)	-0.000	0.002	-0.001	-0.000	0.002	-0.001
	(0.003)	(0.002)	(0.003)	(0.003)	(0.002)	(0.003)
Change in Neighboring Countries' Military Spending				0.001***	0.000	0.000**
				(0.000)	(0.000)	(0.000)
Change in Technology Adoption, Lagged	0.384***	0.381***	0.382***	0.384***	0.381***	0.381***
	(0.020)	(0.020)	(0.020)	(0.021)	(0.021)	(0.021)
Constant	0.061***	-0.006***	0.068***	0.060***	-0.006***	0.067***
	(0.005)	(0.001)	(0.005)	(0.005)	(0.001)	(0.005)
Observations	76932	76932	76932	75196	75196	75196
R^2	0.244	0.247	0.246	0.247	0.249	0.248
Adjusted R^2	0.244	0.247	0.246	0.247	0.249	0.248
Residual Std. Error	0.112	0.112	0.112	0.112	0.112	0.112

$^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$
(Country-Technology-Clustered Standard Errors in Parenthesis)

(b) Lagged Dependent Variable Analysis: Systemic

	Dependent variable: Change in Technology Adoption Level					
	(1)	(2)	(3)	(4)	(5)	(6)
Syscon, World Average	-0.066**			-0.071**		
	(0.031)			(0.028)		
Viable Great Power Coalitions		0.000			-0.000	
		(0.000)			(0.000)	
C4			-0.052***			-0.054***
			(0.015)			(0.014)
Polity2 score				0.002***	0.001**	0.001***
				(0.001)	(0.001)	(0.001)
Change in Technology Adoption, Lagged	0.809***	0.867***	0.746***	0.682***	0.771***	0.624***
	(0.042)	(0.043)	(0.048)	(0.061)	(0.067)	(0.069)
Constant	0.026***	0.002	0.037***	0.032***	0.008**	0.042***
	(0.010)	(0.001)	(0.009)	(0.009)	(0.003)	(0.009)
Observations	186	186	186	186	186	186
R^2	0.787	0.780	0.795	0.802	0.792	0.809
Adjusted R^2	0.785	0.778	0.793	0.799	0.789	0.806
Residual Std. Error	0.010	0.011	0.010	0.010	0.010	0.010

$^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$
(Robust Standard Errors in Parenthesis)

7 Generalized Method of Moments Estimations

In addition to the Granger causality tests, we address potential endogeneity by use of the "internal instruments" used in Generalized Method of Moments (GMM) estimation. For the GMM analysis on the country-technology-year data, we used two lags of the dependent variable as instruments to address endogeneity. Arellano-Bond tests for first difference autocorrelation yielded no evidence of autocorrelation beyond AR(1). We "collapse" the instrument set into a $(T - 1 \times 1)$ column, rather than a $(T - 1) \times (T - 1)$ matrix to avoid misspecification errors from too many instruments (Roodman, 2009). There still exist some concerns regarding potential overidentification due to the number of instruments stemming from the large time variable (188 years). While the Hansen J-statistic implies a properly identified model, the high number of instruments may reduce the efficacy of the Hansen test to properly measure the elimination of all aspects of endogeneity from the modeled equation.

Using a one-step difference GMM analysis, the coefficients on the potentially endogenous variable have largely maintained their specificity in terms of statistical significance ($p < 0.01$).

The GMM Dynamic Panel Data first differences analysis reflects that, even accounting and adjusting for endogeneity concerns, the Systemic Concentration explanatory variable maintains its coefficient magnitude and statistical significance across multiple specifications and multiple measures of system concentration.

Extending this analysis to the systemic tests yields similar results. As this is not panel data, a 1:1 replication of the country-technology-year data GMM analysis would be inappropriate. With that, we ran a Continuously-Updating Generalized Method of Moments Estimator (CUE-GMM) to address potential endogeneity. Using the mean of the Change in Technology Adoption level (by year) as the dependent variable and instrumenting with the number of lags of the dependent variable (by year) at which evidence of autocorrelation was potentially present to address endogeneity, the magnitude of the coefficient of the Systemic Concentration variable increases in magnitude and remains statistically significant at the $p < 0.01$ level for all models without additional covariates. Inclusion of the Polity2 (World Average) Score covariate to control for political change yields largely similar results. In order to ensure that our models are properly specified, we included a series of checks on our analyses, including a GMM-CUE endogeniety test (difference of Sargan-Hansen statistics), Anderson-Rubin Wald test for weak instruments, and reported the Kleibergen-Paap rk Wald F Statistic. Further, we constructed augmented confidence sets addressing potential coverage distortions if there exists weak instrument identification to ensure that our instrument strength is not misreported (stemming from heteroskedasticity or autocorrelation). Even given these conservative confidence sets, our systemic concentration variable coefficient maintained statistical significance at the $p < 0.01$ level. Measuring systemic concentration through the number of viable great power coalitions reflects weak instrument identification when including the Polity2 World Average covariate, as shown in the low Kleibergen-Paap rk Wald F Statistic and the unbounded Two-Step Identification Robust Confidence Set. With that, both the maintained negative and statistically significant coefficient on the measure of systemic concentration in nearly all model combinations and the additional checks to ensure proper model specification should address any endogeneity concerns.

Table 10: Generalized Method of Moments Estimations

(a) GMM Dynamic Panel Data One Step Difference

Country-Technology-Year Tests

	Dependent Variable: ΔTechnology Adoption Level					
Syscon (Singer 1972)	-0.283***	-0.181***				
	(0.059)	(0.038)				
C4			-0.163***	-0.116***		
			(0.038)	(0.025)		
Viable Great Power Coalitions					0.000	0.000
					(0.001)	(0.000)
Spatial Distance to Technology	-0.022***	-0.022***	-0.023***	-0.023***	-0.012	-0.020***
	(0.006)	(0.006)	(0.006)	(0.006)	(0.009)	(0.006)
Polity2 Score	0.002***	0.002***	0.002***	0.001***	0.003***	0.002***
	(0.001)	(0.000)	(0.001)	(0.000)	(0.000)	(0.000)
War (Lagged 1 year)	-0.009***	-0.005*	-0.008***	-0.005*	-0.011***	-0.007**
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
Civil War (Lagged 1 year)	-0.010**	-0.009**	-0.009**	-0.009**	-0.007*	-0.010**
	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
ΔNeighboring Countries' Military Spending		-0.000*		-0.000*		-0.000
		(0.000)		(0.000)		(0.000)
Log(GDP per capita)		0.007		0.005		0.007
		(0.006)		(0.006)		(0.006)
N	76488	72067	76488	72067	76488	72067
Hansen J-Statistic p-value	0.627	0.997	0.612	0.995	0.660	0.999
Arellano-Bond Test for AR(1)	-13.358***	-13.088***	-13.372***	-13.079***	-13.449***	-13.181***
Arellano-Bond Test for AR(2)	1.187	1.053	1.196	1.056	1.331	1.190
Arellano-Bond Test for AR(3)	0.666	0.696	0.664	0.696	0.678	0.701

Note: *p<0.1; **p<0.05; ***p<0.01
(Country-Technology-Clustered Standard Errors in Parentheses)

(b) Continuously Updating Generalized Method of Moments Estimator

Systemic Tests

	Dependent Variable: ΔTechnology Adoption Level					
	(1)	(2)	(3)	(4)	(5)	(6)
Syscon (Singer 1972)	-0.751***			-0.618***		
	(0.041)			(0.066)		
C4		-0.335***			-0.291***	
		(0.016)			(0.025)	
Viable Great Power Coalitions			0.009***			0.074***
			(0.001)			(0.027)
Polity2 Score (World Average)				0.002***	0.001**	-0.083**
				(0.001)	(0.001)	(0.034)
Constant	0.258***	0.221***	-0.041***	0.218***	0.196***	-0.572**
	(0.013)	(0.010)	(0.006)	(0.019)	(0.014)	(0.224)
N	179	183	179	179	183	175
Endogeneity Test p-value (H_0 =Variable is exogenous)	0.000	0.000	0.000	0.000	0.000	0.007
Hansen J-Statistic p-value (H_0 = Orthog. restrictions are valid)	0.891	0.561	0.972	0.528	0.364	0.843
Kleibergen-Paap rk Wald F-Statistic	29.100	67.732	16.236	10.991	30.429	0.426
Anderson-Rubin Wald test p-value (H_0 = Coef. of the endog. regressors = 0)	0.000	0.000	0.000	0.000	0.000	0.000
Two-Step Identification Robust Confidence Sets	[-0.885, -0.661]	[-0.388, -0.300]	[0.008, 0.012]	[-0.854, -0.488]	[-0.385, -0.245]	Unbounded

Note: *p<0.1; **p<0.05; ***p<0.01
(Robust Standard Errors in Parentheses)

8 Error Correction Model

Country-Technology-Year To address concerns regarding the spurious correlation associated with large-T time series analyses, we delineated the effects of transitory vs sustained changes in system concentration, adding a more substantial foundation to the initial Granger Causality results. To achieve this, we ran panel ARDL estimates with dynamic fixed effects as an Error Correction Model using our imputed dataset to avoid misspecification due to dropped panels stemming from missingness. Given the model in Equation 12, the reparameterized ARDL(p, q) error correction model is specified as:

$$\Delta Y_t = \theta[Y_{t-1} - \lambda' X_{t-1}] + \zeta \Delta \Gamma_t + \varphi + \epsilon_t \tag{1}$$

where θ is the speed of adjustment to equilibrium, λ' is a vector of long-run coefficients, X is a vector of variables integrated of the order I(1), ζ is a vector of short-run dynamic coefficients, Γ is a vector of variables integrated of the order I(0), φ is a constant, and ϵ is an error term. Running Fisher-style Dickey-Fuller Unit Root tests to test for stationarity in our data, we find non-stationarity in the Systemic Concentration variable in levels and stationarity in differences, and stationarity in all other included variables in levels.

Estimating optimal lag length by obtaining Schwartz Information Criteria for the non-stationary variables in each panel in our sample, the results suggest an ARDL(1,0) lag selection for each measurement of systemic concentration. We use a dynamic fixed-effects estimator for the error correction model results. The negative coefficient of the speed of adjustment to equilibrium implies an appropriate application of an ECM. The results, as detailed in Table 11, suggest that a permanent change in system concentration has an inverse effect on the equilibrium level of technology adoption, with its effect felt over multiple periods. This long-run causal impact of each measurement of Systemic Concentration is shown in the top panel, and the Error Correction Term in the bottom panel suggests a long-run convergence at a speed of roughly 61% in each case. In the short run, our model results suggest that there is no statistically significant effect of transitory, single period shocks to system concentration on technology adoption at the country-technology-year level. Given that the Systemic Concentration variable is negative and significant in both the long run and speed of adjustment to equilibrium, this suggests that there does not exist spurious long-run correlation.

Systemic Tests Extending the Error Correction Model analysis to the systemic level, and using the same general error correction model given in Equation 1 yields similar results. Again, the negative coefficient of the speed of adjustment to equilibrium implies an appropriate application of an ECM. Running Augmented Dickey Fuller Unit Root tests, we find unit root in levels and stationarity in differences with regards to Systemic Concentration.

Estimating optimal lag length by obtaining Schwartz Information Criteria for each variable, the results suggest an ARDL(4,0), ARDL(1,0), & ARDL(1,0) lag selection for Syscon, Viable Great Power Coalitions, & C4 as the measure of systemic concentration, respectively. Estimating the autoregressive distributed lag regression with the first difference of the dependent variable suggests a short run causal impact of System Concentration for each of our measures. To elaborate, given a one period shock negative shock to system concentration (i.e. a more competitive system) which would dissipate immediately in the subsequent period, we anticipate an inverse change in the rate of technology adoption at the systemic level. In the case of prolonged changes to system concentration, our results suggest that there too exists an inverse relationship with technology adoption. Although the speed of adjustment to equilibrium coefficient implies a long-run oscillating equilibrium level, the results imply that these permanent changes to system concentration still cause a shift in the equilibrium level of the rate of technology adoption. To further tease out a more meaningful understanding of the long-run coefficient, we run a set of bounds tests, as recommended by Pesaran, Shin, and Smith(5). The results suggest that our results implying a long-run causal effect are foundationally sound, as shown in the statistically significant F- and t-statistics.

Table 11: Error Correction Models

Explanatory Variable		Syscon (Singer 1972)	Viable Great Power Coalitions	C4	Syscon (Singer 1972)	Viable Great Power Coalitions	C4
		Dependent Variable Change in Technology Adoption					
		Country-Technology-Year			Systemic		
Long-Run							
	Systemic Concentration	-7.154***	0.040***	-4.636***	-0.340**	0.003*	-0.169*
		(0.920)	(0.004)	(0.597)	(0.159)	(0.002)	(0.096)
Short-Run							
	Speed of Adjustment to Equilibrium	-0.610***	-0.608***	-0.612***	-1.718***	-1.399***	-1.399***
		(0.019)	(0.019)	(0.018)	(0.268)	(0.083)	(0.084)
	ΔSystemic Concentration	0.411	0.003	-0.311	-0.586**	0.004*	-0.236*
		(0.823)	(0.005)	(0.714)	(0.289)	(0.002)	(0.134)
	ΔSpatial Distance to Technology Adoption, lagged	-1.226***	-1.254***	-1.219***			
		(0.059)	(0.060)	(0.060)			
	ΔPolity2 Score	0.009**	0.013***	0.008*			
		(0.005)	(0.005)	(0.005)			
	ΔWar (Lagged One Year)	-0.028	-0.025	-0.018			
		(0.050)	(0.051)	(0.050)			
	ΔCivil War (Lagged One Year)	-0.048	-0.045	-0.045			
		(0.043)	(0.042)	(0.042)			
	Constant	2.281***	0.809***	2.561***	0.193**	-0.019	0.147*
		(0.123)	(0.036)	(0.148)	(0.123)	(0.019)	(0.079)
Pesaran, Shin, & Smith (2001) Bounds Test	F Statistic				34.69***	210.10***	211.30***
	t-statistic				–8.306***	-20.50***	-20.55***

*p<0.1; **p<0.05; ***p<0.01

9 Granger Causality

Table 12: Granger Causality Analysis

	Temporal Causality Direction			
	System Conc. → Tech. Adoption	Tech. Adoption → System	System Conc. → Tech. Adoption†	Tech. Adoption† → System
Lag 1 (N = 172)	17.72***	0.803	9.18***	0.19
Lags 1-2 (N = 168)	16.40***	3.25	10.59***	0.46
Lags 1-3 (N = 164)	25.35***	6.23	12.61***	2.01
Lags 1-4 (N = 160)	24.80***	4.42	13.88***	1.43

Note: *p<0.1; **p<0.05; ***p<0.01
Reported statistic is the Granger causality Wald test χ^2 statistic
† Accounting for the effects of war, civil war (both lagged one year), and polity2 via linear model.

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