Identifying the Growth Effect of Internet Penetration: **Online Appendix**

Mengyuan Cai Guiying Laura Wu

(Click here for the main text)

This online appendix contains three components. First, Appendix A presents the supplementary figures and tables referenced in the main text. Second, Appendix B provides detailed institutional background. Specifically, it discusses the role of the central government, the role of local governments, the construction and rollout of broadband infrastructure in China, and the collaborative governance structure underpinning broadband expansion. Third, Appendix C documents the data construction and cleaning procedures in detail.

Appendix A: Supplementary figures and tables

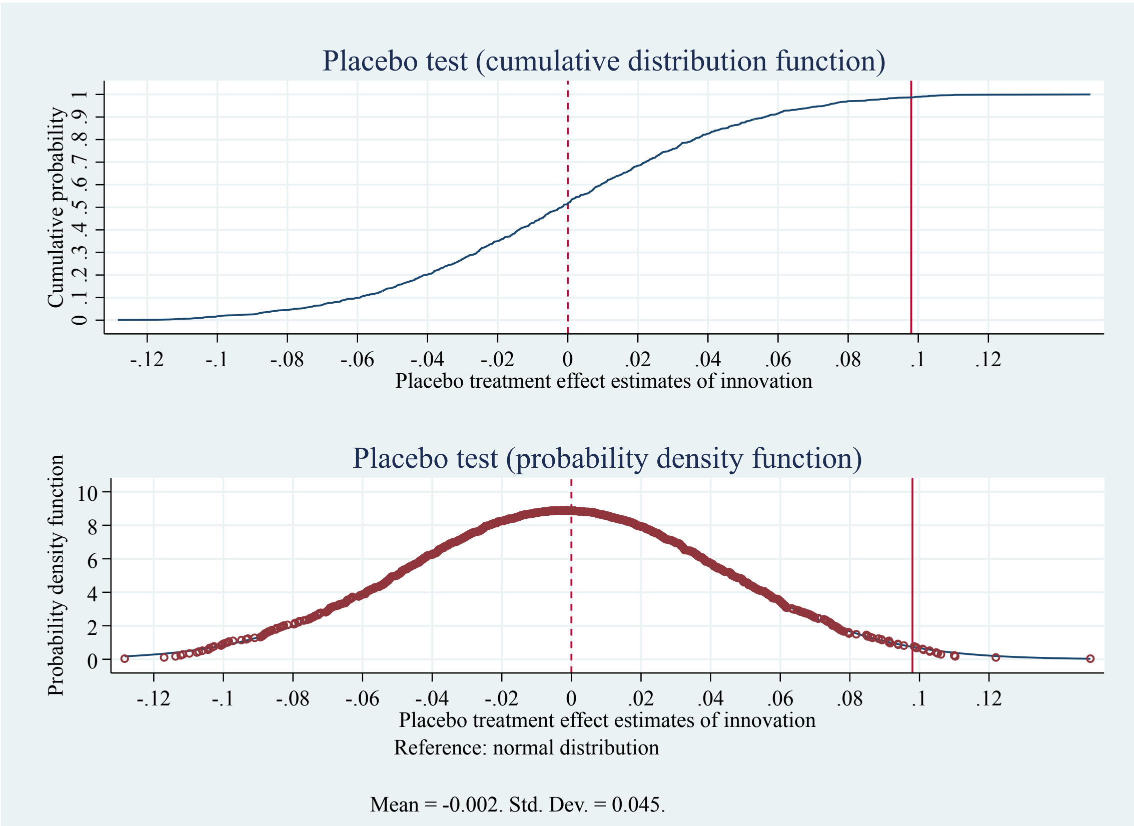

Figure A1: Placebo test: Distribution of pseudo coefficients on innovation

Note: This figure plots the cdf (top panel) and the pdf (bottom panel) of the placebo effects of 1000 times random Broadband China Pilot City designation on the city-level entrepreneurship. The red solid lines denote the benchmark TWFE estimation.

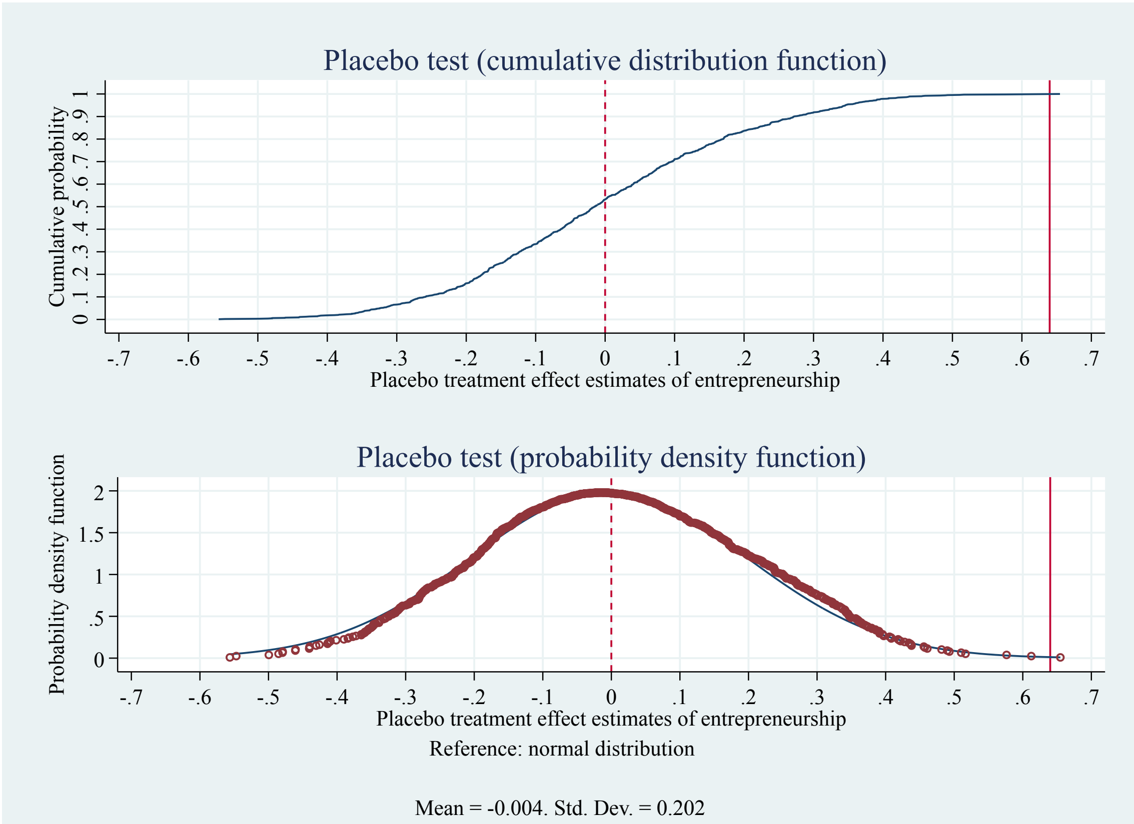

Figure A2: Placebo test: Distribution of pseudo coefficients on entrepreneurship

Note: The format is the same as Figure A1, while the red solid lines denote the benchmark TWFE estimation.

Table A1: The definition of compliers and non-compliers

		No. of telephone users	
		Fewer	More
Broadband penetration growth	Low	✓	✗
	High	✗	✓

		Topographical characteristics	
		Tough	Favorable
Broadband penetration growth	Low	✓	✗
	High	✗	✓

Notes: This table indicates the way to define compliers (✓) and non-compliers (✗). Areas with a number of telephone users below the median for 1984 are considered to have a lesser number of users, while those above the median are considered to have a greater number. Tough or favorable terrain characteristics are determined by comparing them against an RDLS value of one. Specifically, terrain is considered tough when the RDLS is greater than 1, and favorable when the RDLS is less than 1.

Table A2: The average treatment effects for compliers versus non-compliers (OLS)

	(1) IV1 complier	(2) IV1 non-com	(3) IV2 complier	(4) IV2 non-com	(5) IVs com	(6) IVs non-com
Lag of broadband penetration growth	0.059***	0.033***	0.045***	0.033***	0.103**	0.032***
	(0.019)	(0.008)	(0.012)	(0.011)	(0.042)	(0.007)
Saving rate growth	0.145***	0.138***	0.156***	0.123***	0.208***	0.129***
	(0.026)	(0.022)	(0.023)	(0.024)	(0.033)	(0.018)
Human capital growth	0.047**	0.040***	0.052***	0.028*	0.065**	0.037***
	(0.018)	(0.014)	(0.015)	(0.015)	(0.029)	(0.012)
First-difference of population growth	-0.464***	-0.243***	-0.301***	-0.345***	-0.580***	-0.283***
	(0.061)	(0.036)	(0.062)	(0.037)	(0.127)	(0.030)
Logarithm of GDP per capita in 2005	-1.896***	-1.281***	-1.339***	-1.312***	-1.902***	-1.356***
	(0.327)	(0.266)	(0.257)	(0.368)	(0.412)	(0.236)
Constant	24.796***	19.163***	19.434***	19.734***	23.788***	20.014***
	(3.242)	(2.584)	(2.543)	(3.551)	(4.280)	(2.303)
OLS counterpart	0.041	0.041	0.041	0.041	0.041	0.041
Observations	707	1,396	1,135	968	271	1,832
R-squared	0.263	0.231	0.273	0.197	0.356	0.222

Notes: IV1 is the historical number of telephones, and IV2 is the RDLS. We first binarize the two IVs and the independent variable. Specifically, For IV1, we separate the cities according to the median of the historical number of telephones. IV2 is compared with value one, considering the geographic meaning of the RDLS. RDLS equals one for the benchmark mountain that is the dividing elevation between mountain and hill in Landform Classification System of China. RDLS greater (less) than one means that the relief degree is higher (lower) than the height of a benchmark mountain. As for the independent variable, we divide the cities based on the median of the sample period average of internet penetration growth. Then, we define the compliers as those cities fall into the same upper or lower percentile of IV1 and internet penetration growth (IV1 complier), and different upper or lower percentiles of IV2 and internet penetration growth (IV2 complier), and both compliers for IV1 and IV2 are regarded as the IVs compliers. For IV1, there are 66 compliers out of 133 cities. For IV2, there are 89 compliers verses 110 non-compliers. And 27 cities are compliers when considering both IVs. Coefficients on internet penetration growth in columns (1) (3) (5) are greater than those in (2) (4) (6) respectively, and the baseline OLS estimation is 0.041. Therefore, ATE for compliers appears to be systematically higher than that for non-compliers, and IV results are greater than OLS results. Clustered (at city level) robust standard errors are reported in parentheses. $***$ indicates $p < 0.01$; $**$ indicates $p < 0.05$; $*$ indicates $p < 0.1$.

Table A3: The average treatment effect for compliers versus non-compliers (2SLS)

	(1) IV1 complier	(2) IV1 non-com	(3) IV2 complier	(4) IV2 non-com	(5) IVs complier	(6) IVs non-com
Lag of broadband penetration growth	0.197***	0.134***	0.221***	0.095**	0.386*	0.135***
	(0.063)	(0.048)	(0.064)	(0.037)	(0.223)	(0.039)
Saving rate growth	0.147***	0.143***	0.163***	0.124***	0.191***	0.134***
	(0.025)	(0.023)	(0.023)	(0.024)	(0.032)	(0.019)
Human capital growth	0.055***	0.034**	0.051***	0.026*	0.053	0.036***
	(0.020)	(0.016)	(0.019)	(0.016)	(0.043)	(0.013)
First-difference of population growth	-0.554***	-0.296***	-0.368***	-0.394***	-0.699***	-0.342***
	(0.081)	(0.047)	(0.074)	(0.048)	(0.163)	(0.041)
Logarithm of GDP per capita in 2005	-1.539***	-0.615	-0.249	-1.037**	-0.719	-0.759**
	(0.459)	(0.404)	(0.466)	(0.414)	(1.118)	(0.337)
Constant	19.369***	11.418***	6.562	16.223***	8.699	12.868***
	(5.042)	(4.422)	(5.243)	(4.267)	(13.203)	(3.671)
IV counterparts	0.150	0.150	0.207	0.207	0.162	0.162
Observations	707	1,396	1,135	968	271	1,832
R-squared	0.162	0.141	0.052	0.166	0.131	0.130

Notes: The definitions of compliers and noncompliers are the same as Table A2. Clustered (at city level) robust standard errors are reported in parentheses. $***$ indicates $p < 0.01$; $**$ indicates $p < 0.05$; $*$ indicates $p < 0.1$.

Table A4: Robustness: Other measures of digital exposure growth (OLS)

Dep: GDP per capita growth	(1) Baseline	(2) No control	(3) Baseline	(4) No control	(5) Baseline	(6) No control
Lag of broadband penetration growth another measure	0.043***	0.030***				
	(0.008)	(0.007)				
Lag of mobile phone penetration growth			0.077***	0.086***		
			(0.015)	(0.015)		
Lag of per capita telecommunication revenue growth					0.035***	0.033***
					(0.006)	(0.006)
Saving rate growth	0.131***		0.122***		0.128***	
	(0.014)		(0.014)		(0.015)	
Human capital growth	0.033***		0.024***		0.031***	
	(0.009)		(0.009)		(0.010)	
First-difference of population growth	-0.308***		-0.320***		-0.305***	
	(0.030)		(0.031)		(0.030)	
Logarithm of GDP per capita in 2005	-1.306***	-1.893***	-1.284***	-1.703***	-1.451***	-1.944***
	(0.174)	(0.174)	(0.175)	(0.180)	(0.173)	(0.175)
Constant	19.324***	25.573***	19.032***	23.335***	21.172***	26.332***
	(1.696)	(1.649)	(1.693)	(1.726)	(1.640)	(1.630)
Observations	2,608	2,608	2,608	2,608	2,557	2,557
R-squared	0.222	0.047	0.245	0.088	0.219	0.051

Notes: For the key dependent variables in columns (1) and (2), we use the residential population instead of residential household to normalize the broadband subscribers. Columns (3) and (4) use the mobile phone penetration rate as a proxy of digital exposure. And columns (5) and (6) utilized the per capita telecommunication revenue to reflect the level of digital exposure. Clustered (at city level) robust standard errors are reported in parentheses. $***$ indicates $p < 0.01$; $**$ indicates $p < 0.05$; $*$ indicates $p < 0.1$.

Table A5: Robustness: Other measures of digital exposure growth (IV)

Dep: GDP per capita growth	(1) Historical IV	(2) Topographical IV	(3) Both IVs	(4) Historical IV	(5) Topographical IV	(6) Both IVs	(7) Historical IV	(8) Topographical IV	(9) Both IVs
Panel A: Second Stage									
Lag of broadband penetration growth another measure	0.174***	0.235***	0.183***						
	(0.041)	(0.061)	(0.039)						
Lag of mobile phone penetration growth				0.319***	0.374***	0.318***			
				(0.021)	(0.052)	(0.021)			
Lag of per capita telecommunication revenue growth							0.190*	0.314**	0.212**
							(0.102)	(0.138)	(0.098)
Saving rate growth	0.145***	0.146***	0.145***	0.112***	0.108***	0.113***	0.135***	0.133***	0.135***
	(0.015)	(0.015)	(0.015)	(0.015)	(0.015)	(0.015)	(0.016)	(0.016)	(0.016)
Human capital growth	0.034***	0.032**	0.034***	-0.004	-0.012	-0.004	0.024	0.014	0.022
	(0.013)	(0.014)	(0.013)	(0.012)	(0.015)	(0.012)	(0.016)	(0.022)	(0.017)
First-difference of population growth	-0.395***	-0.429***	-0.400***	-0.449***	-0.475***	-0.449***	-0.408***	-0.481***	-0.421***
	(0.057)	(0.062)	(0.056)	(0.059)	(0.069)	(0.059)	(0.084)	(0.103)	(0.083)
Logarithm of GDP per capita in 2005	-0.636**	-0.290	-0.580**	-0.462**	-0.268	-0.467**	-0.955**	-0.509	-0.874**
	(0.303)	(0.385)	(0.289)	(0.231)	(0.278)	(0.232)	(0.435)	(0.596)	(0.429)
Overidentification p-value			0.298			0.241			0.260
Panel B: First Stage									
Historical IV × Broadband another measure	8.294***		7.476***						
	(0.808)		(0.809)						
Topographical IV × Broadband another measure		-10.442***	-5.054***						
		(1.697)	(1.685)						
Historical IV × Mobile phone				11.297***		11.580***			
				(0.476)		(0.682)			
Topographical IV × Mobile phone					-14.821***	1.695			
					(1.711)	(2.211)			
Historical IV × Telecommunication revenue							3.477***		2.966**
							(1.091)		(1.460)
Topographical IV × Telecommunication revenue								-8.912***	-2.981
								(3.349)	(4.553)
Controls and Constant	YES	YES	YES	YES	YES	YES	YES	YES	YES
Kleibergen-Paap rank Wald F statistics	89.158	46.728	46.812	535.343	106.792	277.321	13.160	19.813	12.485
Observations	2,090	2,090	2,090	2,090	2,090	2,090	2,042	2,042	2,042
R-squared	0.099	0.069	0.102	0.224	0.091	0.225	0.034	0.032	0.034

Notes: The definitions of the key independent variables are the same as Table A4. Clustered (at city level) robust standard errors are reported in parentheses. $***$ indicates $p < 0.01$; $**$ indicates $p < 0.05$; $*$ indicates $p < 0.1$.

Table A6: Robustness: Unintended samples (IV)

Dep: GDP per capita growth	(1) Exclude BSG	(2) Exclude BSG	(3) Exclude BSG	(4) Exclude BSG	(5) Exclude 8 nodals	(6) Exclude 8 nodals	(7) Exclude 8 nodals	(8) Exclude 8 nodals
Panel A: Second Stage								
Lag of broadband penetration growth	0.165***				0.165***			
	(0.038)				(0.039)			
Lag of broadband penetration growth another measure		0.187***				0.188***		
		(0.039)				(0.040)		
Lag of mobile phone penetration growth			0.318***				0.320***	
			(0.021)				(0.021)	
Lag of per capita telecommunication revenue growth				0.197**				0.165**
				(0.088)				(0.080)
Saving rate growth	0.145***	0.145***	0.113***	0.136***	0.147***	0.146***	0.113***	0.138***
	(0.016)	(0.015)	(0.015)	(0.016)	(0.016)	(0.016)	(0.015)	(0.016)
Human capital growth	0.037***	0.034**	-0.004	0.023	0.037***	0.035***	-0.003	0.026*
	(0.013)	(0.013)	(0.012)	(0.016)	(0.013)	(0.013)	(0.012)	(0.015)
First-difference of population growth	-0.391***	-0.403***	-0.454***	-0.412***	-0.394***	-0.406***	-0.457***	-0.393***
	(0.056)	(0.056)	(0.060)	(0.078)	(0.057)	(0.058)	(0.061)	(0.074)
Logarithm of GDP per capita in 2005	-0.714**	-0.577*	-0.446*	-0.907**	-0.791***	-0.649**	-0.501**	-1.098***
	(0.286)	(0.295)	(0.247)	(0.398)	(0.290)	(0.300)	(0.254)	(0.370)
Overidentification p-value	0.370	0.355	0.278	0.37	0.433	0.408	0.325	0.262
Panel B: First Stage								
Historical IV × Broadband	7.245***				7.250***			
	(0.833)				(0.844)			
Topographical IV × Broadband	-5.906***				-6.015***			
	(1.775)				(1.783)			
Historical IV × Broadband another measure		7.652***				7.657***		
		(0.823)				(0.834)		
Topographical IV × Broadband another measure		-4.929***				-4.977***		
		(1.716)				(1.723)		
Historical IV × Mobile phone			11.871***				11.988***	
			(0.697)				(0.710)	
Topographical IV × Mobile phone			1.703				1.336	
			(2.265)				(2.291)	
Historical IV × Telecommunication revenue				2.927*				3.490**
				(1.495)				(1.450)
Topographical IV × Telecommunication revenue				-4.564				-4.024
				(4.480)				(4.342)
Controls and Constant	YES	YES	YES	YES	YES	YES	YES	YES
Kleibergen-Paap rank Wald F statistics	47.496	48.596	309.121	7.396	46.631	47.440	316.511	11.432
Observations	2,055	2,055	2,055	2,007	2,016	2,016	2,016	1,968
R-squared	0.095	0.098	0.226	0.034	0.094	0.097	0.228	0.034

Notes: Columns (1)-(4) use the sample that excludes Beijing, Shanghai, and Guangzhou as these three cities are the access points to the world's Internet backbone; and columns (5)-(8) exclude the eight nodal cities (Beijing, Shanghai, Guangzhou, Shenyang, Nanjing, Wuhan, Chengdu, and Xi'an) of the CHINANET. Clustered (at city level) robust standard errors are reported in parentheses. $***$ indicates $p < 0.01$; $**$ indicates $p < 0.05$; $*$ indicates $p < 0.1$.

Table A7: Robustness: IV results with historical post office IV and topographical IV

Dep: GDP per capita growth	(1)	(2)	(3)	(4)
Panel A: Second Stage				
Lag of broadband penetration growth	0.185***			
	(0.040)			
Lag of broadband penetration growth another measure		0.208***		
		(0.041)		
Lag of mobile phone penetration growth			0.341***	
			(0.024)	
Lag of per capita telecommunication revenue growth				0.298**
				(0.116)
Saving rate growth	0.146***	0.146***	0.111***	0.133***
	(0.015)	(0.015)	(0.015)	(0.016)
Human capital growth	0.036***	0.033**	-0.008	0.015
	(0.013)	(0.014)	(0.013)	(0.020)
First-difference of population growth	-0.402***	-0.414***	-0.460***	-0.472***
	(0.056)	(0.056)	(0.061)	(0.093)
Logarithm of GDP per capita in 2005	-0.592**	-0.442	-0.383	-0.568
	(0.283)	(0.295)	(0.237)	(0.509)
Constant	10.509***	8.653***	7.908***	11.228**
	(3.122)	(3.270)	(2.304)	(5.398)
Overidentification p-value	0.609	0.575	0.503	0.863
Panel B: First Stage				
Historical IV × Broadband	12.105***			
	(1.507)			
Topographical IV × Broadband	-7.132***			
	(1.742)			
Historical IV × Broadband another measure		12.555***		
		(1.481)		
Topographical IV × Broadband another measure		-6.225***		
		(1.691)		
Historical IV × Mobile phone			20.762***	
			(1.460)	
Topographical IV × Mobile phone			-1.237	
			(2.218)	
Historical IV × Telecommunication revenue				5.016*
				(3.012)
Topographical IV × Telecommunication revenue				-4.210
				(4.553)
Kleibergen-Paap rank Wald F statistics	48.5243	49.7486	212.137	5.346
Observations	2,090	2,090	2,090	2,042
R-squared	0.094	0.096	0.198	0.033

Notes: The historical IV is the number of post office in 1984. Clustered (at city level) robust standard errors are reported in parentheses. $***$ indicates $p < 0.01$; $**$ indicates $p < 0.05$; $*$ indicates $p < 0.1$.

Table A8: Robustness: IV results with historical telecom revenue IV and topographical IV

Dep: GDP per capita growth	(1)	(2)	(3)	(4)
Panel A: Second Stage				
Lag of broadband penetration growth	0.173***			
	(0.039)			
Lag of broadband penetration growth another measure		0.197***		
		(0.041)		
Lag of mobile phone penetration growth			0.322***	
			(0.022)	
Lag of per capita telecommunication revenue growth				0.236**
				(0.104)
Saving rate growth	0.145***	0.145***	0.112***	0.134***
	(0.015)	(0.015)	(0.015)	(0.016)
Human capital growth	0.036***	0.034**	-0.005	0.020
	(0.013)	(0.013)	(0.012)	(0.018)
First-difference of population growth	-0.395***	-0.408***	-0.451***	-0.435***
	(0.056)	(0.056)	(0.060)	(0.086)
Logarithm of GDP per capita in 2005	-0.656**	-0.504*	-0.451*	-0.788*
	(0.285)	(0.296)	(0.232)	(0.452)
Constant	11.284***	9.400***	8.743***	13.666***
	(3.134)	(3.272)	(2.248)	(4.798)
Overidentification p-value	0.433	0.430	0.279	0.381
Panel B: First Stage				
Historical IV × Broadband	9.612***			
	(1.173)			
Topographical IV × Broadband	-6.387***			
	(1.738)			
Historical IV × Broadband another measure		10.086***		
		(1.159)		
Topographical IV × Broadband another measure		-5.451***		
		(1.683)		
Historical IV × Mobile phone			16.544***	
			(1.034)	
Topographical IV × Mobile phone			1.240	
			(2.247)	
Historical IV × Telecommunication revenue				3.981*
				(2.146)
Topographical IV × Telecommunication revenue				-3.470
				(4.567)
Kleibergen-Paap rank Wald F statistics	47.7968	49.4319	273.961	5.562
Observations	2,090	2,090	2,090	2,042
R-squared	0.096	0.098	0.218	0.034

Notes: The historical IV is the telecommunication revenue in 1984. Clustered (at city level) robust standard errors are reported in parentheses. $***$ indicates $p < 0.01$; $**$ indicates $p < 0.05$; $*$ indicates $p < 0.1$.

Table A9: Robustness: IV interacted with China's major internet infrastructure providers' revenue

	(1) Historical	(2) Topographical	(3) Both IVs	(4) Historical	(5) Topographical	(6) Both IVs
Panel A						
Lag of broadband penetration growth	0.461***	0.366***	0.430***	0.450***	0.371***	0.425***
	(0.075)	(0.082)	(0.065)	(0.074)	(0.083)	(0.064)
Controls	YES	YES	YES	YES	YES	YES
Overidentification p-value			0.335			0.415
Observations	2,090	2,090	2,090	2,074	2,074	2,074
Panel B						
Telephony in 1984 × providers' revenue growth	5.964***		4.784***	6.030***		4.852***
	(0.779)		(0.894)	(0.783)		(0.898)
RDLS × providers' revenue growth		-11.998***	-7.140***		-12.036***	-7.115***
		(2.072)	(2.354)		(2.106)	(2.386)
Controls	YES	YES	YES	YES	YES	YES
Kleibergen-Paap rank Wald F statistics	58.680	33.515	30.062	59.337	32.646	30.660
Observations	2,090	2,090	2,090	2,074	2,074	2,074

Notes: Panel A performs the second-stage regression while panel B presents the first-stage results. Column (1) reports the estimation based on the historical IV which refers to the natural logarithm of the number of telephones in 1984 interacted with the lagged one-year growth rate of operating revenue from China's major internet infrastructure providers. Column (2) is based on the topographical IV which refers to the natural logarithm of the Relief Degree of Land Surface with the same interaction as the historical IV. And Column (3) uses both IVs thus can conduct the overidentification test. Columns (4) to (6) mimic the layout of Columns (1) to (3) while including the growth rates of highway freight and passenger volumes to test exclusion restriction. Clustered (at city level) robust standard errors are reported in parentheses. $***$ indicates $p < 0.01$; $**$ indicates $p < 0.05$; $*$ indicates $p < 0.1$.

Appendix B: Broadband internet–Who, where, why, and how

- **The role of central government**

The central government of China plays an important role in shaping the landscape of broadband infrastructure investment. First, foreseeing the potential of internet in promoting economic growth, the government has proposed a series of national policies to deploy internet infrastructure in a forward-looking fashion. For example, the *Ninth Five-Year Plan of National Informatization and Visionary Goals for 2010*, introduced in 1997, officially recognizes the internet as a fundamental component of national economic informatization. This plan sets targets for expanding domestic fiber-optic networks, increasing the number of connected computers, and achieving a high internet penetration rate. Second, to meet the increasing demand for internet from firms and households as a result of economic growth, in the subsequent *Eleventh Five-Year Plan of Information Industry* in 2007, the central government sets clear targets for the information industry, including the rapid expansion of telecommunications networks, growth in telephone subscribers, and a surge in internet users. Notably, the third generation of wireless mobile telecommunications technology (3G) is commercialized on October 1, 2009, in China, marking a significant milestone in telecommunication progression.

Third, the subsequent *Five-Year Plan of Internet Industry* has a more salient feature of being both supply-led and demand-driven. For example, the Twelfth Five-Year Plan period observes a threefold increase in internet users, the inauguration of super-scale broadband infrastructures, and the burgeoning growth of e-commerce. Furthermore, on March 18, 2014, the fourth generation of broadband cellular network technology (4G) is commercialized, representing another substantial improvement in mobile internet connectivity. The fifth generation of mobile network technology (5G) offers significantly higher speeds, lower latency, and greater capacity than 4G, and is designed to support a wide array of new applications. 5G is commercially launched in China on October 31, 2019, and China has been rapidly expanding the 5G infrastructure since then.

On top of the regular five-year plans, the State Council releases the national strategy *China's Broadband Strategic Program and its Implementation Plan* in 2013 to promote the construction of broadband internet nationwide. This program is divided into three phases: speed-up by the end of 2013, popularization in 2014 and 2015, and upgrading from 2016 to 2020. To carry out this Plan, the Ministry of Industry and Information Technology (MIIT) and the National Development and Reform Commission (NDRC) launch the Broadband China Pilot City Program in January 2014. There are 39 entities designated as "Broadband China Pilot Cities" each year from 2014 to 2016. The variation in the timing of the designation provides a potential staggered DID identification design.

Last but not least, in addition to the growth-promoting goal, the central government has also committed to the equitable goal in internet development. Recognizing the low return on investment in high-cost areas, the central government addresses the underinvestment in broadband infrastructure, aiming to provide universally accessible, non-discriminatory, and inclusively affordable telecommunication services. For example, the *Regulation of the People's Republic of China on Telecommunications* enacted in 2000 stipulates that telecommunication service operators must fulfil specific telecommunications universal service obligations in accordance with national provisions. The focus on rural areas is particularly crucial as these regions often lag behind in terms of infrastructure and access to digital resources. This commitment is also enshrined in various planning policies such as the *National Informatization Development Strategy from 2006 to 2020*[1] by the State Council in 2006 and the *Thirteenth Five-Year Plan for Economic and Social Development and the Poverty Alleviation Plan*[2] in 2016. By enforcing investment in rural broadband infrastructure, these obligations ensure that internet services are extended to undeserved, less-developed and slow-growing areas.

- **The role of local governments**

In China's regionally decentralized authoritarian system, local governments are pivotal in implementing central government policies and plans. This system is characterized by political centralisation at the national level so that the central government has control over personnel, and economic regional decentralisation, whereas subnational governments run the bulk of the economy (Xu, 2011).

[1]See `https://www.gov.cn/gongbao/content/2006/content_315999.htm`.
[2]See `https://www.gov.cn/zhengce/content/2016-12/02/content_5142197.htm?ivk_sa=1024320u`.

This system grants local government officials significant economic autonomy and evaluates them based on standardized economic performance criteria. For example, the literature documents a positive and significant relationship between economic performance and local government leaders, at the province-level (Li and Zhou, 2005), prefecture and county-level (Landry et al., 2018), and in a multi-layered tournament based administration organization of China (Li et al., 2019). This suggests the city-level government officials are heavily incentivized to prioritize rapid GDP growth as a key metric for performance evaluation and career advancement.

Among the toolbox of local governments to pursue economic performance, infrastructure investment is probably the most important one. On the one hand, investment and public expenditure directly account to GDP by contributing to aggregated demand. On the other hand, good infrastructure enhances firm-level productivity, improves resource allocation efficiency, and attracts capital and talents. For example, using a structural model of firm-level production function, and matching Chinese firm-level production data with province-level infrastructure data, Wu et al. (2021) finds infrastructure investment has both a significant Keynesian demand-pull effect and a productivity supply-push effect. Not surprisingly, from 2013 to 2017, local governments finance a major portion of China's infrastructure sector, which constitutes 23.1% of its total capital—higher than the United States' 18.2% and more than double the European Union's 9.9% (Xiong and Song, 2024).

Although local governments have strong incentives to invest in infrastructure, they are also subject to public budget constraints. Before 2008, China's budget law prohibits local governments from running budget deficits. To fund the massive 2008 stimulus program, which required substantial local financing, the central government allows local governments to borrow through the Local Government Financing Vehicle, which becomes a key funding source for infrastructure investment. The financial deregulation becomes a significant force driving the leverage boom and the surge of the shadow banking sector in China in the subsequent years (Bai et al., 2016). Starting from 2014, the Chinese central government launches a series of measures and regulations aiming to resolve the titanic local government debt burden.[3] In December 2015, the central government implements

[3]See the Implementation Opinions on Quota Management of Local Government Debt at https://www.gov.cn/

a top-to-bottom debt quota management system that strictly restrains local government debt.[4] As a result, local governments, while still making efforts to drive local economic growth, do face stringent regulation and fiscal budget constraints. It therefore suggests there could be a competing relationship between broadband expansion and other infrastructure investments during most years of our sample period.

- **Construction and rollout**

The construction and rollout of broadband infrastructure in China are primarily led by the three major telecommunication service operators: China Mobile Limited (China Mobile), China Telecom Corporation Limited (China Telecom), and China United Network Communications Group (China Unicom). These firms have three salient features. First, they are among the world's largest telecommunication service operators in terms of revenue and customers. For example, in 2022, China Mobile achieves a total revenue of 937.3 billion yuan ($139.4 billion), with its extensive customer base reaching 975 million mobile users and 272 million wireline broadband customers. China Telecom and China Unicom report a notable total revenue of 481.4 billion yuan ($71.6 billion) and 354.9 billion yuan ($52.8 billion), respectively. Normalizing the total revenue of the three giants with China's total population implies a 1,256 yuan ($187) telecommunication service revenue per capita in 2022.

Second, all three firms go public around 2000 on both the New York Stock Exchange (NYSE) and the Hong Kong Exchanges and Clearing Limited (HKEX), until their late home-return to the Shanghai Stock Exchange (SSE). Even today, China Mobile and China Telecom are publicly listed on the HKEX with a large investor base and active transactions. Operating in a competitive environment, these publicly listed firms make profit-maximization decisions based on cost and benefit analyses. For instance, due to the high operation and maintenance costs and low service revenue, it is not consistent with their financial interest to supply broadband internet in areas with poor historical endowment and tough topographic conditions.

zhengce/content/2014-10/02/content_9111.htm.

[4] See the Guidelines from the Ministry of Finance on Implementing a Debt Ceiling System for Local Governments at https://www.gov.cn/gongbao/content/2016/content_5059103.htm.

Last but not least, the three telecommunication service operators are all state-owned enterprises (SOEs). For example, China Mobile is majority-owned (69.82%) by China Mobile Communications Group Company Limited, which is a state-owned firm in China. Similarly, the majority stakes in China Telecom (63.78%) and China Unicom (79.9%) also belong to entities fully owned by the central government. With the significant state ownership, these Chinese telecom giants are also influenced by state directives aimed at bridging the digital divide. For example, based on the *Regulation of the People's Republic of China on Telecommunications*, the MIIT initiated the Village Connection Project in 2004, which required telecommunication service operators to provide telephone access to every village and improve network infrastructure in rural areas. As of October 2015, the direct investment in broadband network construction exceeded 30 billion yuan, covering more than 3,000 towns and over 140,000 villages. This increased the proportion of towns and villages with broadband access from 90% and 70% respectively to 100% and 91%.[5]

Facing the high investment-low return policy burden, the profitability of China's major telecom operators is relatively low. For instance, as shown in Figure A3, on November 1, 2023, the three leading telecommunication companies in the United States, T-Mobile US Inc., Verizon Communications Inc., and AT&T Inc., have market capitalizations of $170.15 billion, $151.09 billion, and $111.89 billion, respectively. The corresponding Price-to-Book (P/B) ratios are 2.49, 1.53, and 0.95. In contrast, the market capitalizations for China Mobile Ltd., China Telecom Corp Ltd., and China Unicom Ltd. are at a comparable scale, being $175.30 billion, $62.62 billion, and $19.23 billion, respectively. However, the P/B ratios for their stocks are only 0.97, 0.66, and 0.39, or one-third to one-half of their U.S. counterparts. This highlights the dual identities of the three major telecommunication service operators in China: the state-owned public listed firms.

[5] Source: https://www.gov.cn/zhengce/2015-10/15/content_2947213.htm.

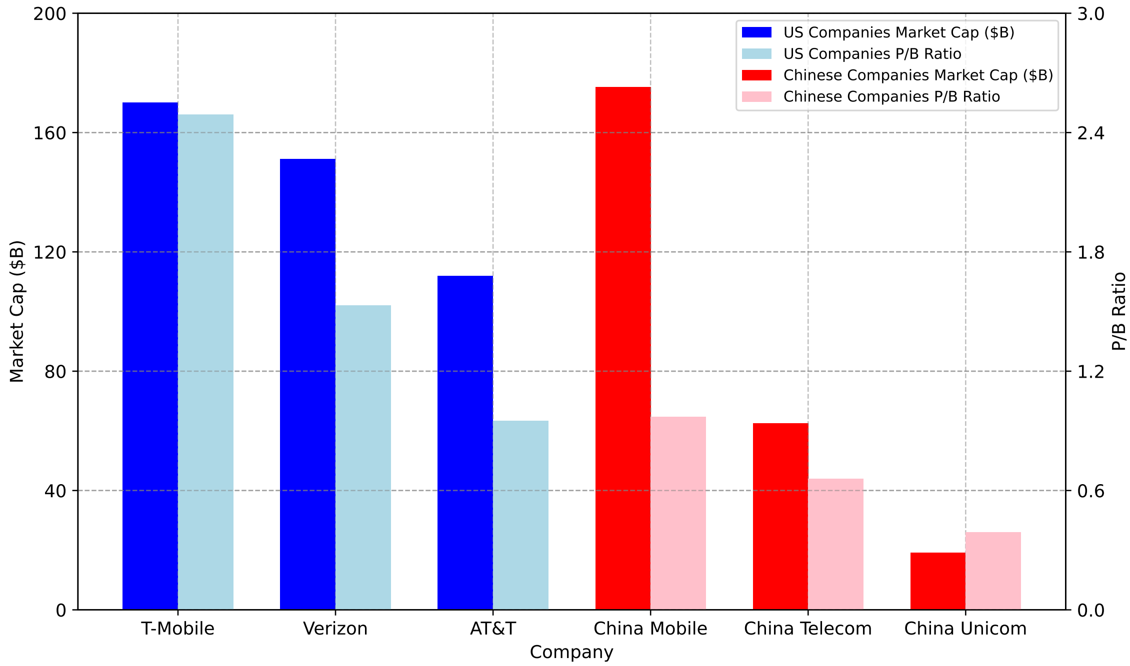

Figure A3: The market capitalization and P/B ratio of the US and Chinese top 3 telecommunication companies

Notes: This figure shows the market capitalization and P/B ratio of the top 3 telecommunication companies in the US (T-Mobile US Inc., Verizon Communications Inc., and AT&T Inc.) and China (China Mobile Ltd., China Telecom Corp Ltd., and China Unicom Ltd.). The left vertical axis denotes market capitalization with unit of billion US dollars. The right vertical axis is the price to book ratio.
Source: Bloomberg terminal at 1st November 2023.

- **A quasi public-private partnership (PPP) in infrastructure investment**

In China, broadband infrastructure development relies on collaboration between telecommunication service operators and local governments through policy coordination, resource sharing, and joint investments. Local governments facilitate deployment by streamlining administrative approvals, granting access to public infrastructure including streetlight poles and government buildings, and providing financial incentives through subsidies and tax benefits, with particular emphasis on rural and underserved areas. Telecommunication service operators utilize these supportive policies while handling technical implementation, operational management, and the majority of capital investment, pursuing commercial return and profitability. Broadband development metrics, including coverage rates and internet speeds, are integrated into the performance evaluation systems of government officials.

This collaborative framework between telecommunication service operators and local governments exhibits characteristics of a PPP model. While traditional PPP arrangements typically involve private sector entities, China's three major telecommunication service operators are publicly listed firms operating with commercial principles and engage with local governments in ways that mirror conventional PPPs: shared risks and resources, hybrid financing mechanisms, and coordinated infrastructure development (Tan and Zhao, 2019). This quasi-PPP model aligns with global trends, as broadband infrastructure in many countries has been developed through PPP frameworks after the liberalisation of the telecommunications sector (Falch and Henten, 2010).

Appendix C: Data cleaning process

We obtain panel data of China's prefecture-level cities between 2005 and 2019 from CCSY and CEIC databases. We exclude the cities with Administrative Division Adjustment (ADA) during our research period 2005-2019. ADA information is collected from the Ministry of Civil Affairs of the People's Republic of China.[6] For example, in 2015, the Shou County of Lu'an City is adjusted to be under the jurisdiction of Huainan City afterward. Hence, there are jumps in the year 2015 in terms of GDP, population, and other variables of our interest. To avoid misleading results, we drop these cities and, in total, there are 19 cities deleted from the data set due to the ADA.

On top of ADA that may lead to unexpected jumps, the disclosed data quality, especially for GDP per capita, is a concern to some extent, considering the economic performance pressure, inevitable hand-collection mistakes of government employees, and revision of former data. Hence, data cleaning is in need to truly reveal the effect of our interests. The data cleaning process in this paper is firstly finding cities with an extremely high or low growth rate of GDP per capita, then searching for possible reasons for the strange data. If there is any reasonable explanation such as natural disasters, we keep the original data. Otherwise, we treat the data as a missing value and use linear interpolation to recover this missing value. For instance, Tangshan's GDP per capita in 2015 recorded in Tangshan Statistical Yearbook 2020 is 65742 yuan, while in 2014 and 2016 is 80450 yuan and 71621 yuan. It drops by 18% in 2015 and increases by 9% in 2016. There is no possible reason for the poor performance in 2015 except the revision of former data according to the 1% Population Sample Survey of China in 2015. Therefore, we replace the value in 2015 with the mean values in 2014 and 2016. We apply this data-cleaning process to other variables as well.

GDP per capita data are collected from each city's Statistical Yearbook. Due to limited data availability of the working-age labour force at the city level, we adopt the local residence population to normalize local GDP, although output in the theoretical model should be normalized by the labour force. The residential population data are not broadly reported until 2010, we need to infer residential population from GDP and GDP per capita data. Before the year 2005, GDP per capita

[6] See http://xzqh.mca.gov.cn/description?dcpid=1.

is officially calculated as GDP divided by registered population. However, there are magnificent differences for metropolitan between the registered population and the residential population in the Chinese context. And only the residential population is a reasonable alternative measure for the working-age labour force, as only these two are the workforce undertaking the local economic activities. In 2005, the National Bureau of Statistics of China standardizes the unified GDP per capita calculation scheme, and afterward, the reported GDP per capita should be normalized by local residence population.[7] Therefore, we use the reported GDP divided by the reported GDP per capita to calculate the number of local residents. To double check whether the reported GDP per capita data are normalized by residence rather than the registered population in the year 2005 and after, we further calculate GDP divided by GDP per capita and compare the results with the reported registered population data for the years 2004 and 2005. There are few differences in 2004 but huge differences for metropolitan in the year 2005. This implies that using the inferred residential population is reliable only for the year 2005 and afterward. And this is also a reason for choosing 2005 as our starting year of the research period. As for the deflators, we use GDP index with the previous year equal to 100 and use the year 2005 as the base year to get the GDP deflator and calculate real GDP per capita. Similarly, we collect the price index of fixed asset investment from the National Bureau of Statistics to deflate the fixed asset investment. Both the deflators are at the province level constrained by data availability.

In both CEIC and CCSY databases, the explanatory note on the variable "broadband internet subscriber" does not state explicitly whether it is in terms of household or individual residence. However, generally, there is only one broadband internet subscriber in each household. Therefore, we adopt the number of residential households to normalize the number of broadband internet subscribers. Here, we use residential residence divided by the average household size to infer the number of residential households, where the average household size is calculated as registered population over registered household. The underlying assumption is the average household sizes for registered households and for residential households are the same. In this way, we can obtain the broadband penetration rate.

[7] See http://www.gov.cn/test/2005-06/24/content_9340.htm.

According to our sample, the average penetration rates over all cities in 2015 and 2019 are 55.1% and 102.4%, respectively, while the national level penetration rates in 2015 and 2020 released by the Cyberspace Administration of China are 50.3% and 70.4%. This overestimated broadband penetration rate is as expected for three reasons. First, the number of broadband internet subscribers collected from the three major telecommunication service operators includes users from organizations such as firms, governments, and universities, which results in double counting for some individuals. Furthermore, this is the reason why the number of broadband internet users is larger than the number of households in cities with a plethora of firms and universities such as Shenzhen, Shanghai, and Wuxi. Second, the average registered household size tends to be larger than the residential household size, since the labour force flows into towns and one registered household breaks out into two residential households in two different cities, for example, reducing the residential household size in each city. Thus, the inferred number of residential households is underestimated, and as a result, the broadband penetration rate is overestimated systematically. Lastly, we are short of data for cities with poor economic performance in western China, and they generally have relatively lower internet penetration rates due to either poor economic performance or tough topographic challenges. Consequently, this sample of 241 cities performs better than the nationwide to some extent. In addition, we also use residential population in each city to normalize the broadband internet users for robustness checks.

Our final panel data set consists of 241 cities over 14 years (2006-2019). The panel structure is described by Table A10. The pattern distribution reveals that approximately 67% of cities have complete data for the first 12 years, while about 12% have complete data for all 14 years. The minimum number of observations for any city is 5 years, while the maximum is 14 years, with the median being 12 years of observations. Data limitation exists in our sample. Most cities cease reporting fixed asset investment data after 2018, which leads to missing observations in the final two years. This systematic truncation post-2018 is consistent across our sample and reflects a change in reporting requirements rather than selective non-reporting by specific cities.

Table A10: Panel Structure Description

Panel A: Dimensions		
code	110000, 120000, ..., 640300	($n = 241$)
year	2006, 2007, ..., 2019	($T = 14$)
	Delta(year) = 1 unit	
	Span(year) = 14 periods	

Panel B: Distribution of Time Periods by City (T_i)

Percentile	Number of Periods
min	5
5%	8
25%	12
50%	12
75%	12
95%	14
max	14

Panel C: Pattern of Observations

Pattern	Frequency	Percent (%)
111111111111..	162	67.22
11111111111111	30	12.45
1111111111111.	17	7.05
11111.........	4	1.66
.1111111111111	2	0.83
111..1111111..	2	0.83
11111..11111..	2	0.83
11111111111...	2	0.83
.........11111	1	0.41
(other patterns)	19	7.88
Total	241	100.00

Notes: Most cities cease reporting fixed asset investment data after 2018, leading to missing observations in our dependent variable. This explains why approximately 67% of cities have complete data for only the first 12 years (2006-2017). In Panel C, pattern "1" indicates available observation and "." indicates missing value.

Reference

Bai, C.-E., Hsieh, C.-T. and Song, Z. M. (2016), 'The long shadow of a fiscal expansion', *National Bureau of Economic Research* .

Falch, M. and Henten, A. (2010), 'Public private partnerships as a tool for stimulating investments in broadband', *Telecommunications Policy* **34**(9), 496–504.

Landry, P. F., Lü, X. and Duan, H. (2018), 'Does performance matter? evaluating political selection along the chinese administrative ladder', *Comparative Political Studies* **51**(8), 1074–1105.

Li, H. and Zhou, L.-A. (2005), 'Political turnover and economic performance: the incentive role of personnel control in china', *Journal of Public Economics* **89**(9-10), 1743–1762.

Li, X., Liu, C., Weng, X. and Zhou, L.-A. (2019), 'Target setting in tournaments: Theory and evidence from china', *Economic Journal* **129**(623), 2888–2915.

Tan, J. and Zhao, J. Z. (2019), 'The rise of public-private partnerships in china: An effective financing approach for infrastructure investment?', *Public Administration Review* **79**(4), 514–518.

Wu, G. L., Feng, Q. and Wang, Z. (2021), 'A structural estimation of the return to infrastructure investment in china', *Journal of Development Economics* **152**, 102672.

Xiong, W. and Song, Z. M. (2024), 'The mandarin model of growth', *National Bureau of Economic Research* .

Xu, C. (2011), 'The fundamental institutions of china's reforms and development', *Journal of Economic Literature* **49**(4), 1076–1151.