The long-run effects of R&D place-based policies: Evidence from Russian Science Cities

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ONLINE APPENDIX

List of appendices *Page*

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A. Russian R&D and scientists over the transition

Figures A.1 and A.2 illustrate the magnitude of the shock that the dissolution of the USSR has represented for Russian science, and the later developments.

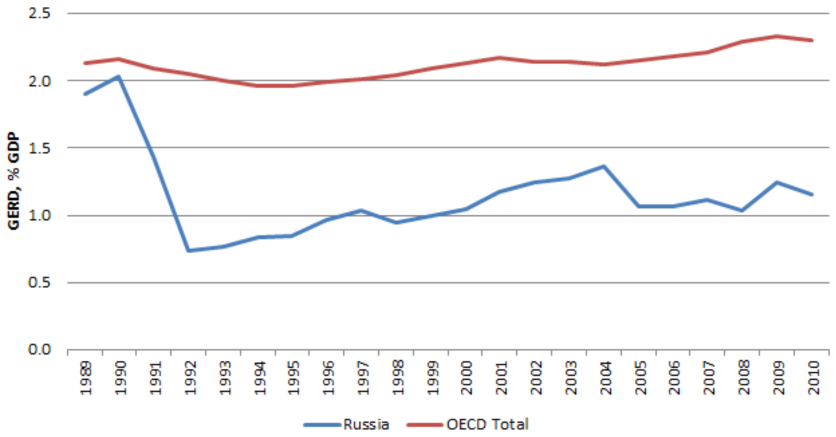

Figure A.1. Gov. spending in R&D as a share of GDP, Russia vs. OECD, 1989-2010

Source: Gokhberg (1997), Federal State Statistics Service - Rosstat (1996, 2000, 2005, 2011), and the OECD Main Science and Technology Indicators (MSTI) database.

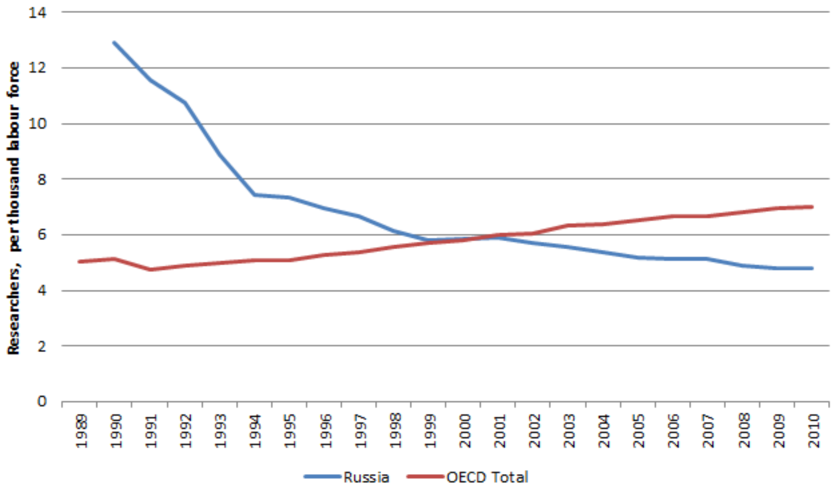

Figure A.2. Share of scientists in the labor force, Russia vs. OECD, 1989-2010

Source: Gokhberg (1997), Federal State Statistics Service - Rosstat (1996, 2000, 2005, 2011), and the OECD Main Science and Technology Indicators (MSTI) database.

B. Science Cities in the Soviet Union and Russia

Table B.1—: Science Cities

				Naukograd			Closed city^{d}		Priority specialization areas^{a}							
No.	Location^{a}	Oblast	Founded^{e}	Year Soviet status^{e}	Year Russian status^{f}	Type^{a}	Past	Now	Military base	Air rocket and space research	Electronics and radio engineering	Automation, IT and instrumentation	Chemistry, chemical physics and new materials	Nuclear complex	Energetics	Biology, biotechnology and agricultural sciences
1	Biysk	Altai Krai	1718	1957	2005	1	No	No	No	No	No	No	Yes	No	No	Yes
2	Mirny	Arkhangelsk	1957	1966		2	Yes	Yes	No	Yes	No	No	No	No	No	No
3	Severodvinsk	Arkhangelsk	1936	1939		2	Yes	No	Yes	No	No	Yes	No	No	No	No
4	Znamensk	Astrakhan	1948	1962		2	Yes	Yes	Yes	Yes	No	No	No	No	No	No
5	Miass	Chelyabinsk	1773	1955		1	No	No	No	Yes	No	Yes	No	No	No	No
6	Ozyorsk	Chelyabinsk	1945	1945		2	Yes	Yes	No	No	No	No	No	Yes	No	No
7	Snezhinsk	Chelyabinsk	1957	1957		2	Yes	Yes	No	No	No	No	No	Yes	No	No
8	Tryokhgorny	Chelyabinsk	1952	1952		2	Yes	Yes	No	No	No	Yes	No	Yes	No	No
9	Ust-Katav	Chelyabinsk	1758	1942		1	No	No	No	Yes	No	Yes	No	No	No	No
10	Kaspiysk^{c}	Dagestan	1932	1936		2	No	No	No	No	No	Yes	No	No	No	No
11	Akademgorodok	Irkutsk	1949	1988		5	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
12	Angarsk^{c}	Irkutsk	1948	1957		2	No	No	No	No	No	No	Yes	Yes	No	No
13	Obninsk	Kaluga	1946	1946	2000	2	No	No	No	No	No	Yes	No	Yes	Yes	No
14	Sosensky^{c}	Kaluga	1952	1973		3	No	No	No	No	No	Yes	No	No	No	No
15	Komsomolsk-on-Amur	Khabarovsk	1932	1934		1	No	No	No	Yes	No	Yes	No	No	No	No
16	Krasnodar-59^{b}	Krasnodar					No	No		No	No	No	No	No	No	No
17	Akademgorodok	Krasnoyarsk	1944	1965		5	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
18	Zelenogorsk	Krasnoyarsk	1956	1956		2	Yes	Yes	No	No	No	No	Yes	Yes	No	No
19	Zheleznogorsk	Krasnoyarsk	1950	1954		2	Yes	Yes	No	Yes	No	No	No	Yes	No	No
20	Kurchatov^{c}	Kursk	1968	1976		2	No	No	No	No	No	No	No	Yes	Yes	No
21	Gatchina	Leningrad	1928	1956		1	No	No	No	No	No	Yes	No	Yes	No	No
22	Primorsk	Leningrad	1268	1948		1	No	No	No	Yes	No	No	No	No	No	No
23	Sosnovy Bor	Leningrad	1958	1962		3	Yes	Yes	No	No	Yes	No	No	Yes	Yes	No
24	Zelenograd	Moscow City	1958	1958		2	No	No	No	No	Yes	Yes	No	No	No	No
25	Avtopoligon	Moscow Oblast	1964	1964		4	No	No	No	No	No	Yes	No	No	No	No
26	Balashikha	Moscow Oblast	1830	1942		1	No	No	No	Yes	No	Yes	No	No	No	No
27	Beloozersky	Moscow Oblast	1961	1961		4	No	No	No	Yes	No	No	No	No	No	No
28	Chernogolovka	Moscow Oblast	1710	1956	2008	3	No	No	No	No	No	Yes	Yes	No	No	No
29	Dolgoprudny	Moscow Oblast	1931	1951		2	No	No	No	No	No	Yes	Yes	No	No	No
30	Dubna	Moscow Oblast	1956	1956	2001	2	No	No	No	Yes	No	Yes	No	Yes	No	No
31	Dzerzhinsky	Moscow Oblast	1938	1956		3	No	No	No	Yes	No	Yes	Yes	No	No	No
32	Fryazino	Moscow Oblast	1584	1953	2003	3	No	No	No	Yes	Yes	Yes	No	No	No	No
33	Istra	Moscow Oblast	1589	1946		1	No	No	No	Yes	No	Yes	No	No	Yes	No
34	Khimki	Moscow Oblast	1850	1950		1	No	No	No	Yes	No	Yes	No	No	No	No
35	Klimovsk	Moscow Oblast	1882	1940		1	No	No	No	No	No	Yes	No	No	No	No
36	Korolyov	Moscow Oblast	1938	1946	2001	1	No	No	No	Yes	No	Yes	Yes	No	No	No
37	Krasnoarmeysk	Moscow Oblast	1928	1934		1	No	No	No	No	No	Yes	Yes	No	No	No
38	Krasnogorsk^{c}	Moscow Oblast	1932	1942		3	No	No	No	No	Yes	No	No	No	No	No

Notes: [a] Based on Agirrechu's 2009 list, unless specified otherwise. Type: 1 - Science Cities, "scientific core" established in existing cities, which often had a particular historical significance; 2 - Science Cities that received city status simultaneously (or a few years later) with the creation of a scientific or scientific-industrial complex at a practically new location (often in the "open field"); 3 - Science Cities that have arisen in existing settlements and received city status after obtaining scientific functions; 4 - Science Cities that do not have city status; 5 - academic town. [b] Based on NAS (2002). [c] Based on Lappo and Polyan (2008). [d] Russian Wikipedia article on closed cities (ZATO), 28 September 2016. [e] Wikipedia articles for each city, 28 September 2016. [f] Russian Wikipedia article on Science Cities, 28 September 2016.

Table B.1 – continued from previous page

				Naukograd			Closed city[d]		Priority specialization areas[a]							
No.	Location[a]	Oblast	Founded[e]	Year Soviet status[e]	Year Russian status[f]	Type[a]	Past	Now	Military base	Air rocket and space research	Electronics and radio engineering	Automation, IT and instrumentation	Chemistry, chemical physics and new materials	Nuclear complex	Energetics	Biology, biotechnology and agricultural sciences
39	Krasnoznamensk	Moscow Oblast	1950	1950		2	Yes	Yes	No	Yes	No	No	No	No	No	No
40	Lukhovitsy	Moscow Oblast	1594	1957?		1	No	No	No	Yes	No	No	No	No	No	No
41	Lytkarino	Moscow Oblast	1939	1957		1	No	No	No	Yes	No	Yes	No	No	No	No
42	Lyubertsi[c]	Moscow Oblast	1623	1948		1	No	No	No	No	No	Yes	No	No	No	No
43	Mendeleyevo	Moscow Oblast	1957	1965		4	No	No	No	No	No	Yes	No	No	No	No
44	Mytishchi[c]	Moscow Oblast	1460	1935		1	No	No	No	No	No	Yes	No	No	No	No
45	Obolensk	Moscow Oblast	1975	1975		4	Yes	No	No	No	No	No	No	No	No	Yes
46	Orevo	Moscow Oblast	1954	1954		4	No	No	No	Yes	No	No	No	No	No	No
47	Peresvet	Moscow Oblast	1948	1948		2	No	No	No	Yes	No	No	No	No	No	No
48	Protvino	Moscow Oblast	1960	1960	2008	3	Yes	No	No	No	No	Yes	No	Yes	No	No
49	Pushchino	Moscow Oblast	1956	1966	2005	3	No	No	No	No	No	No	No	No	No	Yes
50	Remmash	Moscow Oblast	1957	1957		4	No	No	No	Yes	No	No	No	No	No	No
51	Reutov	Moscow Oblast	1492-1495	1940	2003	1	No	No	No	Yes	No	Yes	No	No	No	No
52	Tomilino	Moscow Oblast	1894	1961		4	No	No	No	Yes	No	Yes	No	No	No	No
53	Troitsk	Moscow Oblast	1617	1977	2007	3	No	No	No	No	No	Yes	No	Yes	No	No
54	Yubileyny	Moscow Oblast	1939	1950		3	Yes	No	No	Yes	No	No	No	No	No	No
55	Zheleznodorozhny	Moscow Oblast	1861	1952		3	No	No	No	No	No	Yes	No	No	No	No
56	Zhukovsky	Moscow Oblast	1933	1947	2007	2	No	No	No	Yes	No	No	No	No	No	No
57	Zvyozdny gorodok	Moscow Oblast	1960	1960		4	Yes	Yes	No	Yes	No	No	No	No	No	No
58	Apatity (Akademgorodok)	Murmansk	1926	1954		2	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
59	Polyarnye Zori[c]	Murmansk	1968	1973		2	No	No	No	No	No	No	No	Yes	Yes	No
60	Balakhna (Pravdinsk)	Nizhny Novgorod	1932	1941		1	No	No	No	No	Yes	No	No	No	No	No
61	Dzerzhinsk	Nizhny Novgorod	1606	1930		2	No	No	No	No	No	No	Yes	No	No	No
62	Sarov	Nizhny Novgorod	1310	1947		1	Yes	Yes	No	No	No	No	No	Yes	No	No
63	Akademgorodok	Novosibirsk	1957	1957		5	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
64	Koltsovo	Novosibirsk	1979	1979	2003	4	Yes	No	No	No	No	No	No	No	No	Yes
65	Krasnoobsk	Novosibirsk	1970	1978		4	No	No	No	No	No	No	No	No	No	Yes
66	Novosibirsk-49[b]	Novosibirsk					No	No		No	No	No	No	No	No	No
67	Omsk-5[b]	Omsk					No	No								
68	Zarechny	Penza	1954	1958		2	Yes	Yes	No	No	No	No	No	Yes	Yes	No
69	Perm-6[b]	Perm					No	No								
70	Bolshoy Kamen[c]	Primorsk Krai	1947	1954		2	Yes	Yes	No	No	No	Yes	No	No	No	No
71	Volgodonsk[c]	Rostov	1950	1976		3	No	No	No	No	No	No	No	Yes	Yes	No
72	Zernograd	Rostov	1929	1935		1	No	No	Yes	No	No	No	No	No	No	Yes
73	Petergof	Saint Petersburg	1711	1960	2005	1	No	No	No	No	No	Yes	Yes	No	No	No
74	Desnogorsk[c]	Smolensk	1974	1982		2	No	No	No	No	No	No	No	Yes	Yes	No
75	Lesnoy	Sverdlovsk	1947	1954		2	Yes	Yes	No	No	No	No	No	Yes	No	No
76	Nizhnyaya Salda	Sverdlovsk	1760	1958		1	No	No	No	Yes	No	No	No	No	No	No
77	Novouralsk	Sverdlovsk	1941	1949		2	Yes	Yes	No	No	No	No	Yes	Yes	No	No
78	Verhnyaya Salda[c]	Sverdlovsk	1778	1933		3	No	No	No	No	No	No	Yes	No	No	No
79	Zarechny	Sverdlovsk	1955	1955		2	No	No	No	No	No	No	No	Yes	Yes	No
80	Michurinsk	Tambov	1635	1932	2003	1	No	No	No	No	No	Yes	No	No	No	Yes
81	Zelenodolsk[c]	Tatarstan	1865	1949		1	No	No	No	No	No	Yes	No	No	No	No
82	Akademgorodok	Tomsk	1972	1972		5	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
83	Seversk	Tomsk	1949	1949		2	Yes	Yes	No	No	No	No	Yes	Yes	No	No

Notes: [a] Based on Agirrechu's 2009 list, unless specified otherwise. Type: 1 - Science Cities, "scientific core" established in existing cities, which often had a particular historical significance; 2 - Science Cities that received city status simultaneously (or a few years later) with the creation of a scientific or scientific-industrial complex at a practically new location (often in the "open field"); 3 - Science Cities that have arisen in existing settlements and received city status after obtaining scientific functions; 4 - Science Cities that do not have city status; 5 - academic town. [b] Based on NAS (2002). [c] Based on Lappo and Polyan (2008). [d] Russian Wikipedia article on closed cities (ZATO), 28 September 2016. [e] Wikipedia articles for each city, 28 September 2016. [f] Russian Wikipedia article on Science Cities, 28 September 2016.

Table B.1 – continued from previous page

				Naukograd			Closed city[d]		Priority specialization areas[a]							
No.	Location[a]	Oblast	Founded[e]	Year Soviet status[e]	Year Russian status[f]	Type[a]	Past	Now	Military base	Air rocket and space research	Electronics and radio engineering	Automation, IT and instrumentation	Chemistry, chemical physics and new materials	Nuclear complex	Energetics	Biology, biotechnology and agricultural sciences
84	Redkino	Tver	1843	1950		4	No	No	No	No	Yes	No	Yes	No	No	No
85	Solnechny	Tver	1947	1951		4	Yes	Yes	Yes	No	No	Yes	No	No	No	No
86	Udomlya[c]	Tver	1478	1984		3	No	No	No	No	No	No	No	Yes	Yes	No
87	Glazov[c]	Udmurtia	1678	1948		1	No	No	No	No	No	No	No	Yes	No	No
88	Votkinsk[c]	Udmurtia	1759	1957		1	No	No	No	Yes	No	Yes	No	No	No	No
89	Dimitrovgrad	Ulyanovsk	1698	1956		1	No	No	No	No	No	No	No	Yes	Yes	No
90	Kovrov	Vladimir	1778	1916		1	No	No	No	No	No	Yes	No	No	No	No
91	Melenki	Vladimir	1778			1	No	No	No	No	No	Yes	No	No	No	No
92	Raduzhny	Vladimir	1971	1971		2	Yes	Yes	No	No	Yes	Yes	No	No	No	No
93	Novovoronezh[c]	Voronezh	1957	1964		2	No	No	No	No	No	No	No	Yes	Yes	No
94	Borok	Yaroslavl	1807	1956		4	No	No	No	No	No	No	No	No	No	Yes
95	Pereslavl-Zalessky	Yaroslavl	1152	1964		1	No	No	No	No	No	Yes	Yes	No	No	No

Notes: [a] Based on Agirrechu's 2009 list, unless specified otherwise. Type: 1 - Science Cities, "scientific core" established in existing cities, which often had a particular historical significance; 2 - Science Cities that received city status simultaneously (or a few years later) with the creation of a scientific or scientific-industrial complex at a practically new location (often in the "open field"); 3 - Science Cities that have arisen in existing settlements and received city status after obtaining scientific functions; 4 - Science Cities that do not have city status; 5 - academic town. [b] Based on NAS (2002). [c] Based on Lappo and Polyan (2008). [d] Russian Wikipedia article on closed cities (ZATO), 28 September 2016. [e] Wikipedia articles for each city, 28 September 2016. [f] Russian Wikipedia article on Science Cities, 28 September 2016.

C. Detailed data description and sources

Table C.1—: Municipal level data sources and variables

Data type	Data sub-type	Data source	Description
Factors guiding the selection of location of Science Cities			
Administrative	Various identification information for municipality, region and federal district	OpenStreetMap, available through GIS-LAB (`http://gis-lab.info/qa/osm-adm.html`)	Unique municipality, federal district and region (oblast, krai, republic) identificators, codes and names
Population	1897 population data	First General Census of the Population of the Russian Empire in 1987, available through Demoscope (`http://www.demoscope.ru/weekly/ssp/rus1897_02.php`)	All population in cities in 1897
	1926 population data	1926 Soviet Census, available through Demoscope (`http://www.demoscope.ru/weekly/ssp/1926.xls`)	All population in cities in 1926
	1939 population data	1939 Soviet Census, available through Demoscope (`http://www.demoscope.ru/weekly/ssp/rus_pop_39_2.php`)	All population in cities in 1939
	1959 census data	January 1959 Soviet Census, available through Demoscope (`http://www.demoscope.ru/weekly/ssp/rus59_reg1.php`)	All population in municipality in 1959, estimates for some municipalities
	1989 census data	January 1989 Soviet Census, available through Demoscope (`http://www.demoscope.ru/weekly/ssp/rus89_reg1.php`)	All population in municipality in 1989, estimates for some municipalities
Geography	Area	Calculated in QGIS based on OpenStreetMap	Municipality area calculated in QGIS, measured in square kilometers
	Coordinates of the municipality center		GPS coordinates of the center of municipality calculated in QGIS
	Altitude	Jarvis et al. (2008). Consortium for Spatial Information (CGIAR-CSI) SRTM 90m Digital Elevation Data, version 4, available at `http://srtm.csi.cgiar.org/`	Altitude of municipality in meters (mean, median, SD, min and max value)
	Temperatures in January and July	WorldClim version 1 (`http://www.worldclim.org/version1`), developed by Hijmans et al. (2005)	Monthly temperature data, for the period 1960-90, assigned to municipalities in QGIS. Average, median, standard deviation, minimum, and maximum.
	Railroad	Vernadsky State Geological Museum and United States Geological Survey, 20010600 (2001) and Central management unit of the military communications of the Red Army (1943)	Data on railroads were constructed using railroads shapefile describing the railroads of the former Soviet Union as of the early 1990s prepared by Vernadsky State Geological Museum and United States Geological Survey, 20010600 (2001), along with a map of railroads from 1943 from Central management unit of the military communications of the Red Army (1943) to manually remove any differences between the situation depicted in the shapefile and the 1943 map. Indicator equal to 1 if municipality has access to railroad, and 0 otherwise. Railroads are as of late 1940s.

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Data type	Data sub-type	Data source	Description
	Coastline/major river/lake	Natural Earth, 1:10m Physical Vectors version (`http://www.naturalearthdata.com/downloads/10m-physical-vectors/`)	Indicator equal to 1 if municipality has access to coast/major river/lake and 0 otherwise.
	Distances	Calculated in QGIS based on the sources specified above	Distance (in km) from the center of municipality to the nearest railroad, coast, major river, lake, USSR border, plant (of any type), and HEI (of any type).
Level of industrial development	Data on the factories, research and design establishments of the Soviet defense industry in 1947	Dexter and Rodionov (2016). The dataset contains almost 30,000 entries and includes the name, location, main branch of defense production, establishment type as well as the start and end date for the establishment's military work.	Number of factories (*zavod*) and subordinated organizations.
R&D institutes			Number of Scientific Research & Design Institutes (*NII*, *TsNII*, and *GSPI*), design bureaus, and test sites.
Higher education institutes (HEI)	HEIs in the municipality in 1959	De Witt (1961)	Number of all HEIs, HEIs specialisng in technical sciences, and HEIs specialising in biology and medical sciences
State Bank	State bank State Bank branches in 1946	Bircan and De Haas (2020), originally in State Bank (1946)	Number of State Bank branches
		Long-term outcomes of interest	
Patents	Applications to EPO	European Patent Office (2015)'s PATSTAT European Patent Register. Patents are matched to municipalities via inventors' addresses.	Number of patent applications to EPO in 1978-2013, by inventor (simple and fractional counting)
Population	2010 census data	Federal State Statistics Service - Rosstat 2010 Russian census, available at `http://www.gks.ru/free_doc/new_site/perepis2010/croc/perepis_itogi1612.htm`	All population, population with higher education, and population with PhD or doctoral degrees in municipality in 2010
SMEs	Results of the 2010 SME census	Federal State Statistics Service - Rosstat Complete statistical observation of small and medium-sized businesses, available at `https://rosstat.gov.ru/small_business`	The dataset contains information on the number of firms, revenue, and number of employees. We use No. of SMEs (per 1,000 inhabitants) and SME labor productivity (revenue per worker). The SME census does not cover ZATOs, so 16 Science Cities, which are also ZATOs, are not covered.
Night time lights	Average stable night lights	Version 4 DMSP-OLS Nighttime Lights Time Series, National Oceanic and Atomspheric Administration (`http://ngdc.noaa.gov/eog/dmsp/downloadV4composites.html`)	Average night lights for 1992-94 and 2009-11, cleaned of gas flares
Other municipal indicators	Municipal budget	Federal State Statistics Service - Rosstat, available at `https://gks.ru/free_doc/new_site/bd_munst/munst.htm`	Average annual municipal budget revenues and expenditures over 2006-16, in 2010 prices. Total values and breakdown by major categories.
	Amenities		Length of local roads that are lit during the night, number of museums, theatres and libraries in a municipality in 2010.
	Salaries		Salaries in R&D and wholesale-retail in a municipality in 2010.
	Employment		Employment in R&D in a municipality in 2010.

D. Municipal-level summary statistics

Table D.1 below displays summary statistics for all variables featured in our empirical analysis (in five panels, by variable category), separately for Science Cities and other municipalities. For each variable, the table also displays the p-value obtained from a t-test for the differences in means between the two groups.

Table D.1—: Municipal-level data: descriptive statistics

	Science Cities		Other municipalities		
	Obs.	Mean (s.d.)	Obs.	Mean (s.d.)	p-value
Panel A: Socio-economic outcomes					
Population in 2010 (th.)	84	95.175 (71.773)	2250	58.324 (278.488)	0.000
Graduate share in 2010	84	0.224 (0.078)	2250	0.110 (0.044)	0.000
Postgraduate share in 2010	84	0.006 (0.004)	2250	0.003 (0.002)	0.000
Fractional patents before 2000	84	3.743 (6.512)	2250	1.090 (32.153)	0.007
Fractional patents after 2000	84	11.878 (15.640)	2250	3.539 (89.093)	0.001
Night lights (standardized), 2009-11	84	1.505 (1.411)	2250	-0.062 (0.926)	0.000
Employment share in R&D-ICT	67	0.036 (0.034)	2176	0.007 (0.009)	0.000
Average salary in R&D-ICT (th.)	67	25.047 (11.423)	2127	15.363 (7.750)	0.000
Average salary in retail (th.)	67	22.744 (11.807)	2060	13.137 (6.713)	0.000
No. of SMEs (per 1,000 inhabitants)	65	24.119 (8.568)	2159	27.492 (9.617)	0.003
SME labor productivity	65	1.615 (0.709)	2153	0.794 (0.427)	0.000
Panel B: Budget measures					
Avg. total revenues p.c.	64	19.468 (5.984)	2173	24.761 (51.671)	0.000
Avg. transfers p.c.	64	9.538 (3.786)	2173	18.380 (32.718)	0.000
Avg. tax income p.c.	64	9.930 (4.136)	2173	6.380 (22.790)	0.000
Avg. total expenditures p.c.	64	9.577 (3.059)	2173	10.842 (15.374)	0.013
Avg. exp. on roads p.c.	64	0.626 (0.476)	2173	0.731 (1.164)	0.106
Avg. exp. on security p.c.	64	0.149 (0.126)	2173	0.208 (0.739)	0.009
Avg. exp. on transportation p.c.	64	0.164 (0.156)	2173	0.237 (0.981)	0.012
Avg. exp. on utilities p.c.	64	2.230	2173	3.057	0.006

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	Science Cities		Other municipalities		
	Obs.	Mean (s.d.)	Obs.	Mean (s.d.)	p-value
		(1.118)		(12.431)	
Avg. exp. on education p.c.	64	9.577 (3.059)	2173	10.842 (15.374)	0.013
Avg. exp. on health p.c.	64	2.181 (1.569)	2173	2.095 (2.305)	0.673
Avg. exp. on social services p.c.	64	1.441 (1.301)	2173	2.087 (3.165)	0.000
Panel C: Local amenities					
Share of streets lit in the night	63	0.752 (0.264)	1962	0.477 (0.278)	0.000
Libraries per 1,000 inhabitants	64	0.185 (0.207)	2030	0.792 (0.564)	0.000
Museums per 1,000 inhabitants	64	0.019 (0.020)	2000	0.048 (0.072)	0.000
Theaters per 1,000 inhabitants	64	0.003 (0.005)	1964	0.001 (0.007)	0.009
Panel D: Geographical characteristics					
Latitude	84	55.698 (3.739)	2250	53.981 (5.110)	0.000
Longitude	84	47.794 (20.860)	2250	59.955 (29.410)	0.000
Average temperature in January (°C)	84	-11.350 (3.699)	2250	-13.559 (7.045)	0.000
Average temperature in July (°C)	84	18.528 (1.729)	2250	18.755 (2.675)	0.251
Average altitude higher than 1,000km	84	0.000 (0.000)	2250	0.040 (0.196)	0.000
Has access to rivers or lakes	84	0.369 (0.485)	2250	0.445 (0.497)	0.161
Direct access to the coast	84	0.095 (0.295)	2250	0.061 (0.239)	0.295
(Log) area in km^2	84	5.196 (1.933)	2250	7.398 (1.741)	0.000
Is a closed city	84	0.202 (0.404)	2250	0.011 (0.105)	0.000
Panel E: Historical characteristics					
Has R&D institutes in 1947	84	0.333 (0.474)	2250	0.055 (0.227)	0.000
(Log) distance from railroads in 1943	84	1.240 (1.328)	2250	2.582 (1.953)	0.000
(Log) no. of plants in 1947	84	0.937 (1.001)	2250	0.363 (0.756)	0.000
(Log) no. of plants within 200km in 1947	84	6.027 (1.529)	2250	3.959 (1.765)	0.000
(Log) distance from the USSR border in 1946	84	6.148 (1.272)	2250	6.134 (1.206)	0.923
No. of State Bank branches in 1946	84	0.631 (0.788)	2250	1.096 (0.987)	0.000

Continued on next page

	Science Cities		Other municipalities		
	Obs.	Mean (s.d.)	Obs.	Mean (s.d.)	p-value
No. of universities in 1959	84	0.143 (0.415)	2250	0.196 (2.205)	0.409
(Log) urban population in 1897	84	2.476 (4.079)	2250	1.996 (3.735)	0.291
(Log) urban population in 1926	84	3.772 (4.534)	2250	2.738 (4.205)	0.043
(Log) urban population in 1939	84	5.698 (5.002)	2250	3.127 (4.604)	0.000
(Log) urban population in 1959	84	7.390 (4.784)	2250	5.629 (4.894)	0.001
(Log) total population in 1959	84	9.632 (2.079)	2250	10.227 (1.311)	0.011
(Log) total population within 200km in 1959	84	15.494 (1.068)	2250	14.123 (2.413)	0.000
(Log) total population in 1989	82	11.019 (1.187)	2232	10.374 (1.058)	0.000

Notes: The p-values in the rightmost columns are obtained from two-sided t-tests on the equality of each variable's mean between Science Cities and other municipalities. "Average altitude higher than 1,000km," "Has access to rivers or lakes," "Direct access to the coast," "Is a closed city," and "Has R&D institutes in 1947" are coded as dummy variables. Distances are expressed in kilometers. th. – thousands; avg. – average; p.c. – per capita; exp. – expenditures. Refer to Appendix C for detailed data sources.

E. Construction and analysis of the matched sample

This appendix describes the strategy we adopted for constructing the matched sample, with special attention to the possible issues of the Stable Unit Treatment Value Assumption (SUTVA) violation.

Construction of the matched sample. When constructing the matched sample following our empirical strategy (motivated by the historical and institutional features discussed in section I of the paper), we must take into account two possibly conflicting requirements. On the one hand, we would preferably match cities as close in space as possible, to control for spatially correlated unobservables: local characteristics that are shared within a geographical area (such as, for instance, proximity to a major city like Moscow) that predict current economic outcomes. At the very least, we must match Science Cities located in "usable", more urbanized areas to control municipalities from similar places, and Science Cities located in "secret", more isolated locations to places alike. On the other hand, we must account for possible violations of the SUTVA ("interference"): the assignment of the Science City treatment to one city might also affect the cities nearby, either through positive spillovers, negative spillovers (draining their resources), or a combination of both. This leads to a trade-off: we want to match cities that are "close, but not too close".

We can obtain matches that are close in space, at least in the more densely populated and urbanized areas of Russia, by including geographical coordinates as well as local demographic and economic intensity measures (historical population and plants within 200km) in our set of matching covariates X_{ik}. In order to mitigate concerns of SUTVA violation, a common approach is that of removing cities that are "too close" to Science Cities from the set of potential control municipalities. We believe that a distance of 50km between the two municipalicities' geographical centroids is a suitable threshold for enforcing a restriction of this sort. In our setting, however, we found that enforcing restriction of this sort can lead to a matched sample that is undesirable in two respects. First, the matching covariates would not be very well balanced. Second, matches would be too far away in space, contradicting our requirement of controlling for spatially correlated unobservables. The contradiction is largely due to those Science Cities that are clustered in especially densely populated areas: the Moscow region and (to a much lesser extent) the Urals. In these areas, such a strong restriction would remove most local municipalities from the set of potential controls.

Our approach is thus as follows. First, we make the following assumption.

No-SUTVA hypothesis. The effect of Science Cities only spills over other close control cities – specifically, control cities that are not more than 50km apart.

The key assumption is that the effect of a Science City does not spill over other Science Cities. We find this hypothesis tenable in our setting, given the unique specialization typical for each Science City and the fact that those few connections that used to exist between some pairs of Science Cities (e.g. input-output linkages) were disrupted following the collapse of the USSR.

Thus, we construct our matching sample by imposing a milder restriction: that Science Cities and their matches must be at least 50km apart. This leads to a matched sample with adequate balance properties, at the cost of making some matched pairs farther apart in geographical space. By the No-SUTVA hypothesis above, no treated city can be subject to interference, while the sample of matched control cities has the following characteristics.

- In some matched pairs, the control unit is not subject to interference: it is at least 50km away from its paired Science City and any other Science City.
- In other matched pairs, the control unit may be subject to interference, due to the presence of other Science Cities within a 50km radius.

This allows us to *test* possible instances of SUTVA violation, by comparing the average differences between treated and control cities across these two components of the matched sample. The results in Table 5 in the paper do not allow us to rule out that interference occurs, but they indicate that if they do, positive and negative effects likely offset one another.

Our approach is inspired by recent advances from the statistical literature. In particular, Forastiere, Airoldi and Mealli (2020) propose a strategy to perform causal inference when treated and control units are related through a network and SUTVA is violated. Under a modified Conditional Independence Assumption that allows for interference, they propose a sample subclassification approach based on the propensity score that allows them to both estimate and test interference, since the observations of each subsample in their classification has a similar number of treated network "neighbors." While our approach is not as refined, we believe that the key idea by Forastiere, Airoldi and Mealli (2020) – that is, grouping observations with a similar "neighborhood" of treated units – can be transferred to our setting. Ultimately, a geographical space is a particular kind of network.

Analysis of the matched sample. We now examine the matched pairs more closely: Figure E.1 displays them on the map of Russia. Thanks to our choice of covariates and our balanced approach described above, Science Cities and their counterparts are matched fairly close in space, especially so in the more densely populated and developed areas of Russia. In particular, municipalities very close to Moscow are typically matched to other municipalities that are also very close to Moscow, which mitigates concerns about the proximity of many Science Cities to the capital of Russia and the possible beneficial implications of it.

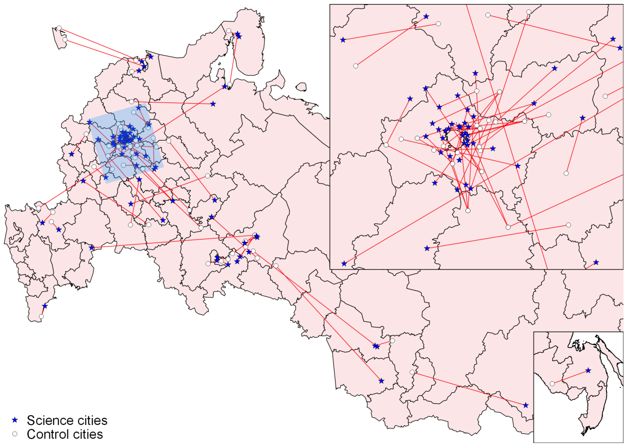

Figure E.1. Mapping Science Cities and their matches

Table E.1 reports the analysis of covariate balance; it displays the standardized mean difference and the variance ratio between treated and control observations, in both the original and the matched samples. The table shows that matching achieves a remarkable degree of balance in both the first and the second moment, despite the rigidity of the Mahalanobis algorithm. Recall that the 78 matched pairs also satisfy exact matching constraints imposed on five dummy variables, including that for closed city status. In our matched sample, exactly 39 control units have at least one other treated city that is less than 50km away (the average minimal distance is 28.52km) while the remaining 39 control units are not as close to other Science Cities (the average minimal distance is 158.54km). This perfect split is ideal towards our approach to testing for instances of SUTVA violation described above.

Table E.1—Covariate balance: Science Cities and their matched municipalities

	Standardized bias		Variance ratio	
	Raw	Matched	Raw	Matched
Latitude	0.383	0.061	0.535	1.272
Longitude	-0.477	0.032	0.503	1.235
January average temperature (°C)	0.393	0.033	0.276	0.820
July average temperature (°C)	-0.101	0.011	0.418	1.250
(Log) area in km^2	-1.197	0.019	1.232	0.808
(Log) distance from the USSR border	0.011	-0.090	1.113	1.095
(Log) distance from railroads in 1943	-0.803	0.050	0.462	1.098
(Log) urban population in 1897	0.123	-0.029	1.193	0.969
(Log) urban population in 1926	0.236	-0.026	1.163	0.944
(Log) urban population in 1939	0.535	0.072	1.180	0.965
(Log) urban population in 1959	0.364	-0.036	0.956	1.088
(Log) total population in 1959	-0.343	0.045	2.514	0.776
(Log) total population within 200km in 1959	0.735	0.027	0.196	1.045
(Log) no. of plants in 1947	0.648	0.053	1.751	0.957
(Log) no. of plants within 200km in 1947	1.253	0.061	0.751	0.991
No. of universities in 1959	-0.034	-0.060	0.035	0.555
No. of State Bank branches in 1946	-0.521	0.000	0.638	1.000

Notes. For each variable listed in the first column, this table reports the difference in the variance-standardized mean (the "standardized bias," reported in percentage points) and the variance ratio between treated and control observations, for both the raw sample and the matched sample. The matched sample is obtained by "genetic" Mahalanobis matching on the variables reported above, forcing exact matching on the five dummy variables included in our list of covariates (see the paper and the notes to Table D.1).

F. Additional empirical results

This appendix reports miscellaneous empirical results that complement those in section IV in the paper. First, we discuss additional estimates related to potential drivers of our main results: variables that measure flows and stocks of expenditures in public goods. Subsequently, we report a set of results that are restricted to the subsample of "historical" Science Cities. For all these estimates, we draw conclusions about statistical significance while controlling for multiple hypotheses (specifically, we control for the FWER using Holm's method by grouping outcome variables as discussed in the main text). Lastly, we elaborate the analysis of the night lights time series in our matched sample, and their persistence over time (Figure 2 in the paper) with the aid of a regression model.

ATT estimation: Detailed budget outcomes and local public goods. In light of the estimates reported in Table 4 in the paper, we argue that the total size of local municipal expenditures is unlikely to drive the main results. What if Science Cities differed not in the total size, but in the composition of local expenditures? This idea is at the core of the vES hypothesis, which postulates enduring effects from the local investment in specific categories of public goods (such as physical infrastructure). To explore this possibility, we separately analyze the following categories of municipal-level expenditures: roads, security, transportation, utilities, education, health, and social services. Local expenditures in roads and education are prime candidates to act as drivers of our main results. However, the estimates reported in Table F.1, panel A dispel all of these suspects. In fact, the ATT estimates are generally not statistically different from zero and the values of Γ^* are consistently equal to 1. Note that the raw differences are in most cases negative and statistically significant.

TABLE F.1—MUNICIPAL-LEVEL MATCHING: ADDITIONAL RESULTS, ALL SCIENCE CITIES

	Whole sample	*Matched sample* (1 nearest neighbor)				
Outcome	Raw difference	T	C	ATT	ATT b.a.	Γ^*
Panel A: Detailed budget outcomes						
Exp. on roads p.c.	-0.110 (0.065)	64	51	-0.096 (0.107)	0.027 (0.098)	1.00
Exp. on security p.c.	-0.061 (0.023)	64	51	-0.006 (0.017)	-0.004 (0.016)	1.00
Exp. on transportation p.c.	-0.080 (0.029)	64	51	-0.071 (0.046)	-0.049 (0.044)	1.00
Exp. on utilities p.c.	-0.891 (0.311)	64	51	-0.425 (0.229)	-0.646 (0.258)	1.00
Exp. on education p.c.	-1.126 (0.512)	64	51	0.662 (0.355)	0.094 (0.447)	1.00
Exp. on health p.c.	0.061 (0.203)	64	51	-0.022 (0.178)	-0.316 (0.187)	1.00
Exp. on social services p.c.	-0.631 (0.177)	64	51	-0.260 (0.185)	-0.187 (0.191)	1.00
Panel B: Local amenities						
Libraries per 1,000 inhabitants	-0.601 (0.029)	64	49	-0.113 (0.028)	-0.109 (0.031)	1.00
Museums per 1,000 inhabitants	-0.029 (0.003)	64	49	-0.004 (0.003)	-0.005 (0.003)	1.00
Theaters per 1,000 inhabitants	0.002 (0.001)	64	49	0.001 (0.001)	0.002 (0.001)	1.00
Share of streets lit in the night	0.267 (0.034)	63	49	0.118 (0.046)	0.045 (0.048)	1.40

Notes. See the notes accompanying Table 1 in the paper. exp. – expenditures; p.c. – per capita.

Results in Table 4 in the paper and Table F.1 concern the flows of expenditures in public goods. What if Science Cities and their matched counterparts differed in the stock of public goods, instead? As Science Cities were shaped for the purpose of accommodating researchers and scientists, their higher density of skilled workers today may be explained by a larger inherited endowment of cultural public goods, such as libraries, museums and theaters, or other types of public goods. Table F.1, panel B reports our estimates for this hypothesis using ROSSTAT data. To our surprise, former Science Cities appear to possess, if anything, fewer cultural amenities than ordinary municipalities. This difference, however, is not statistically significant in the matched sample, except for libraries (though Γ^* equals one there). We believe that the equal distribution of cultural amenities can be explained through the emphasis placed on shared education and culture by the communist ideology. Science Cities appear to have a higher share of streets lit in the night, but this evidence is too weak (in magnitude and statistically). Overall, these factors appear unlikely to drive our main results.

ATT estimation: Other results for the historical Science Cities. While Table 2 estimates in the paper suggest that our main results – except in part those for patent applications and employment share in R&D and ICT – are not driven by the present-day Naukogrady, the latter may differ in other respects, such as patterns of population growth or use of local resources. To examine these possibilities, we replicate the "demographic dynamics" results from Table 3 in the paper on the sample of historical Science Cities. The estimates reported in Table F.2 below suggest that the demographic dynamics in the restricted sample is similar to that in the full sample.

Table F.2—Municipal-level matching, demographic dynamics: "historical" Science Cities

	Whole sample	*Matched sample* (1 nearest neighbor)				
Outcome	Raw difference	T	C	ATT	ATT b.a.	Γ^*
Graduate share: b.y. $\leq$ 1965	0.106 (0.011)	64	51	0.063 (0.010)	0.059 (0.011)	3.40
Graduate share: b.y. $>$ 1965	0.097 (0.008)	64	51	0.048 (0.008)	0.043 (0.009)	2.80
Postgraduate share: b.y. $\leq$ 1955	0.003 (0.001)	64	51	0.002 (0.000)	0.002 (0.001)	2.20
Postgraduate share: b.y. $>$ 1955	0.003 (0.000)	64	51	0.002 (0.001)	0.002 (0.001)	1.85

Notes. See the notes accompanying Table 1 in the paper. b.y. – birth year.

Next, we replicate the budget and "amenity" outcome estimates (Tables 4 and F.1) in the restricted subsample; estimates are reported in Table F.3. The main budget estimates (Panel A) show the same pattern as in the larger sample: in per capita terms, historical Science Cities receive on average more resources from local taxes and less federal transfers, leaving the overall amount available for expenditures unchanged. Some of the ATT estimates for the detailed budget categories (Panel B) and for the stock of public goods (Panel C) are statistically significant, with typically low associated values of Γ^* (we draw these conclusions about statistical significance by controlling for the FWER grouping all outcomes from Table F.3 below and using Holm's method; for additional details, one can consult the replication data accompanying this online appendix). The signs of the statistically significant coefficients, however, go in opposite directions, suggesting that one cannot extrapolate major conclusions from these findings.

Table F.3—Municipal-level matching: additional results, "historical" Science Cities

	Whole sample	*Matched sample* (1 nearest neighbor)				
Outcome	Raw difference	T	C	ATT	ATT b.a.	Γ^*
Panel A: Main budget outcomes						
Total revenues p.c.	-5.976 (1.400)	51	44	-0.974 (0.748)	-1.308 (0.952)	1.00
All transfers p.c.	-8.840 (0.919)	51	44	-2.780 (0.630)	-2.773 (0.787)	1.00
Tax income p.c.	2.864 (0.753)	51	44	1.806 (0.395)	1.466 (0.413)	1.75
Total expenditures p.c.	-5.861 (1.357)	51	44	-0.996 (0.798)	-1.295 (1.256)	1.00
Panel B: Detailed budget outcomes						
Exp. on roads p.c.	-0.117 (0.075)	51	44	0.035 (0.057)	0.137 (0.065)	1.00
Exp. on security p.c.	-0.071 (0.024)	51	44	-0.013 (0.014)	-0.001 (0.013)	1.00
Exp. on transportation p.c.	-0.083 (0.030)	51	44	-0.037 (0.025)	-0.018 (0.025)	1.00
Exp. on utilities p.c.	-1.054 (0.313)	51	44	-0.555 (0.208)	-0.751 (0.242)	1.00
Exp. on education p.c.	-1.384 (0.521)	51	44	0.374 (0.290)	-0.027 (0.368)	1.00
Exp. on health p.c.	-0.070 (0.215)	51	44	-0.042 (0.143)	-0.308 (0.164)	1.00
Exp. on social services p.c.	-0.529 (0.208)	51	44	-0.329 (0.174)	-0.116 (0.201)	1.00
Panel C: Local amenities						
Libraries per 1,000 inhabitants	-0.577 (0.034)	51	42	-0.129 (0.027)	-0.118 (0.030)	1.00
Museums per 1,000 inhabitants	-0.028 (0.003)	51	42	-0.008 (0.003)	-0.007 (0.003)	1.00
Theaters per 1,000 inhabitants	0.002 (0.001)	51	42	0.002 (0.001)	0.002 (0.001)	2.90
Share of streets lit in the night	0.237 (0.038)	50	42	0.129 (0.038)	0.046 (0.038)	1.40

Notes. See the notes accompanying Table 1 in the paper. exp. – expenditures; p.c. – per capita.

The dynamics of night lights: Regression-based test of persistence. In what follows, we provide a regression-based formal test to support the claim that the two trends for night lights in Figure 2 in the paper, the one for the treated and the one for the control municipalities, do not converge over the time interval 1992-2010. Table F.4 below reports estimates of the following simple regression model:

$$Y_{it} = \pi_0 T_t + \pi_1 S_i \cdot T_t + \tau_t + \varepsilon_{it}, \tag{F.1}$$

where i indexes a city from the matched sample, t indexes the year, Y_{it} is the standardized night lights measure for that year, T_t is a linear trend, S_i is a dummy indicating Science City status, τ_t is a year fixed effect and ε_{it} is an error term which is allowed to be autocorrelated in time. Parameter π_1 in (F.1) represents differences in the linear trend between Science Cities and their matched counterparts. The estimates in Table F.4 are obtained from the sample comprising all matched Science Cities and their controls (column 1) and the subsample restricted to the "historical" Science Cities and their matches (column 2). Standard errors are calculated via the Newey-West HAC formula, allowing autocorrelation of ε_{it} up to 10 years. The estimates of π_1, albeit small in magnitude, are positive and statistically significant; this suggests that, if anything, Science Cities are on a divergent trend of economic development (as proxied by the night lights measure). Allowing for a longer autocorrelation time window of ε_{it} delivers virtually identical inferences and qualitative conclusions.

TABLE F.4—ESTIMATES OF PARAMETERS π_0 AND π_1 FROM MODEL (F.1)

	All Science Cities (1)	Historical Science Cities (2)
Linear trend, all (π_0)	0.0071	0.0063
	(0.0001)	(0.0001)
Trend difference for Science Cities (π_1)	0.0003	0.0002
	(0.0001)	(0.0001)
Year fixed effects	YES	YES
Number of observations	2964	2527

Notes. Standard errors reported in parentheses are estimated with the Newey-West HAC formula, allowing for autocorrelation up to 10 years. Dependent variable is standardized night lights measure.

The dynamics of night lights: "Grand ATT" estimation. Having ensured that there is no convergence, we estimate a "grand ATT" on the night lights matched panel by estimating the following simple model:

$$Y_{it} = \psi S_i + \tau_t' + \varepsilon_{it}'. \tag{F.2}$$

Here, parameter ψ represents the causal effect of Science City status, and identification is ensured by restricting the analysis to the matched sample. It is reasonable to expect the estimate(s) of ψ to be positive, but not necessarily statistically significant when allowing for autocorrelated disturbances. Note that this exercise cannot be performed along with the estimation of separate linear trends for Science Cities and their matches, because it would result in data overfitting. Once again, the autocorrelation of the error term is allowed for up to 10 years. The results are displayed in Table F.5. The baseline estimate reported in column 1 amounts to about one half of the standard deviation of the night lights measure, which is similar – if not slightly higher – to the ATT estimate of the 2009-11 average from Tables 1-2 in the paper, and is statistically significant. Adding bias adjustment terms *à la* Abadie and Imbens to the left-hand side measures Y_{it} (columns 2 and 4) and restricting the analysis to the "historical" Science Cities (columns 3 and 4) are of little consequence for our grand ATT estimates. To summarize, it appears that the long-run effect of Science City status on local economic activity – as proxied by the night lights measures – is statistically robust, of considerable magnitude, and constant over time.

TABLE F.5—ESTIMATES OF PARAMETER ψ FROM MODEL (F.2)

	All Science Cities		Historical Science Cities	
	(1)	(2)	(3)	(4)
Science City (ψ)	0.5207	0.5339	0.4814	0.5174
	(0.1541)	(0.1725)	(0.1618)	(0.1811)
Year fixed effects	YES	YES	YES	YES
Bias-adjusted estimate	NO	YES	NO	YES
Number of observations	2964	2964	2527	2527

Notes. Standard errors reported in parentheses are estimated with the Newey-West HAC formula, allowing for autocorrelation up to 10 years. Dependent variable is standardized night lights measure. In columns 2 and 4, the latter incorporates a bias adjustment *à la* Abadie and Imbens.

G. Robustness checks: visual representation

This appendix provides a visual representation of the treated-control differences used in the t-tests discussed in section IV, Table 5 in the paper. For each category and outcome variable combination, a bar chart is reported; each bar represents a matched pair, and their (possibly negative) heights represent a pair's treated-control difference. The bars are arranged in ascending order and colored according to the value of the category. An uneven distribution of colors along the horizontal axis is indicative of differences between categories, and vice versa. In what follows, the bar charts that are specific to a single sample splitting criterion (e.g. "secret" vs. "usable") are grouped on the same page.

G.1. “Secret” vs. “usable” Science Cities

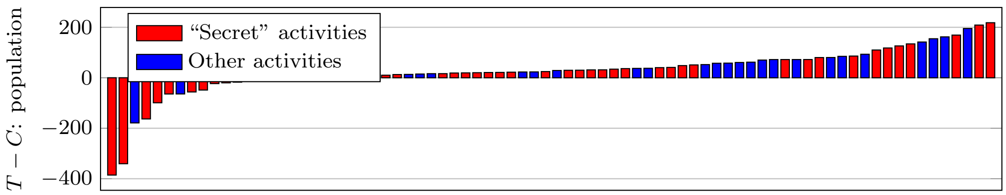

Figure G.1. Differences in total population, 2010

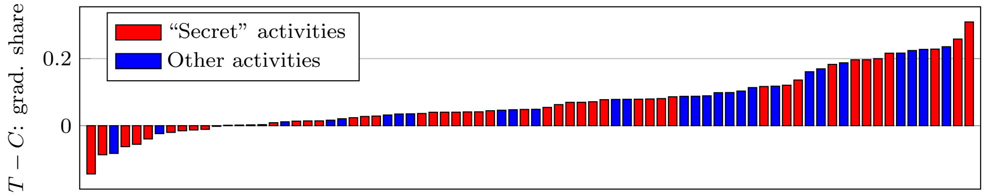

Figure G.2. Differences in the graduate share, 2010

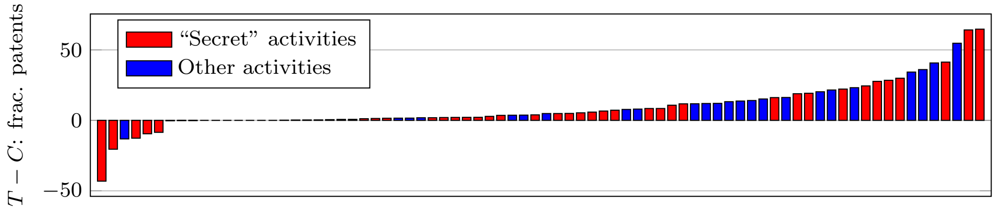

Figure G.3. Differences in fractional patents since 2000

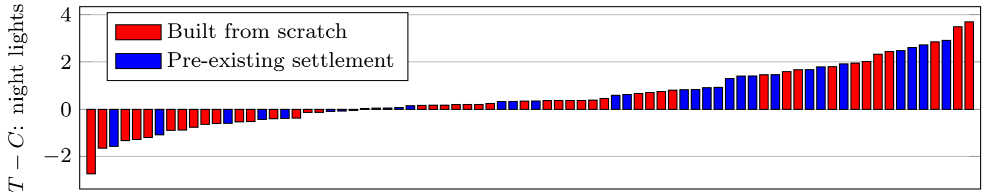

Figure G.4. Differences in standardized night lights (2009-11)

G.2. Science Cities built from scratch versus others

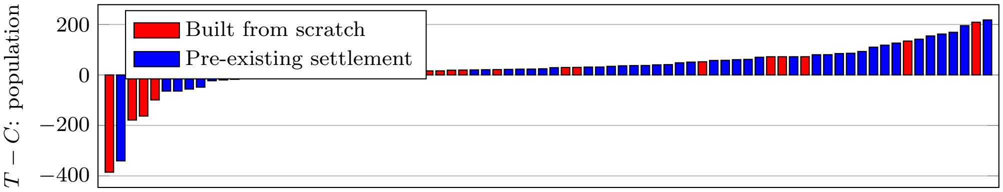

Figure G.5. Differences in total population, 2010

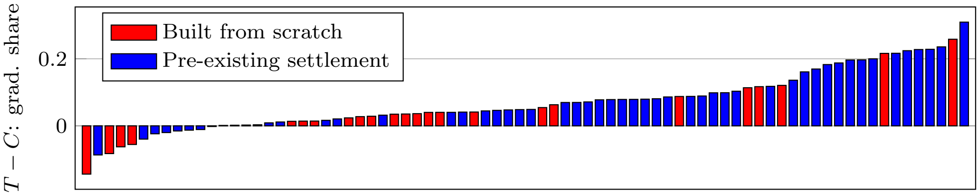

Figure G.6. Differences in the graduate share, 2010

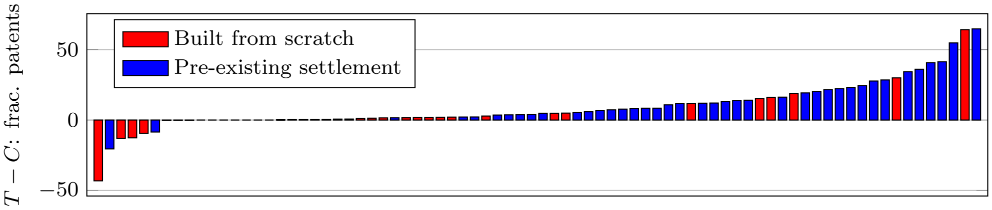

Figure G.7. Differences in fractional patents since 2000

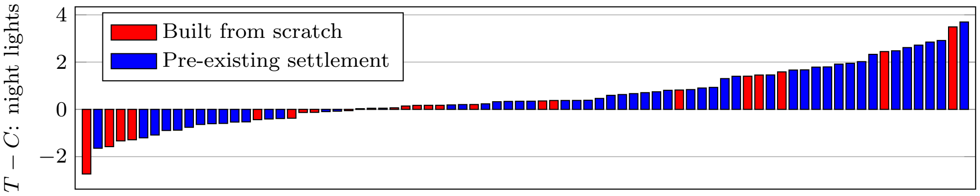

Figure G.8. Differences in standardized night lights (2009-11)

G.3. Science Cities from Agirrechu's list versus others

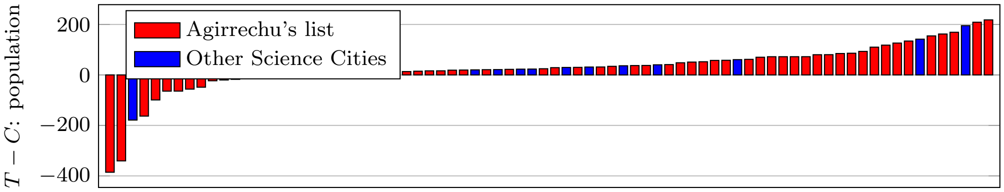

Figure G.9. Differences in total population, 2010

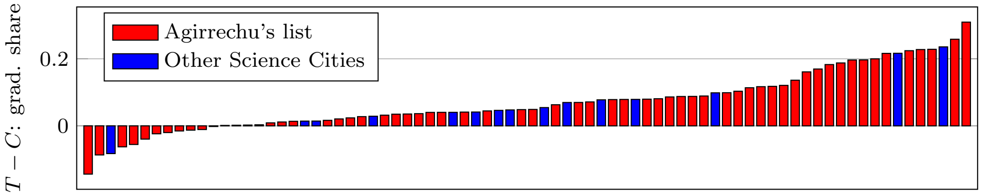

Figure G.10. Differences in the graduate share, 2010

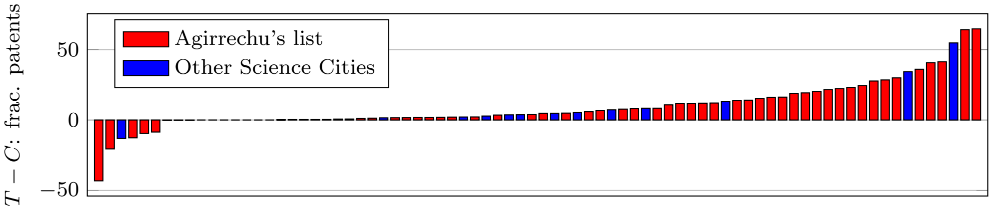

Figure G.11. Differences in fractional patents since 2000

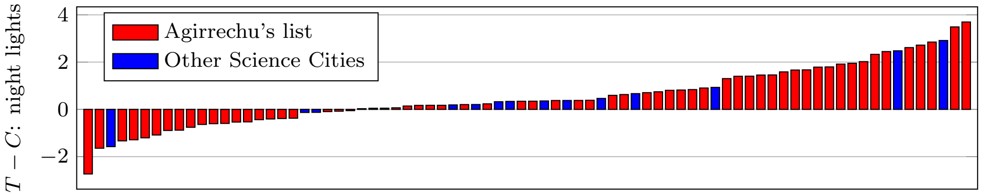

Figure G.12. Differences in standardized night lights (2009-11)

G.4. Other Science Cities close to the matched control, or none

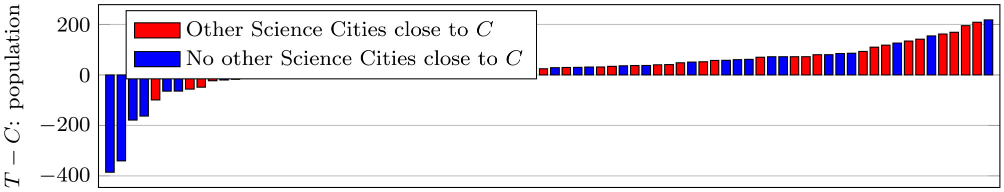

FIGURE G.13. DIFFERENCES IN TOTAL POPULATION, 2010

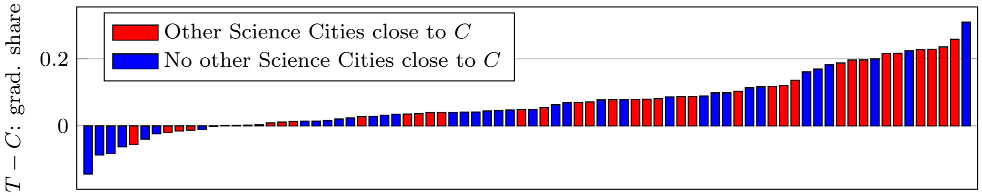

FIGURE G.14. DIFFERENCES IN THE GRADUATE SHARE, 2010

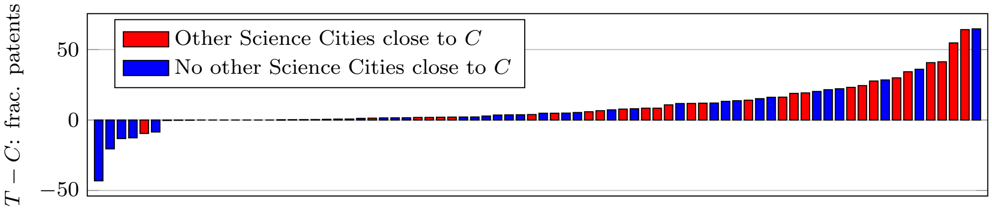

FIGURE G.15. DIFFERENCES IN FRACTIONAL PATENTS SINCE 2000

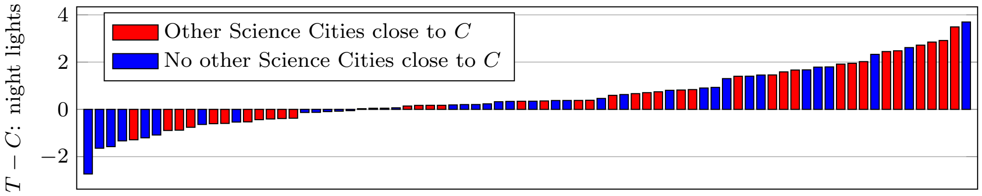

FIGURE G.16. DIFFERENCES IN STANDARDIZED NIGHT LIGHTS (2009-11)

G.5. *Science Cities founded before 1950 versus later ones*

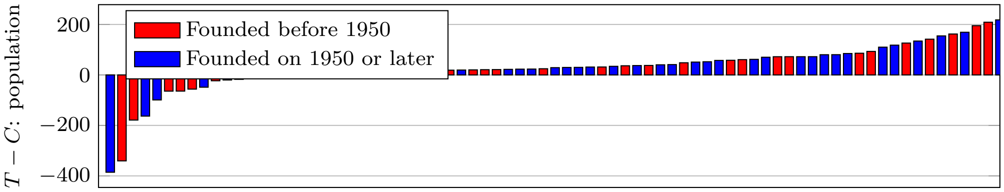

Figure G.17. Differences in total population, 2010

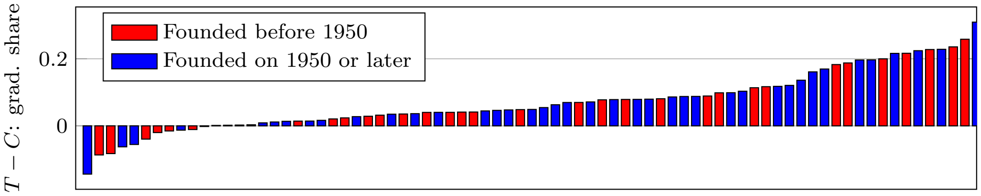

Figure G.18. Differences in the graduate share, 2010

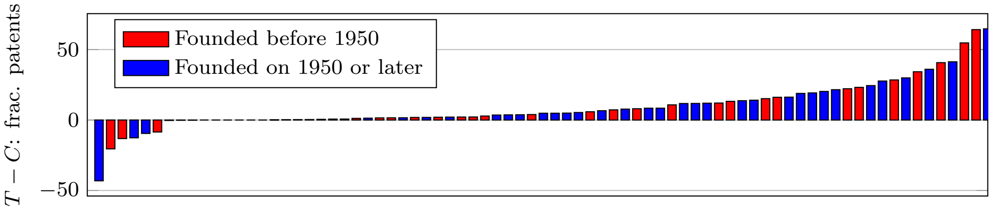

Figure G.19. Differences in fractional patents since 2000

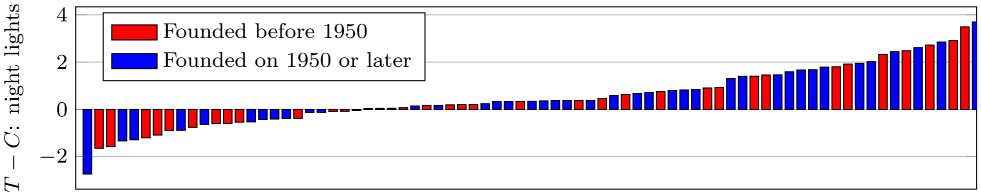

Figure G.20. Differences in standardized night lights (2009-11)

G.6. Science Cities founded before 1960 versus later ones

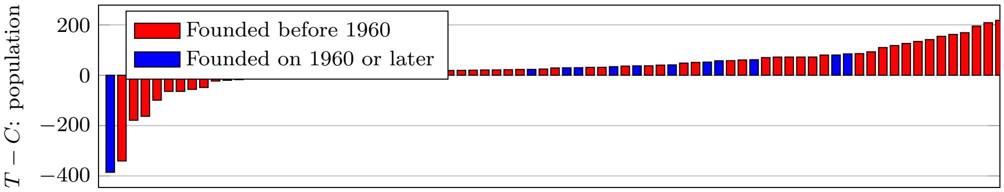

Figure G.21. Differences in total population, 2010

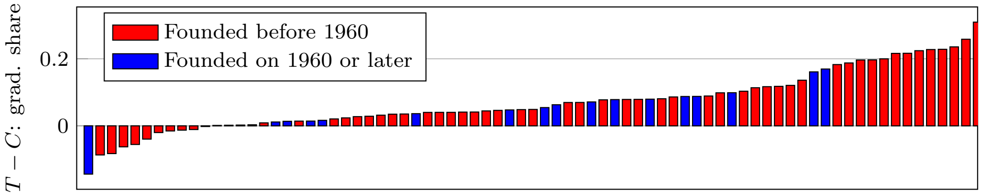

Figure G.22. Differences in the graduate share, 2010

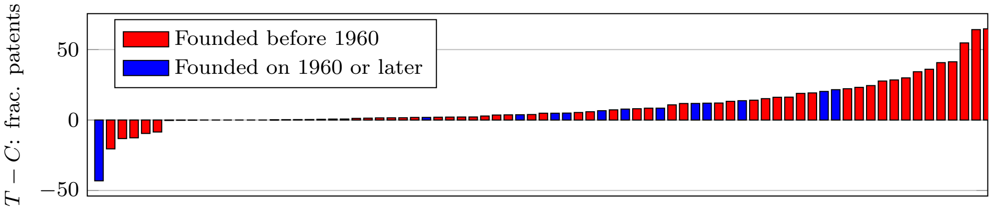

Figure G.23. Differences in fractional patents since 2000

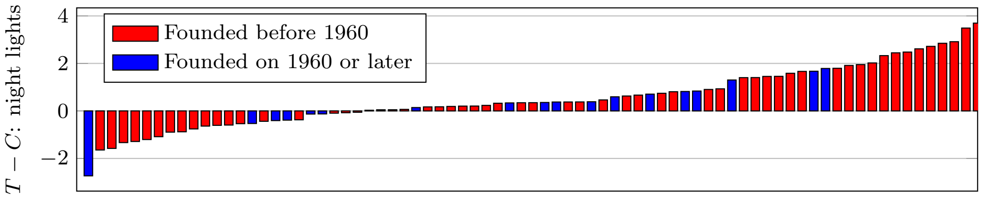

Figure G.24. Differences in night lights (2009-11)

H. Detailed analysis of the structural model

In this appendix we discuss the structural model presented in section V in more detail. We start from a brief discussion on how it relates to other existing models of spatial equilibrium. Next, we analyze the decisions of both workers and firms, and their interplay in the equilibrium. Later, we set out our approach for empirically operationalizing and estimating the model, and show the results of an estimation exercise performed on the whole sample of Russian municipalities. Finally, we discuss possible extensions of the model.

H.1. Extended discussion of the setup

The model builds upon a simplified version of the recent framework by Allen and Donaldson (2020). We apply two major simplifications to their setup: we remove both inter-location trade and the distance-based migration costs. This makes the model much easier to empirically operationalize and estimate; without them, we would need detailed longitudinal data on cross-municipality trade and migration (at present unavailable in our setting) for estimation. These two gravity-based mechanisms are not the focus of our analysis, and we see little cost in neglecting them. In addition, we remove spillovers that depend on past population values from our production functions in equation (2). As we mentioned, we cannot identify these effects with the data available to us. Note that Allen and Donaldson (2020) estimate very small production function elasticities (in the order of 0.04) associated with the past population.

Unlike Allen and Donaldson, our setup features two distinct types of workers, distinguished by their skill level. In this respect, our framework is closer to the one by Moretti (2011, 2013). We also express the equilibrium in terms of log-differences between cities – although we adopt slightly different functional forms and distributional assumptions. In Moretti's analysis the main objective was to perform a welfare analysis of workers' choices by looking at the interplay between forces of agglomeration and congestion (where the latter are due to higher rent prices, in the Rosen-Roback tradition). Our main objective instead is to express equilibrium equations that are well-suited to empirical estimation on the matched sample. The dependence of individual utility (1) on current population, under the restriction that parameters β_1 and δ_1 are negative, embeds congestion and other negative population externalities, such as higher rents in Moretti's model. In this regard, our setup can be seen as an extension of his, one that introduces both path-dependence and skill-specific spillovers.

H.2. Workers' choices

We analyze the properties of the model by restricting the analysis to a given pair of cities s and z. By the standard properties of multinomial choice models based on generalized extreme value distributions, in a spatial equilibrium the ratio between the populations of the two cities, for each skill type, must be equal to the ratio between the two probabilities that an individual chooses either city. Hence:

$$\text{(H.1)} \qquad \frac{\exp\left(n_{s1}\right)}{\exp\left(n_{z1}\right)} = \frac{\left[\exp\left(w_s^n + \beta_0^n \ell_{s0} + \beta_1^n \ell_{s1} + \delta_0^n h_{s0} + \delta_1^n h_{s1} + a_s^n\right)\right]^{\frac{1}{\sigma^n}}}{\left[\exp\left(w_z^n + \beta_0^n \ell_{z0} + \beta_1^n \ell_{z1} + \delta_0^n h_{z0} + \delta_1^n h_{z1} + a_z^n\right)\right]^{\frac{1}{\sigma^n}}}$$

for $n = h, \ell$, as the denominators of both probabilities cancel out thanks to the removal of distance-based migration costs (while this is an unrealistic assumption, it does not affect the main mechanics of the model). Taking logs, the above yields the labor supply equations at the municipal pair level:

$$\text{(H.2)} \quad \left(h_{s1} - h_{z1}\right) = \frac{\left(w_s^h - w_z^h\right) + \beta_0^h\left(\ell_{s0} - \ell_{z0}\right) + \beta_1^h\left(\ell_{s1} - \ell_{z1}\right) + \delta_0^h\left(h_{s0} - h_{z0}\right) - \left(a_s^h - a_z^h\right)}{\sigma^h - \delta_1^h},$$

$$\text{(H.3)} \quad \left(\ell_{s1} - \ell_{z1}\right) = \frac{\left(w_s^\ell - w_z^\ell\right) + \beta_0^\ell\left(\ell_{s0} - \ell_{z0}\right) + \delta_0^\ell\left(h_{s0} - h_{z0}\right) + \beta_1^\ell\left(h_{s1} - h_{z1}\right) - \left(a_s^\ell - a_z^\ell\right)}{\sigma^\ell - \beta_1^\ell}.$$

The elasticities of labor supply to local wages are given by the two denominators of (H.2) and (H.3), inverted. Similarly to other models of spatial equilibrium, negative values of δ_1^h (β_1^l) lead to a more homogeneous distribution of high-skilled (low-skilled) workers in space, due to congestion effects and/or higher rents.

H.3. Firms' choices

The analysis of the firm side is standard. Consider first the production function of firms employing high-skilled workers. The assumption of perfectly mobile capital (the larger implications of which are discussed at the end of this appendix) leads to equalized rates of returns for k_c^h. Hence:

$$\text{(H.4)} \qquad \left(k_s^h - k_z^h\right) = \frac{1}{\lambda}\left[\left(g_s^h - g_z^h\right) + \left(\theta^h + \lambda\right)\left(h_{s1} - h_{z1}\right) + \varphi^h\left(\ell_{s1} - \ell_{z1}\right)\right],$$

as follows from equating the marginal product of capital across cities s and z. Labor is not as mobile as capital and wages are location-specific. The standard labor market equilibrium condition, in log-differences, leads to:

$$\text{(H.5)} \quad \left(w_s^h - w_z^h\right) = \left(g_s^h - g_z^h\right) + \left(\theta^h + \lambda - 1\right)\left(h_{s1} - h_{z1}\right) + \varphi^h\left(\ell_{s1} - \ell_{z1}\right) + (1-\lambda)\left(k_s^h - k_z^h\right),$$

and, combining (H.4) with (H.5), we obtain an equation that can be interpreted as the inverse labor demand if one takes low-skilled workers as given:

$$\left(w_s^h - w_z^h\right) = \frac{1}{\lambda}\left[\left(g_s^h - g_z^h\right) + \theta^h\left(h_{s1} - h_{z1}\right) + \varphi^h\left(\ell_{s1} - \ell_{z1}\right)\right]. \tag{H.6}$$

A symmetric analysis delivers the low-skilled version of (H.6), again interpretable as the inverse labor demand if one takes high-skilled workers as given:

$$\left(w_s^\ell - w_z^\ell\right) = \frac{1}{\lambda}\left[\left(g_s^\ell - g_z^\ell\right) + \theta^\ell\left(h_{s1} - h_{z1}\right) + \varphi^\ell\left(\ell_{s1} - \ell_{z1}\right)\right]. \tag{H.7}$$

Note that differentiating the labor elasticity parameter λ between firms of different skill type is straightforward, as it is in the model at large. Given our homogeneous calibration approach to λ in the empirical analysis, however, we prefer to avoid doing this so as to keep the notation slightly simpler.

H.4. Spatial equilibrium

Equations (3) and (4) in the paper are obtained by combining equations (H.2), (H.3), (H.6), (H.7) and solving them for present-day population and wage ratios. The history multipliers discussed in the text are algebraically derived as:

$$\mu^{hh} = M\left[\left(\sigma^\ell - \beta_1^\ell - \frac{\varphi^\ell}{\lambda}\right)\delta_0^h + \left(\beta_1^h + \frac{\varphi^h}{\lambda}\right)\delta_0^\ell\right] \tag{H.8}$$

$$\mu^{h\ell} = M\left[\left(\sigma^\ell - \beta_1^\ell - \frac{\varphi^\ell}{\lambda}\right)\beta_0^h + \left(\beta_1^h + \frac{\varphi^h}{\lambda}\right)\beta_0^\ell\right] \tag{H.9}$$

$$\mu^{\ell h} = M\left[\left(\sigma^h - \delta_1^h - \frac{\theta^h}{\lambda}\right)\delta_0^\ell + \left(\delta_1^\ell + \frac{\theta^\ell}{\lambda}\right)\delta_0^h\right] \tag{H.10}$$

$$\mu^{\ell\ell} = M\left[\left(\sigma^h - \delta_1^h - \frac{\theta^h}{\lambda}\right)\beta_0^\ell + \left(\delta_1^\ell + \frac{\theta^\ell}{\lambda}\right)\beta_0^h\right] \tag{H.11}$$

where:

$$M = \left[\left(\sigma^h - \delta_1^h - \frac{\theta^h}{\lambda}\right)\left(\sigma^\ell - \beta_1^\ell - \frac{\varphi^\ell}{\lambda}\right) - \left(\beta_1^h + \frac{\varphi^h}{\lambda}\right)\left(\delta_1^\ell + \frac{\theta^\ell}{\lambda}\right)\right]^{-1}. \tag{H.12}$$

Inspecting the above expression, it appears clear that in the equilibrium, more positive values of the productivity spillovers (θ^n, φ^n), as well as of the contemporaneous externalities (β_1^n, δ_1^n), amplify the effect of the path-dependence parameters (β_0^n, δ_0^n), for $n = h, \ell$ – and vice versa. This is a typical feature of spatial equilibrium models in urban economics. Like in those models, some parametric restrictions are necessary in order to guarantee the existence and uniqueness of a non-degenerate equilibrium. Specifically, all the parameters featured in (H.8)-(H.11) must be such that $\mu^{nn'} \geq 0$ for all $n = h, \ell$ and $n' = h, \ell$.

The constant terms in (3) are obtained, for $c = s, z$, as:

$$p_c^h = M\left[\left(\sigma^\ell - \beta_1^\ell - \frac{\varphi^\ell}{\lambda}\right)\left(a_c^h + \frac{g_c^h}{\lambda}\right) + \left(\beta_1^h + \frac{\varphi^h}{\lambda}\right)\left(a_c^\ell + \frac{g_c^\ell}{\lambda}\right)\right] \tag{H.13}$$

$$p_c^\ell = M\left[\left(\sigma^h - \delta_1^h - \frac{\theta^h}{\lambda}\right)\left(a_s^\ell + \frac{g_s^\ell}{\lambda}\right) + \left(\delta_1^\ell + \frac{\theta^\ell}{\lambda}\right)\left(a_s^h + \frac{g_s^h}{\lambda}\right)\right], \tag{H.14}$$

whereas those in (4) are as follows, for $n = h, \ell$:

$$r_c^n = \frac{1}{\lambda}\left(g_c^n + \theta^n p_c^h + \varphi^n p_c^\ell\right), \tag{H.15}$$

that is, they are simple linear functions of p_c^h and p_c^ℓ above. These constant terms are functions of all the factors that affect the outcomes of local labor markets, such as local amenities a_c^n or productivity-enhancing variables embedded in g_c^n.

H.5. Econometric model

We make no attempt to reshape the spatial equilibrium equations into an econometric model in a way that would allow us to identify the persistence force parameters β_0^n and δ_0^n from the contemporaneous externalities β_1^n and δ_1^n, or from the Gumbel scale parameter σ^n, for $n = h, \ell$. While this would be an important and worthwhile exercise that could be pursued with additional data, it is not the objective of our analysis: identification of the history multipliers $\mu^{nn'}$ suffices for the sake of calculating the wage bill ratios (5) discussed in the paper.

To build our econometric model, we assume that a_c^n and g_c^n are linear functions of observable city characteristics as well as econometric error terms. Since the contemporaneous externalities β_1^n and δ_1^n are not identified, this implies that equations (H.13) and (H.14) are also linear functions of the same aforementioned objects, and their linear parameters cannot be linked via (identified) structural relationships. Therefore we write, for $n = h, \ell$:

$$p_c^n = \gamma_0^n + \gamma_S^n S_c + \sum_{f=1}^{F} \gamma_f^n x_{fc} + \varepsilon_c^n \tag{H.16}$$

where $(x_{1c}, \ldots, x_{Fc})$ are observable city characteristics; $(\gamma_1^n, \ldots, \gamma_F^n)$ are their associated parameters; S_c is a dummy variable that equals one if c is a Science City and is zero otherwise; γ_S^n is the associated parameter that measures the additional average attractiveness of Science Cities, for workers of type n, that is not captured by the other variables of the model; γ_0^n is a constant term; and ε_c^n is an error term with mean zero. Since r_c^n also depends on g_c^n – in addition to p_c^h and

p_c^ℓ – we need to specify a separate functional form for g_c^n. Thus we also write, for $n = h, \ell$:

$$g_c^n = \kappa_0^n + \kappa_S^n S_c + \sum_{f'=1}^{F'} \kappa_f^n \tilde{x}_{f'c} + \upsilon_c^n \tag{H.17}$$

where $F' \leq F$ is the dimension of the vector $(\tilde{x}_{1c}, \ldots, \tilde{x}_{F'c})$, itself a subset of $(x_{1c}, \ldots, x_{Fc})$; the new parameters are written as $\left(\kappa_0^n, \kappa_S^n, \kappa_1^n, \ldots, \kappa_{F'}^n\right)$, where κ_S^n represents average productivity advantages of Science Cities for firms of type n not captured by other features of the model; and the new error term (with zero mean) as υ_c^n.

By plugging all these specifications into equations (3) and (4), we complete the construction of a model of four simultaneous equations. To specify the set of moment conditions that we use in our GMM approach, it is useful to define the following four error terms – one for each equation of the model:

(H.18)

$$\eta_{sz}^n = (n_{s1} - n_{z1}) - \gamma_S^n - \sum_{f=1}^{F} \gamma_f^n (x_{fs} - x_{fz}) - \mu^{nh} (h_{s0} - h_{z0}) - \mu^{n\ell} (\ell_{s0} - \ell_{z0})$$

(H.19)

$$\begin{aligned} \omega_{sz}^n = {} & (w_s^n - w_z^n) - \frac{\kappa_S^n}{\lambda} - \frac{1}{\lambda} \sum_{f'=1}^{F'} \kappa_f^n (\tilde{x}_{fs} - \tilde{x}_{fz}) \\ & - \frac{\theta^n}{\lambda} \left[\gamma_S^h + \sum_{f=1}^{F} \gamma_f^h (x_{fs} - x_{fz}) \right] - \frac{\varphi^n}{\lambda} \left[\gamma_S^\ell + \sum_{f=1}^{F} \gamma_f^\ell (x_{fs} - x_{fz}) \right] \\ & - \frac{\theta^n \mu^{hh} + \varphi^n \mu^{\ell h}}{\lambda} (h_{s0} - h_{z0}) - \frac{\theta^n \mu^{h\ell} + \varphi^n \mu^{\ell\ell}}{\lambda} (\ell_{s0} - \ell_{z0}), \end{aligned}$$

for $n = h, \ell$. These four error terms are functions of the underlying errors ε_s^h, ε_z^ℓ, υ_s^h and υ_z^ℓ in (H.16) and (H.17). Thus, the moment conditions are constructed as $\mathbb{E}[\eta_{sz}^n] = 0$ and $\mathbb{E}[\omega_{sz}^n] = 0$ for $n = h, \ell$, and:

$$\mathbb{E}\left[\eta_{sz}^n \left(n'_{s0} - n'_{z0}\right)\right] = 0 \text{ for } n = h, \ell \text{ and } n' = h, \ell, \tag{H.20}$$

$$\mathbb{E}\left[\eta_{sz}^n (x_{fs} - x_{fz})\right] = 0 \text{ for } n = h, \ell \text{ and } f = 1, \ldots, F, \tag{H.21}$$

$$\mathbb{E}\left[\omega_{sz}^n \left(n'_{s0} - n'_{z0}\right)\right] = 0 \text{ for } n = h, \ell \text{ and } n' = h, \ell, \tag{H.22}$$

$$\mathbb{E}\left[\omega_{sz}^n \left(\tilde{x}_{f's} - \tilde{x}_{f'z}\right)\right] = 0 \text{ for } n = h, \ell \text{ and } f' = 1, \ldots, F'. \tag{H.23}$$

Observe that the parameters from (H.16), except γ_0^h and γ_0^ℓ, are identified in the population equations (3) – specifically, by the moments of the form (H.21) that use $(x_{fs} - x_{fz})$ for $f = 1, \dots, F$ as instruments; similarly, the parameters from (H.17), except κ_0^h and κ_0^ℓ, are identified in the wage equations (4). Since λ is not identified, we calibrate it as $\lambda = 0.66$ using a conventional choice for the labor elasticity, which in our setting is corroborated by previous exercises of production function estimation on Russian firms (Kuboniwa, 2011). Taking a value of λ as given, all the parameters in (H.18) and (H.19) are exactly identified.

We estimate the model via one-step GMM with an identity weighting matrix; the key assumptions that enable consistent estimation are:

$$\mathbb{E}\left[\eta_{sz}^n \middle| \left(n'_{s0} - n'_{z0}\right)\right] = 0 \tag{H.24}$$

$$\mathbb{E}\left[\omega_{sz}^n \middle| \left(n'_{s0} - n'_{z0}\right)\right] = 0 \tag{H.25}$$

for $n = h, \ell$ and $n' = h, \ell$. These conditions state that the model's error terms are mean-independent of differences in the Soviet-era allocation of population of either skill. This is consistent with the empirical strategy from our main matching analysis, motivated by the idea that conditional on the characteristics that determine the construction of our matching sample, Science City status (and thus, the local allocation of labor in Soviet times) is orthogonal to current outcomes. This makes it natural to estimate the model in our restricted matched sample. Since some matched pairs share the same control city, we cluster standard errors by grouping all such pairs into a single cluster; matched pairs whose control city is unique form one-observation clusters.

The right-hand side variables from (H.16) and (H.17) that we chose for producing our main estimates are referred to as "covariates" in Table 6. They are as follows. The variables $(\tilde{x}_{1c}, \dots, \tilde{x}_{F'c})$ from specification (H.17) include all the specific items of municipal budget expenditure that are listed in Table 4, Panel A – in logarithms. This is meant to control for the vES hypothesis and the possible implications of municipal-level expenditures on local productivity. In addition to them, we include the amenity "stocks" listed in Table 4, Panel B – again in logarithms – in our list of variables $(x_{1c}, \dots, x_{Fc})$ from specification (H.16), because p_c^n also subsumes other factors, represented by a_c^n, that can affect individual location preferences. Given the limited sample size we keep the model parsimonious and abstain from adding more covariates, such as local geographical or historical characteristics. In light of how our matching sample is constructed, (H.24) and (H.25) would hold regardless.

H.6. Wage bill ratios

The total wage bill ratios from equation (5) can be calculated as a function of the allocation at $t = 0$, using the history multipliers and the spillovers parameters that we estimate, as follows. The ratio of total wage bills paid to high-skilled workers is derived from the equilibrium equations of the model as:

$$\mathcal{W}^h_{sz} = \exp\Big(\Big[\Big(1-\theta^h\Big)\mu^{hh} + \varphi^h\mu^{\ell h}\Big](h_{s0}-h_{z0}) \\ + \Big[\Big(1-\theta^h\Big)\mu^{h\ell} + \varphi^h\mu^{\ell\ell}\Big](\ell_{s0}-\ell_{z0})\Big), \tag{H.26}$$

while the corresponding ratio for low-skilled workers is derived as:

$$\mathcal{W}^\ell_{sz} = \exp\Big(\Big[\theta^\ell\mu^{hh} + \Big(1-\varphi^\ell\Big)\mu^{\ell h}\Big](h_{s0}-h_{z0}) \\ + \Big[\theta^\ell\mu^{h\ell} + \Big(1-\varphi^\ell\Big)\mu^{\ell\ell}\Big](\ell_{s0}-\ell_{z0})\Big). \tag{H.27}$$

To clarify how a "ratio of ratios" interpretation can help draw useful implications from the calculation of (H.26) and (H.27), consider two alternative allocations $(h^*_{s0}, h^*_{z0}, \ell^*_{s0}, \ell^*_{z0})$ and $(h^\circ_{s0}, h^\circ_{z0}, \ell^\circ_{s0}, \ell^\circ_{z0})$. The ratio between the two corresponding values $\mathcal{W}^{h*}_{sz}$ and $\mathcal{W}^{h\circ}_{sz}$ can also be written as:

$$\frac{\mathcal{W}^{h*}_{sz}}{\mathcal{W}^{h\circ}_{sz}} = \frac{\exp\left(\left(w^{h*}_s + h^*_{s1}\right) - \left(w^{h\circ}_s + h^\circ_{s1}\right)\right)}{\exp\left(\left(w^{h*}_z + h^*_{z1}\right) - \left(w^{h\circ}_z + h^\circ_{z1}\right)\right)}, \tag{H.28}$$

where asterisks and circles denote the respective allocation. Under the hypothesis that the city z allocations are identical ($h^*_{z0} = h^\circ_{z0}$ and $\ell^*_{z0} = \ell^\circ_{z0}$) and that the general equilibrium effects due to a change in city s allocation are negligible, the denominator of (H.28) is approximately equal to 1 and the whole expression can thus be interpreted as the actual effect of the city s allocation, equal to the numerator of (H.28). This argument supports our claim in the paper that the ratio between the values of $\mathcal{W}^h_{sz}$, respectively given in columns 2 and 1 of Table 7, can be interpreted as reflecting the effect of the additional high-skilled allocation on city s. As remarked in the paper, these calculations cannot provide an answer about the overall welfare effects of Science Cities. We plan to develop a more extensive structural model that would allow us to do so in future work.

H.7. Governmental subsidies

Our model can extrapolate a subsidy t^*_H that the government needs to provide to the high-skilled inhabitants of city s in order to reproduce, in the spatial equilibrium, an allocation equal to $H^* = H_{s1}/H_{z1}$, under the hypothesis that cities s and z are ex-ante identical. Specifically, t^*_H is derived from (H.13) as:

$$t^*_H = \frac{(h^*_{s1} - h^*_{z1})}{M\left(\sigma^\ell - \beta^\ell_1 - \dfrac{\varphi^\ell}{\lambda}\right)}. \tag{H.29}$$

An analogous expression can also be obtained for low-skilled workers via (H.14). Calculating (H.29) requires the knowledge of the unidentified structural parameters that are subsumed into the history multipliers. The value proposed in the paper as the appropriate subsidy for the reproduction of a typical Science City allocation: $(h^*_{s1} - h^*_{z1}) = \log(22/14)$, is obtained through our estimates of ϑ^n/λ for $n = h, \ell$ from column 4 in Table 6, and plausible values of the unidentified parameters. Specifically, the latter are chosen as follows.

- We set $\sigma^h - \delta^h_1$ and $\sigma^\ell - \beta^\ell_1$, the inverse wage elasticities of the municipal-level labor supply, at 3.8. This value is based on an econometric analysis of migration patterns across Russian regions by Vakulenko (2016), which suggests that 0.26 is a realistic magnitude for the elasticity of population to local income. This number is also close to the typical estimates of the extensive margin labor supply elasticity from a structural study by Larin, Maksimov and Chernova (2016).
- We set $\beta^h_1 = \delta^\ell_1 = -0.15$, equaling the estimate of contemporaneous population externalities by Allen and Donaldson (2020) in the United States.

H.8. *Estimation on the full sample*

To provide external validation for our results in Table 6 in the paper, we estimate the model in the larger sample of Russian municipalities. We perform this additional analysis by estimating a one-city version of the model summarized by equations (3) and (4) in the paper. Specifically, our four equations are:

$$n_{c1} = p^n_c + \mu^{nh} h_{c0} + \mu^{n\ell} \ell_{c0} \tag{H.30}$$

$$w^n_c = r^n_c + \frac{\theta^n \mu^{hh} + \varphi^n \mu^{\ell h}}{\lambda} h_{c0} + \frac{\theta^n \mu^{h\ell} + \varphi^n \mu^{\ell\ell}}{\lambda} \ell_{c0}, \tag{H.31}$$

for $n = h, \ell$, maintaining specifications (H.16) and (H.17) for p^n_c and r^n_c alongside the choice of covariates discussed above. Note that this "one-city" specification is not fully consistent with our structural model since it ignores the denominator of the probability of choosing city c for either skill type (and this denominator is a function of the structural parameters). As in analogous empirical applications based on multinomial choice models, we assume this problem away by postulating that the endogenous response effects implied by the model bear negligible effects on that denominator, which can thus be treated as a constant to be incorporated into p^n_c (more specifically, into parameter γ^n_0) for $n = h, \ell$. Another implication of this one-city version of the model is that instead of clustering standard errors, we calculate them using the heteroscedasticity-consistent formula.

The results from this analysis are presented in Table H.1: they are remarkably similar to those in Table 6 in the paper, across both approaches described there. Thanks to the increased sample size, all estimates appear to be more precise (especially those for the spillover parameters φ^h and φ^ℓ). However, the "high-on-low" spillovers $\mu^{h\ell}$ are in most cases not statistically different from zero. This confirms our interpretation of these parameters in the paper: a higher relative number of high-skilled workers in the past attracts more low-skilled workers in the future, while the reverse is not true. The restrictions on the spillover parameters ($\vartheta^n \equiv \theta^n = -\varphi^n$ for $n = h, \ell$) are now rejected; however the absolute magnitudes of estimated values for θ^n and φ^n are very similar, suggesting that the constrained specification is a good approximation. In the constrained model we obtain similar values for both ϑ^h and ϑ^ℓ, around 0.31 for Approach 1 and 0.25 for Approach 2, whereas the estimate for ϑ^ℓ is smaller and less precise in the matched sample. While this may be a by-product of increased statistical power, it could be indicative of a difference specific to Science Cities, due to their traditional specialization in sectors characterized by high human capital intensity.

Table H.1—Estimation of the spatial equilibrium model on the full sample

	Approach 1		Approach 2	
Parameter	(1)	(2)	(3)	(4)
θ^h (ϑ^h): high-to-high spillovers	0.236	0.298	0.231	0.236
	(0.024)	(0.013)	(0.022)	(0.021)
φ^h: low-to-high spillovers	-0.202		-0.189	
	(0.033)		(0.031)	
θ^ℓ (ϑ^ℓ) : high-to-low spillovers	0.243	0.331	0.239	0.245
	(0.026)	(0.016)	(0.024)	(0.024)
φ^ℓ: low-to-low spillovers	-0.194		-0.182	
	(0.036)		(0.033)	
μ^{hh}: history: high-on-high	0.974	0.933	1.674	1.729
	(0.022)	(0.024)	(0.021)	(0.024)
$\mu^{h\ell}$: history: high-on-low	0.019	0.095	0.008	0.041
	(0.028)	(0.034)	(0.020)	(0.023)
$\mu^{\ell h}$: history: low-on-high	0.124	0.165	0.142	0.087
	(0.023)	(0.023)	(0.025)	(0.029)
$\mu^{\ell\ell}$: history: low-on-low	0.835	0.759	1.128	1.096
	(0.029)	(0.030)	(0.024)	(0.023)
Spillover constraints test: p-value	0.000		0.000	
Full set of covariates	YES	YES	YES	YES
Constrained model	NO	YES	NO	YES
No. of observations	1806	1806	1806	1806

Notes. The table displays estimates of the model expressed by equations (H.30) and (H.31) for $n = h, \ell$, where p_c^n, r_c^n and g_c^n are expressed as linear functions of a set of city characteristics ("covariates") and an error term as in (H.15), (H.16) and (H.17), and for both approaches described in the text. Estimation is performed on the entire sample via one-step GMM using an identity weighting matrix. In constrained models, the parameter restrictions $\vartheta^n \equiv \theta^n = -\varphi^n$ for $n = h, \ell$ are applied; in unconstrained models, the p-value from a joint test of these restrictions ("spillover constraints test") is reported. Heteroscedasticity-consistent standard errors are reported in parentheses.

H.9. *Imperfectly mobile capital*

The derivation and consequent estimation of our model are based on the assumption that capital is perfectly mobile in Russia, which implies that the returns to capital are equal across locations. This is a key assumption that allows us to sidestep our inability to obtain accurate measures of capital at the municipal level. While fixed assets data are provided by ROSSTAT at the municipal level, we found that they are inconsistent with the values it reports at the regional level, casting doubt on the accuracy and reliability of its capital measurements. While one may question the realism of our key assumption, our reading of the literature on the spatial variation of capital costs in Russia suggests that this is not much worse an approximation than it would be in advanced western economies. Most notably, Ledyaeva (2009) shows that the set of geographical predictors of FDI in Russia partly overlaps with the set of covariates included in our matching strategy, suggesting that departures from the assumption are less of a concern if the empirical analysis is restricted to our matched sample.

Here we sketch how the key equations of the model would change following alternative assumptions about capital mobility. Suppose first that capital is immobile in the short run – an extreme assumption, but a good approximation for a cross-sectional estimation exercise. In this case, the equilibrium population equations (3) would be modified, for $n = h, \ell$, as:

$$\begin{aligned}(n_{s1} - n_{z1}) = {} & (\tilde{p}_s^n - \tilde{p}_z^n) + \tilde{\mu}^{nh}(h_{s0} - h_{z0}) + \tilde{\mu}^{n\ell}(\ell_{s0} - \ell_{z0}) \\ & + \chi^{nh}\left(k_s^h - k_z^h\right) + \chi^{n\ell}\left(k_s^\ell - k_z^\ell\right),\end{aligned} \tag{H.32}$$

where tildes denote alternative values of variables and parameters, λ^h and λ^ℓ are differentiated labor elasticity parameters for the two types of firm h and ℓ, while

$$\chi^{hh} = \tilde{M}\left(1 - \lambda^h\right)\left(2 - \beta_1^\ell - \varphi^\ell - \lambda^h\right), \tag{H.33}$$

$$\chi^{h\ell} = \tilde{M}\left(1 - \lambda^h\right)\left(\beta_1^h + \varphi^h\right), \tag{H.34}$$

$$\chi^{\ell h} = \tilde{M}\left(1 - \lambda^\ell\right)\left(2 - \delta_1^h - \theta^h - \lambda^\ell\right), \tag{H.35}$$

$$\chi^{\ell\ell} = \tilde{M}\left(1 - \lambda^\ell\right)\left(\delta_1^\ell + \theta^\ell\right), \tag{H.36}$$

and

$$\tilde{M} = \left[\left(2 - \beta_1^\ell - \varphi^\ell - \lambda^h\right)\left(2 - \delta_1^h - \theta^h - \lambda^\ell\right) - \left(\beta_1^h + \varphi^h\right)\left(\delta_1^\ell + \theta^\ell\right)\right]^{-1}. \tag{H.37}$$

The increase in model complexity is clear; the equilibrium wage equations (4) would result from plugging both equations expressed in (H.32) into (H.5) and its low-skilled analogue, giving rise to complicated expressions that are functions of the log-differences in both types of capital. The resulting model would allow identification of λ^h and λ^ℓ at the cost of increased complexity, provided that reliable municipal-level capital data are available.

Consider next an intermediate assumption: let capital be imperfectly mobile. Specifically, to change the capital allocation between periods $t = 0$ and $t = 1$, firms have to pay a quadratic cost equal to $\chi^n \left(k_{c1}^n - k_{c0}\right)^2/2$ for $n = h, \ell$, which acts as an effective tax on capital returns. This assumption would deliver even more complexity: to illustrate the key implications, we showcase a streamlined version of the model with only one type of labor: the low-skilled one, where $\theta = 0$, and where we drop all $n = h, \ell$ subscripts. The spatial equilibrium equation for the (low-skilled) population is:

$$(\ell_{s1} - \ell_{z1}) = \frac{\varkappa \left(g_s - g_z\right) + \left(a_s - a_z\right) + \beta_0 \left(\ell_{s0} - \ell_{z0}\right) + \xi \left(k_{s0} - k_{z0}\right)}{1 - \beta_1 - \varkappa\varphi + \xi}, \tag{H.38}$$

where $\varkappa = (1 + \chi) / (\lambda + \chi)$ and $\xi = \chi (1 - \lambda) / (\lambda + \chi)$. The equilibrium equation for wages is, instead:

$$\begin{aligned}(w_s - w_z) = &\frac{\varkappa \left(1 - \beta_1\right) \left(g_s - g_z\right) + \left(\varkappa\varphi - \xi\right) \left(a_s - a_z\right) + \beta_0 \left(\varkappa\varphi - \xi\right) \left(\ell_{s0} - \ell_{z0}\right)}{1 - \beta_1 - \varkappa\varphi + \xi} \\ &+ \frac{\xi \left(2 - \beta_1 - \varkappa\varphi + \xi\right) \left(k_{s0} - k_{z0}\right)}{1 - \beta_1 - \varkappa\varphi + \xi}.\end{aligned} \tag{H.39}$$

The challenge that this model would entail is twofold. On the one hand, a version of the model with two skill types would be considerably more complex, as suggested by the one skill type equations (H.38) and (H.39). On the other hand, empirical estimation of this model would require data on capital at $t = 0$. If accessing reliable municipal-level capital data in today's Russia is challenging, analogous data that would trace back to Soviet times or the early transition years would be altogether impossible for obvious institutional reasons. Overall, we find our main assumption about capital, together with a realistic choice for the calibration of parameter λ, to be the most appropriate choice for estimating our model.

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[1] Provided separately due to difficulties with displaying Cyrillic characters in BibTeX/LaTeX and/or length.

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