The Economic Dynamics of City Structure: Evidence from Hiroshima’s Recovery

Kohei Takeda
NUS

Atsushi Yamagishi
Princeton

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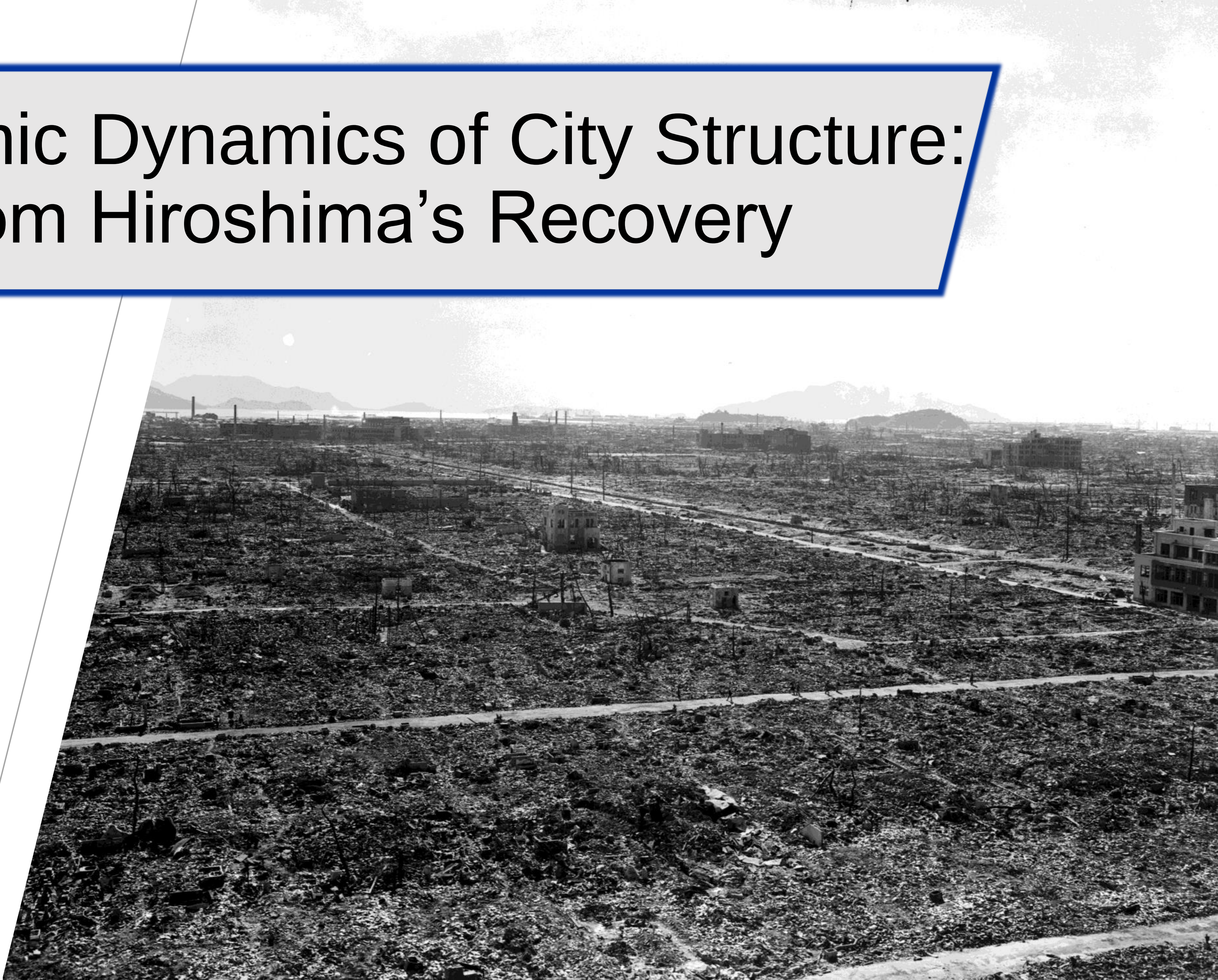


Motivation

- A major source of public policy debate is the **resilience of cities** in the face of large shocks
  - Natural disasters, including earthquakes, hurricanes and flooding
  - Wartime destruction
- How resilient is city structure in the face of a large-scale shock?
- What is the key driver of the resilience of city structure?
- Understanding the mechanisms is relevant for rebuilding cities after large-scale shocks and revitalization policies to address urban decline

This paper

- We look at the atomic bombing and recovery of **Hiroshima**
  - The city center experienced destruction by the atomic bombing in 1945
  - We newly digitize the variation of economic activities within the city from 1936 to 1975

- We find that Hiroshima's internal city structure was **remarkably resilient**: the city center recovered just five years after the bombing
  - Our reduced-form analysis suggests that it is hard to explain this resurgence of the city center in terms of location characteristics

- We develop **a new quantitative dynamic urban model** that combines key ingredients central to evaluating the impact of a large shock on the organization of economic activity within a city

- We estimate the model parameters using the observed data of Hiroshima

- Model's calibration shows that **strong agglomeration forces** are required to explain the recovery of the city center, and these agglomeration forces imply the existence of **multiple equilibria**
  - The re-emergence of the pre-war city structure is driven by a coordination of expectations around the focal point

Literature

- **Agglomeration in spatial economics (with a focus on internal city structure)**
  - Fujita & Ogawa (1988); Fujita (1989); Fujita & Thisse (1996); Fujita, Krugman & Venables (1999); Lucas & Rossi-Hansberg (2002); Ahlfeldt et al. (2015); Redding & Rossi-Hansberg (2017); Heblich et al. (2020)

- **History dependence in the spatial economy**
  - Davis & Weinstein (2002, 2008); Brakman et al. (2004); Bosker et al. (2007); Miguel & Roland (2011); Redding et al. (2011); Bleakley & Lin (2012); Schumann (2014); Siodla (2015); Hornbeck & Keniston (2017); Michaels & Rauch (2018); Brooks & Lutz (2019); Ahlfeldt et al. (2020); Heblich et al. (2021); Harada et al. (2022); Lin & Rauch (2022)

- **Multiple equilibria in economic geography**
  - Krugman (1991); Matsuyama (1991); Fukao & Bénabou (1993); Ottaviano (2001); Baldwin (2001); Oyama (2009); Barreda-Tarrazona et al. (2021)

- **Quantitative dynamic spatial economics models**
  - Desmet et al. (2018); Caliendo et al. (2019); Balboni (2021); Heblich et al. (2021); Warnes (2021); Kleinman et al. (2022); Almagro & Dominguez-Iino (2022); Allen & Donaldson (2022); Monte et al. (2023)

Road map

- Historical background and data
- Reduced-form evidence
- Theoretical framework
- Estimation
- Quantitative results
- Conclusion

Atomic bombing in Hiroshima

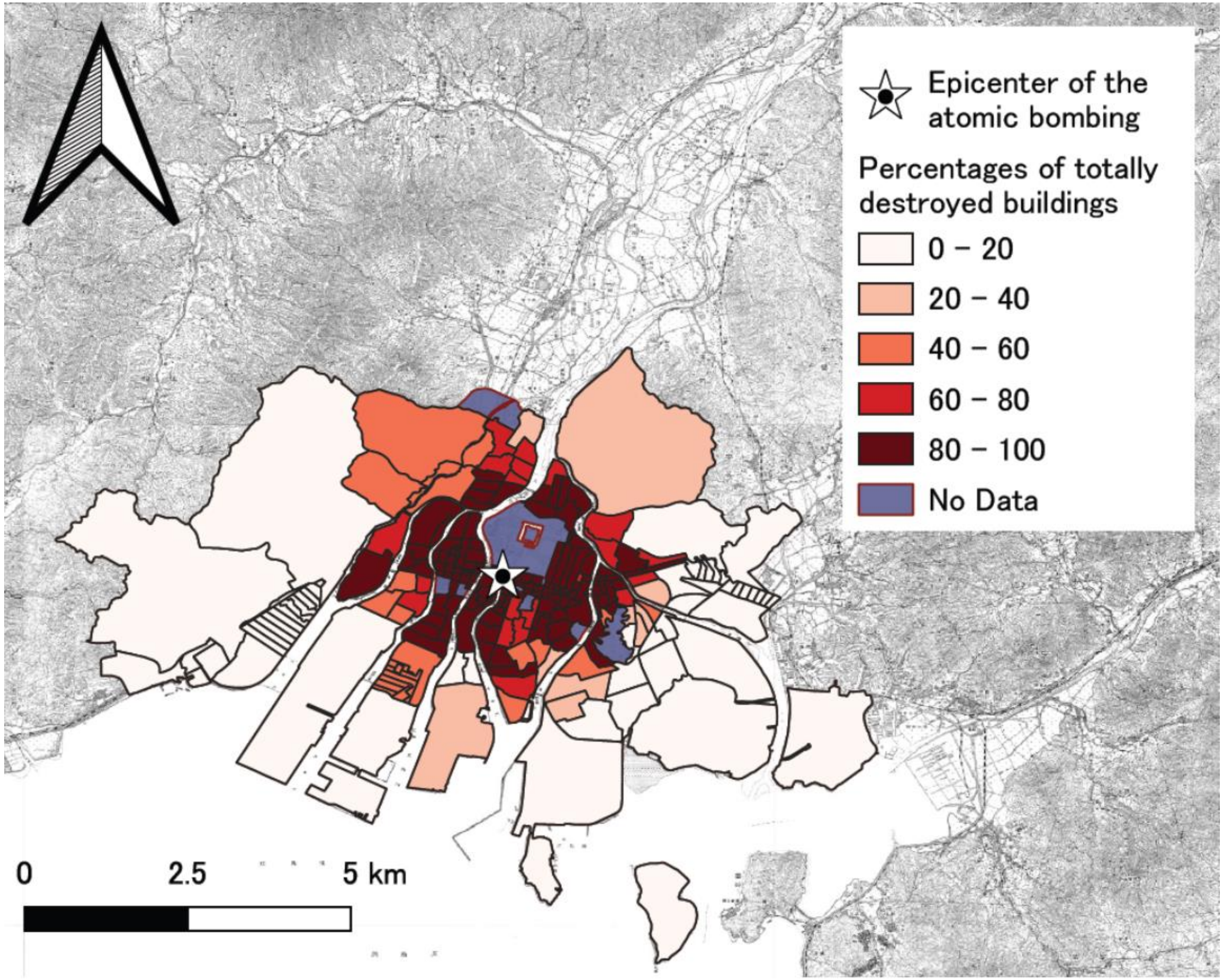
- Hiroshima has been a major city in Japan
  - Population approximately 400,000 in 1940: 7th largest city in Japan

- US Army Air Forces dropped the atomic bomb ("*Little Boy*") on August 6, 1945, close to Hiroshima's city center
  - US did not conduct conventional air raids before the atomic bombing to assess the effect of the atomic bomb

- The serious radioactive contamination caused by the bombing decayed quickly
  - Radiation level at the epicenter became 1/1,000 a day after the bombing and 1/1,000,000 a week later (source: Government official and US Army)

- Public recovery plan was severely underfunded until 1949

- The death rate was nearly 100% for those within 1km of the epicenter
- Almost **all buildings** within 2 km of the epicenter were destroyed
- City outskirts avoided the severest destruction and even experienced a population **increase**



Data

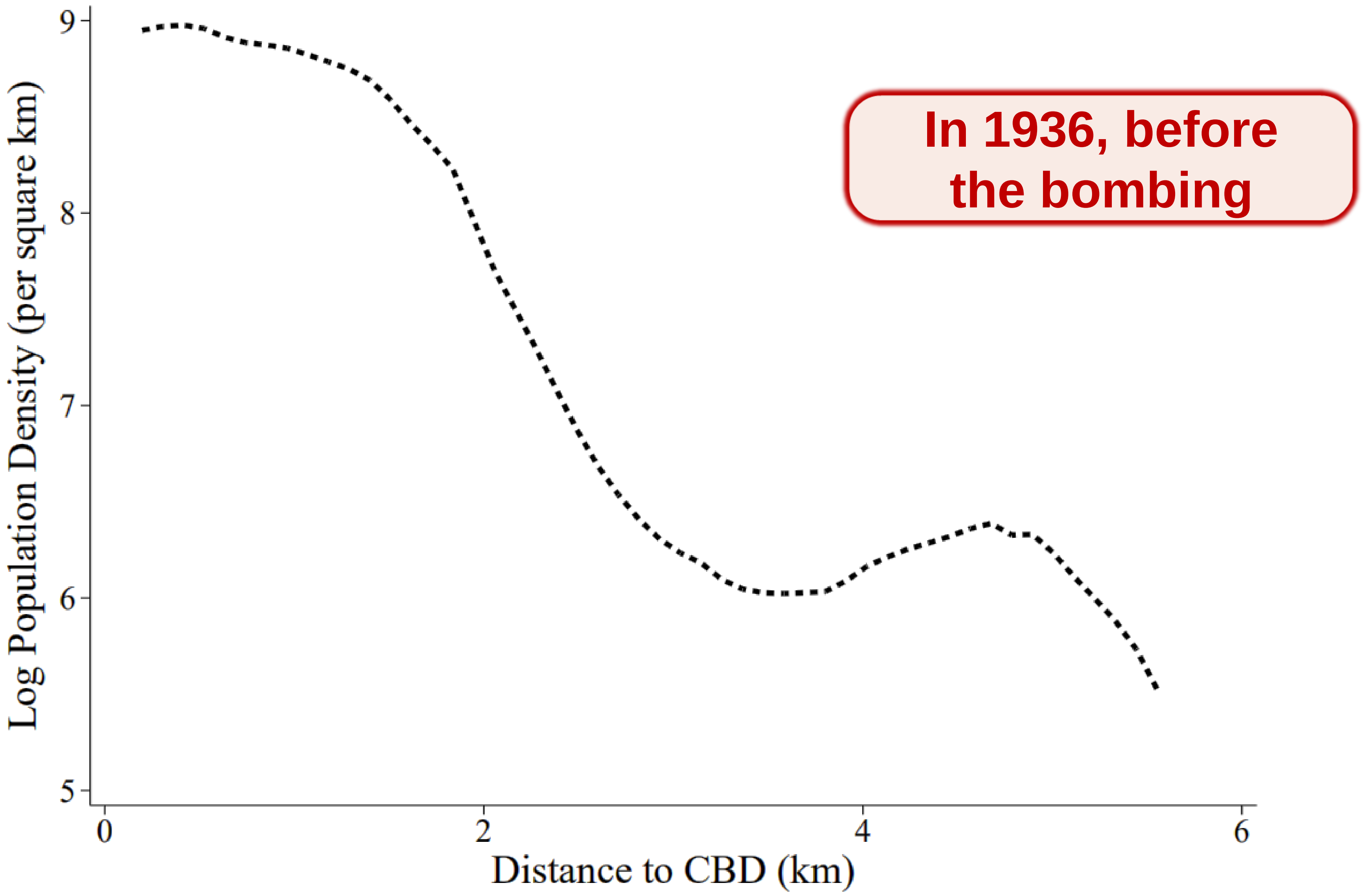
- The unit of analysis is the "block" (*cho-cho-moku*), and we use **174 blocks** in Hiroshima City
  - Average block size is 0.32 km^2

- We have collected and digitized a variety of historical sources on Hiroshima City, beginning in the 1930s:
  - Fraction of destroyed buildings in each block
  - **Population** in each block from 1933 to 1975
  - **Employment** and establishment in each block from 1938 to 1975
  - **Commuting** pattern
  - Proxies of fundamental locational amenities and productivity
  - GIS data for map and transport network

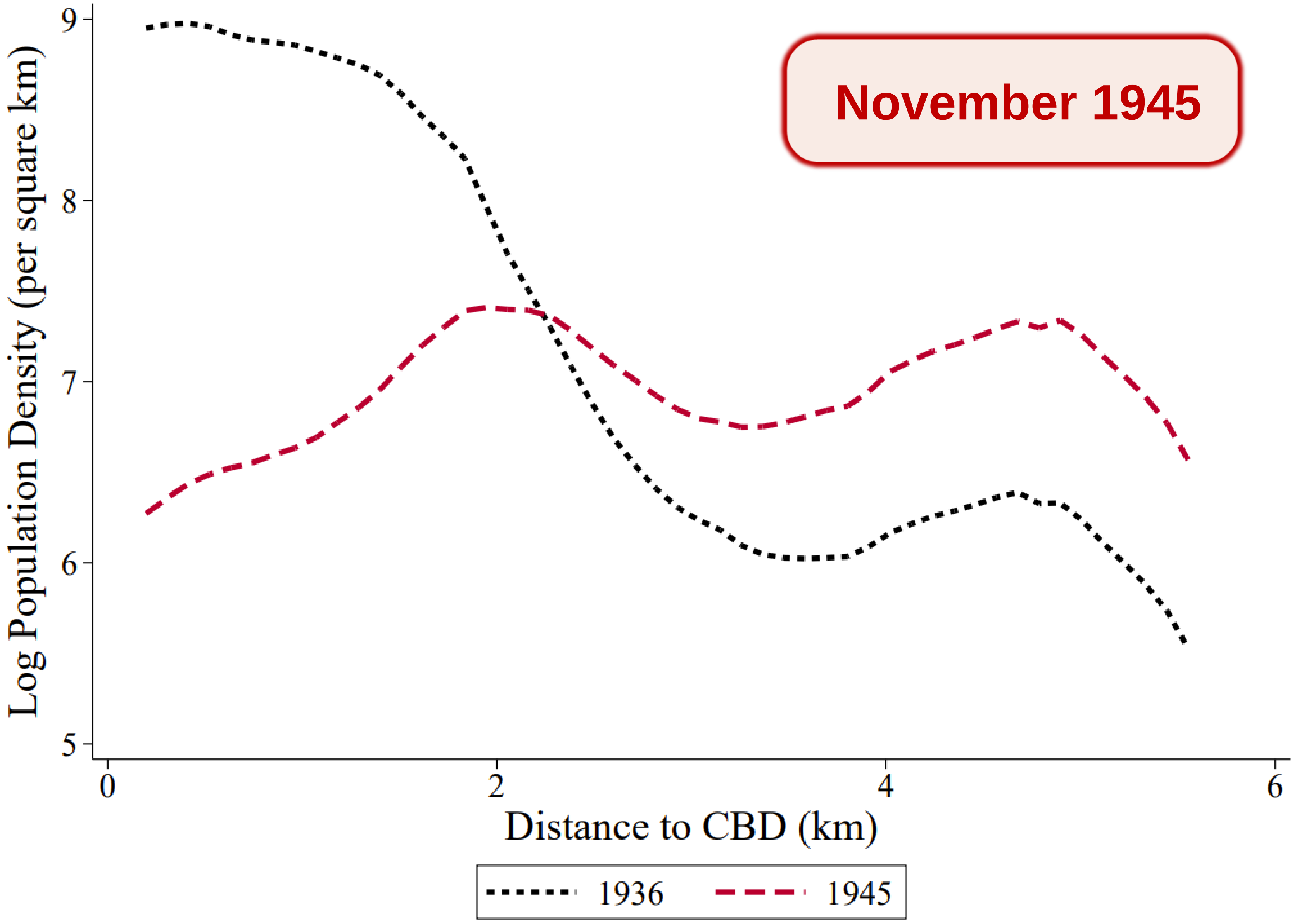
- We focus on the administrative Hiroshima city as of the bombing throughout our analysis
  - This approximately equals the metropolitan area of Hiroshima City in the pre-war period

Descriptive and reduced-form evidence

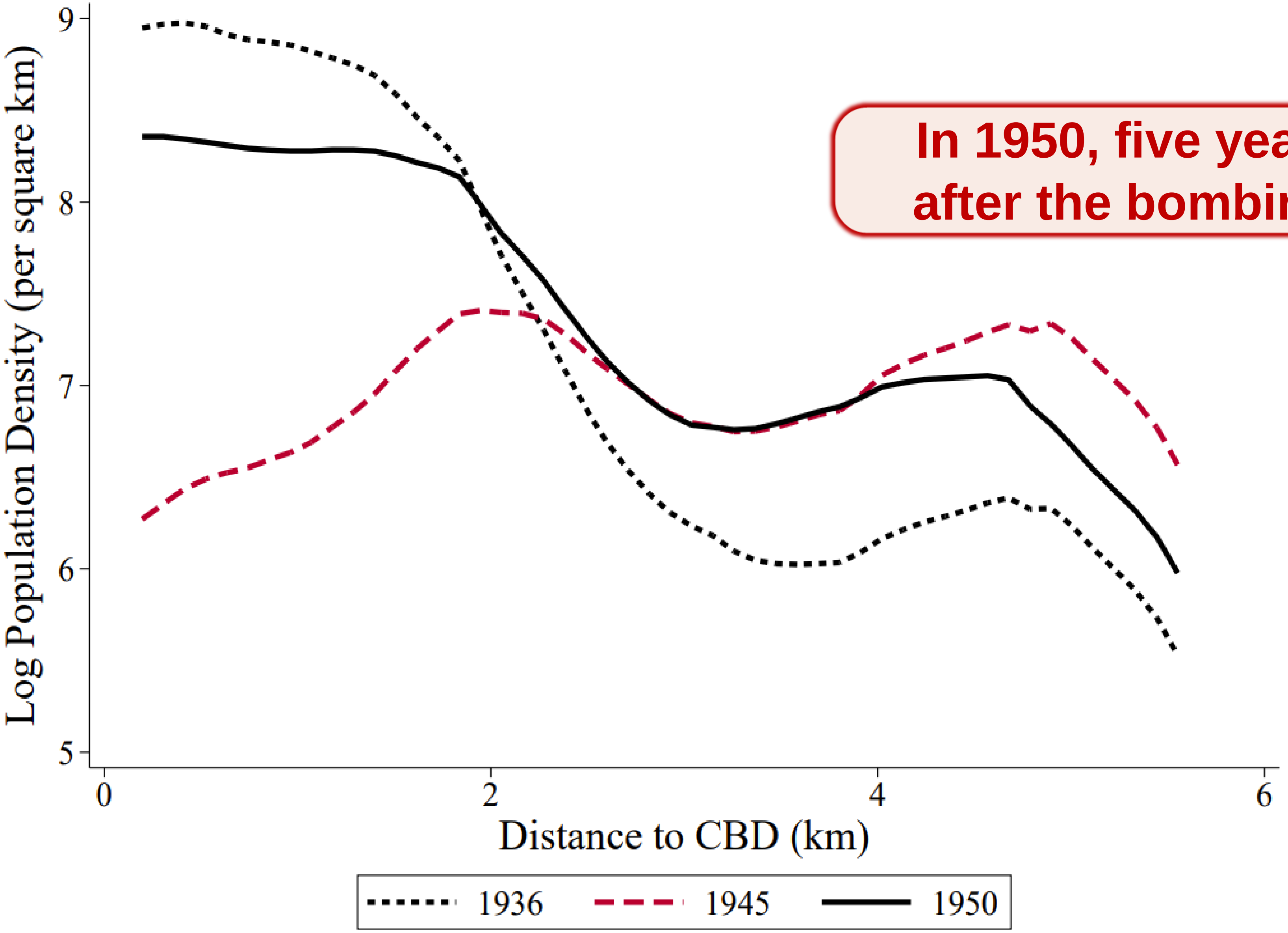
Dynamics of city structure



Dynamics of city structure



Dynamics of city structure



In 1950, five years after the bombing

Reduced-form evidence

$$\ln\left(\frac{\text{Popdens}_{i,t}}{\text{Popdens}_{i,1945}}\right) = \gamma \ln\left(\frac{\text{Popdens}_{i,1945}}{\text{Popdens}_{i,1936}}\right) + \eta X_i + v_i$$

Block characteristics

$\gamma = -1$ → **The bombing had only temporal effects**

	(1)	(2)	(3)	(4)	(5)	(6)
	Change in log population density 1945–1950					
Change in log population density 1936–1945 (γ)	-0.7124^a	-0.7443^a	-0.8004^a	-0.8383^a	-0.8307^a	-0.9034^a
	(0.0271)	(0.0343)	(0.0424)	(0.0560)	(0.0533)	(0.0465)
p-value from testing $\gamma = -1$	0.000	0.000	0.000	0.004	0.002	0.040
Natural location characteristics (first nature)		Yes		Yes	Yes	Yes
Built location characteristics (second nature)			Yes	Yes	Yes	Yes
Pre-war trends in population					Yes	
Within 3 km of the city center						Yes
Number of blocks	174	174	174	174	174	158
R-squared	0.809	0.828	0.823	0.846	0.848	0.859

Little evidence that the fundamental locational advantages of the city center explain the recovery

Theoretical framework

Environment

- Time is discrete and finite, and there is a continuum of workers who are endowed with one unit of labor that is supplied inelastically
- A city (**Hiroshima City**) is embedded in a larger economy that offers a reservation level of utility
- The city consists of a discrete number of locations that correspond to city **blocks**
- There is a single final good that is produced under perfect competition and constant return to scale, which is freely traded within Hiroshima and the wider economy and chosen as numeraire
- Blocks differ in terms of their productivity, amenities, land endowment and bilateral commuting costs
  - Productivity and amenities depend on both location fundamentals and **agglomeration forces**
  - Bilateral commuting costs depend on the observed transport network, including both private and public transportation

Dynamic quantitative urban model

The model combines three key ingredients central to evaluating the impact of the shock on the organization of economic activity within a city

1. **Workers commute from their residence to their workplace subject to commuting costs**

2. **Worker mobility decisions are assumed to take a Calvo form**
   - In each period, there is a Poisson probability that a worker receives an opportunity to change their residence and workplace block
   - This captures the gradual response of the spatial distribution of economic activity

3. **Workers take forward-looking location choices**
   - Upon receiving a moving opportunity, workers draw idiosyncratic preferences for each residence-workplace pair in a city and the wider economy, and choose the pair that offers the highest option values

Model overview

The **option value** of living in n and working in i assessed in period t is:

$$V_{int} = \ln u_{int} + (1 - \theta_{t+1})\rho V_{int+1} + \theta_{t+1}\sigma \ln \left[\sum_{i' \in C} \sum_{n' \in C} \exp(\rho V_{i'n't+1})^{1/\sigma} + \exp(\rho V_{ot+1})^{1/\sigma} \right]$$

Migration Opportunity

Amenity Wage

$$\ln u_{int} = \ln B_{nt} + \ln w_{it} - \ln \kappa_{int}$$

Local labor market

$$w_{it} = A_{it}$$

Model overview

The **option value** of living in n and working in i assessed in period t is:

$$V_{int} = \ln u_{int} + (1-\theta_{t+1})\rho V_{int+1} + \theta_{t+1}\sigma \ln \left[\sum_{i' \in \mathcal{C}} \sum_{n' \in \mathcal{C}} \exp(\rho V_{i'n't+1})^{1/\sigma} + \exp(\rho V_{ot+1})^{1/\sigma} \right]$$

Migration Opportunity

Amenity Wage

$$\ln u_{int} = \ln B_{nt} + \ln w_{it} - \ln \kappa_{int}$$

Local labor market

$$w_{it} = A_{it}$$

Agglomeration

$$A_{it} = a_{it}\left(\frac{L_{it}}{S_i}\right)^{\alpha}, B_{nt} = b_{nt}\left(\frac{R_{nt}}{S_n}\right)^{\beta}$$

$$\lambda_{int+1} = \frac{\exp(V_{int+1})^{\rho/\sigma}}{\sum_{i' \in \mathcal{C}} \sum_{n' \in \mathcal{C}} \exp(V_{i'n't+1})^{\rho/\sigma} + \exp(V_{ot+1})^{\rho/\sigma}}$$

The **mass of workers** who live in n and work in i in period $t+1$ is:

$$L_{int+1} = (1-\theta_{t+1})L_{int} + \theta_{t+1}\lambda_{int+1}M$$

Estimation

Model's calibration

The calibration of the model proceeds in three steps:

1. Estimate commuting and mobility parameters using the historical data for Hiroshima

2. Using the observed population and employment **from 1955 to 1975**, the model is inverted for option values attached to the locations in their migration choices

3. Accounting for the fixed fundamentals, we estimate the amenity and productivity spillovers by the method of moments
   – Identification: **changes** in the structural errors are not correlated with the distance from the city center

Estimate the agglomeration parameters

	(1) Productivity	(2) Amenities	(3) Productivity	(4) Amenities
Elasticity of employment density (α)	0.193^a		0.196^a	
	(0.0001)		(0.0002)	
Elasticity of population density (β)		0.184^a		0.203^a
		(0.0009)		(0.0007)
Sample of blocks	**All blocks in the city**		**Blocks within 3 km of CBD**	
Sample of periods	Every 5 years from 1955 to 1975		Every 5 years from 1955 to 1975	
Instruments	5 grids for CBD distance		5 grids for CBD distance	

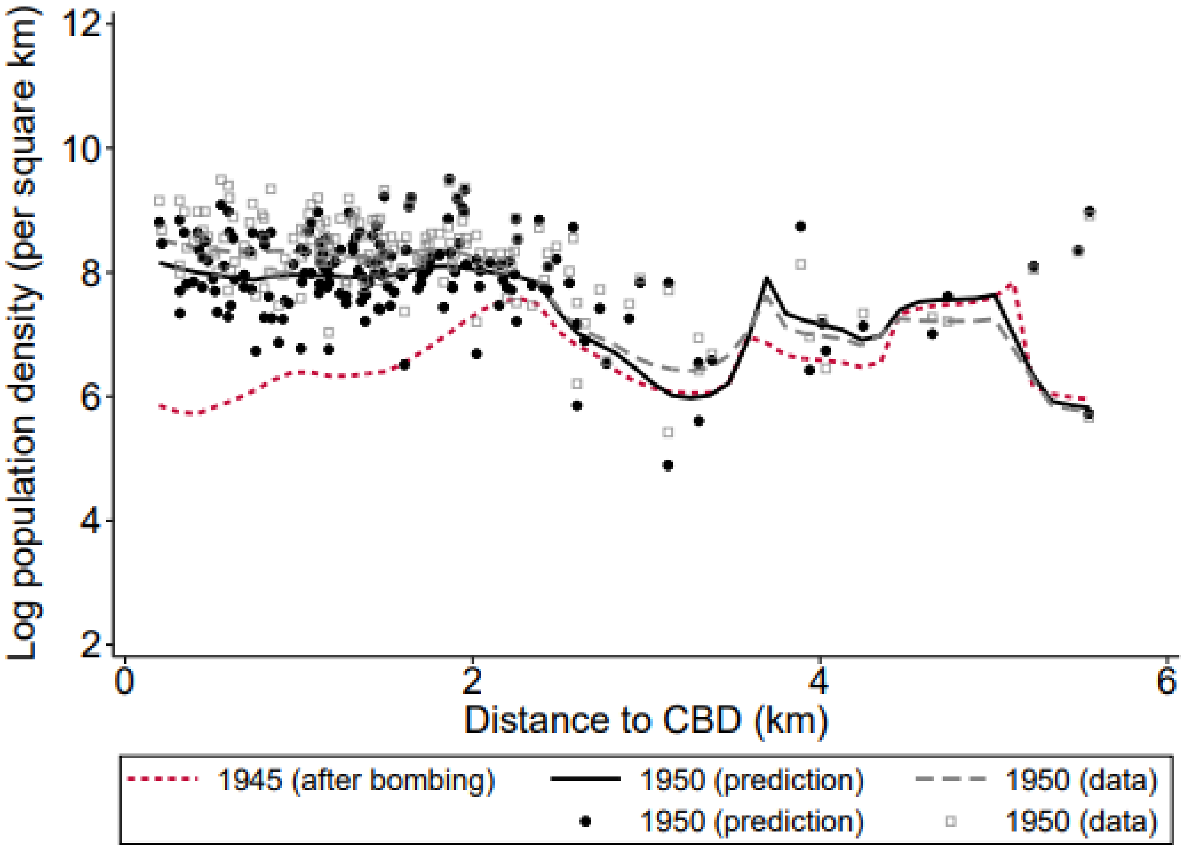
Note: This table reports two-step generalized method of moments (GMM) estimates exploiting the moment conditions (20). The Eicker-Huber-White heteroskedasticity-robust standard errors are in parentheses. We use data for five periods (1955, 60, 65, 70 and 75). We define five grid cells according to the distance to the CBD for the moment conditions. In Columns (1) and (2) we use all 174 blocks in the city. In Columns (3) and (4) we use 158 blocks that lie within 3 kilometers of the CBD. ^{a} indicates significance at the 1 percent level.

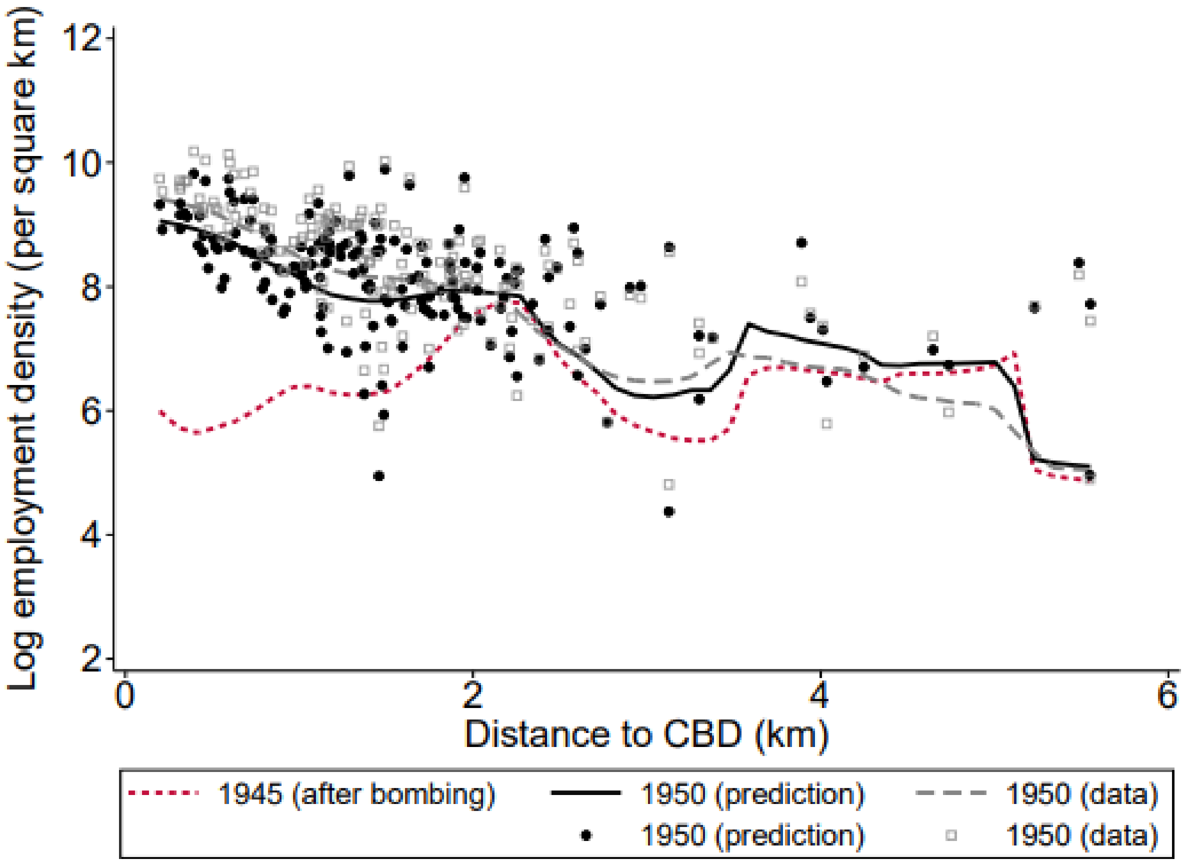
Accounting for the recovery of Hiroshima

Accounting for the recovery in 1945–50

Question: How well can the **endogenous mechanisms** in our model explain the recovery of central Hiroshima in **1945-50**?

We simulate the model **without** the change in structural residuals in the fundamentals

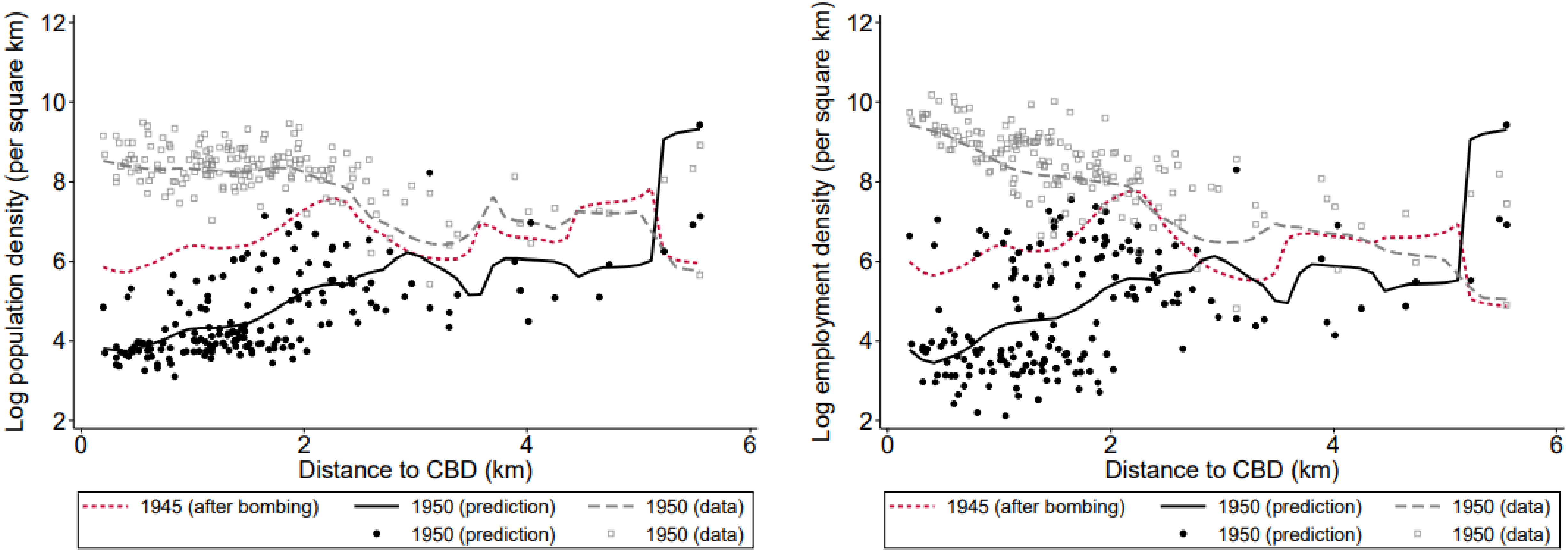




Role of agglomeration economies

Question: How important are agglomeration forces relative to fundamental advantages for the re-emergence of the city center?

We simulate the model by **shutting down** the agglomeration forces in amenities and productivity



Existence of multiple equilibria

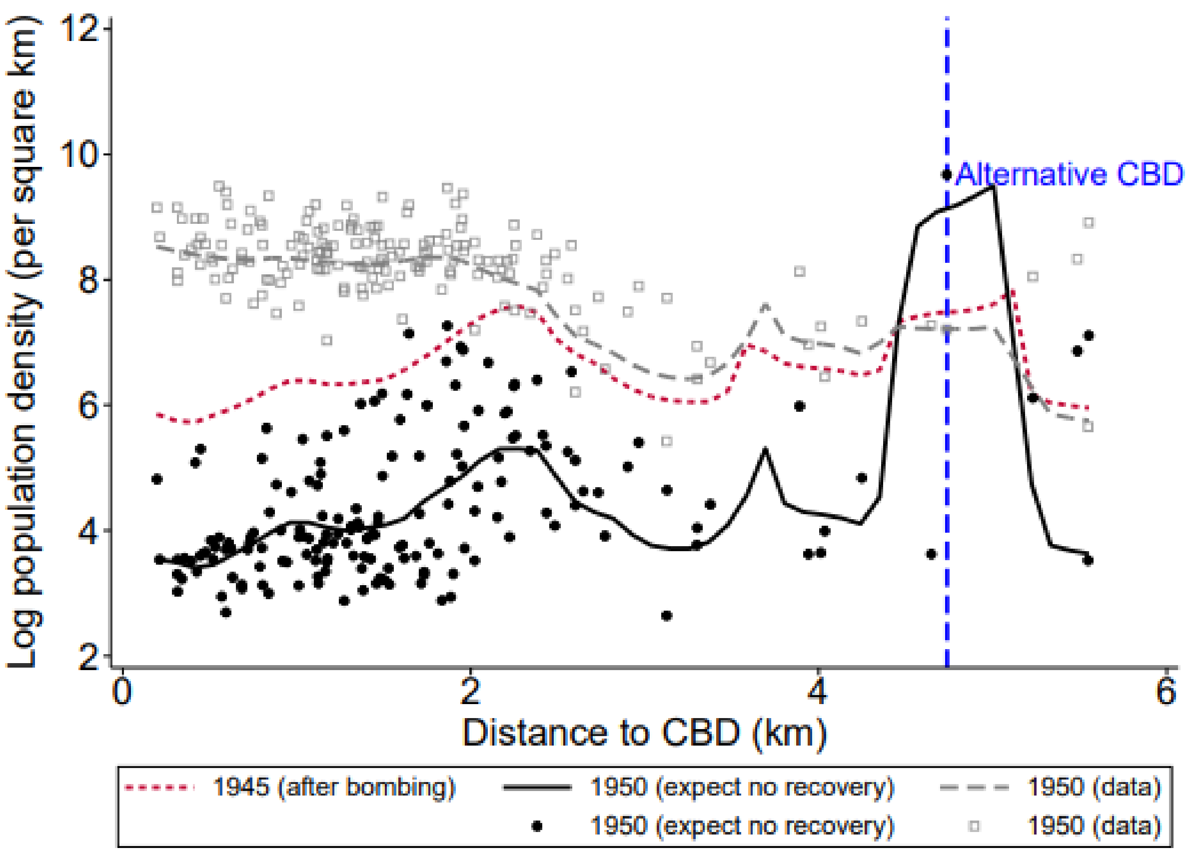
- Tension between agglomeration forces and differences in location fundamentals shapes the spatial concentration of economic activity in both steady state and transition

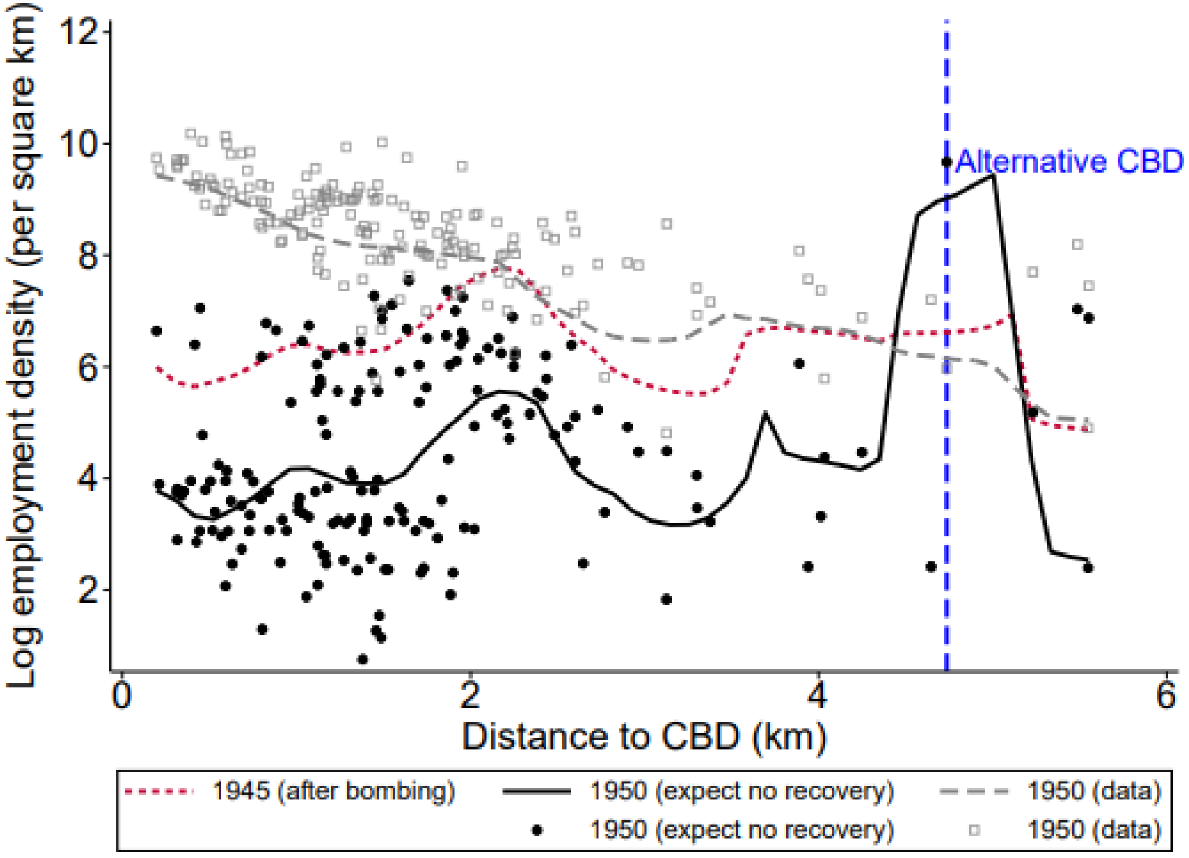
- With strong agglomeration forces, there can be an alternative equilibrium
  – Given the same initial condition, the economy could show a completely different transition in equilibrium

- In the current setting there can be an alternative equilibrium, in which economic activity could have remained concentrated in the outskirts of the city instead of coalescing around the pre-war center

- We show that there exists another possible rational expectation equilibrium
  – We find the equilibrium under the same initial condition and parameter values as our calibration

No recovery equilibrium





Emergence of expectations

- ***Question***: Why was the recovery equilibrium selected in reality?

  Our model and data do not allow us to investigate why the expectations emerged …

- Self-fulfilling expectations

- There are potential factors that helped the coordination of expectations:
  - The presence of a preliminary public recovery plan/debate
  - Anchoring effect of salient location characteristics (e.g., the tram system in the city survived)
  - Remaining property rights
  - Narratives of rebuilding the city

- Together with our reduced-form results and structural analysis, the most likely explanation for the re-emergence of the pre-war city structure is a coordination of expectations
  - Direct influence of the above factors would be limited, given the good fit of our model, additional reduced-form results, and institutional setting

Conclusion

- What is the key driver of the resilience of city structure?
- We investigate this by examining one of the most dramatic natural experiments from history - the atomic bombing of the city of Hiroshima in Japan – and show the remarkable resilience of the internal city structure
- We develop a dynamic spatial GE model that combines the key ingredients central to evaluating the impact of a shock on the organization of economic activity within cities
- We estimate the structural parameters of the model using the data for Hiroshima and show that **strong agglomeration forces** in productivity and amenities are required to explain the re-emergence of the pre-war city structure of Hiroshima
- We show that there exists **another possible rational expectations equilibrium**, in which economic activity could have remained concentrated in the outskirts of the city
- Public policymakers can play a key role in fostering the resilience of cities by helping to coordinate individuals' expectations about the patterns of recovery

Thank You

Source of data

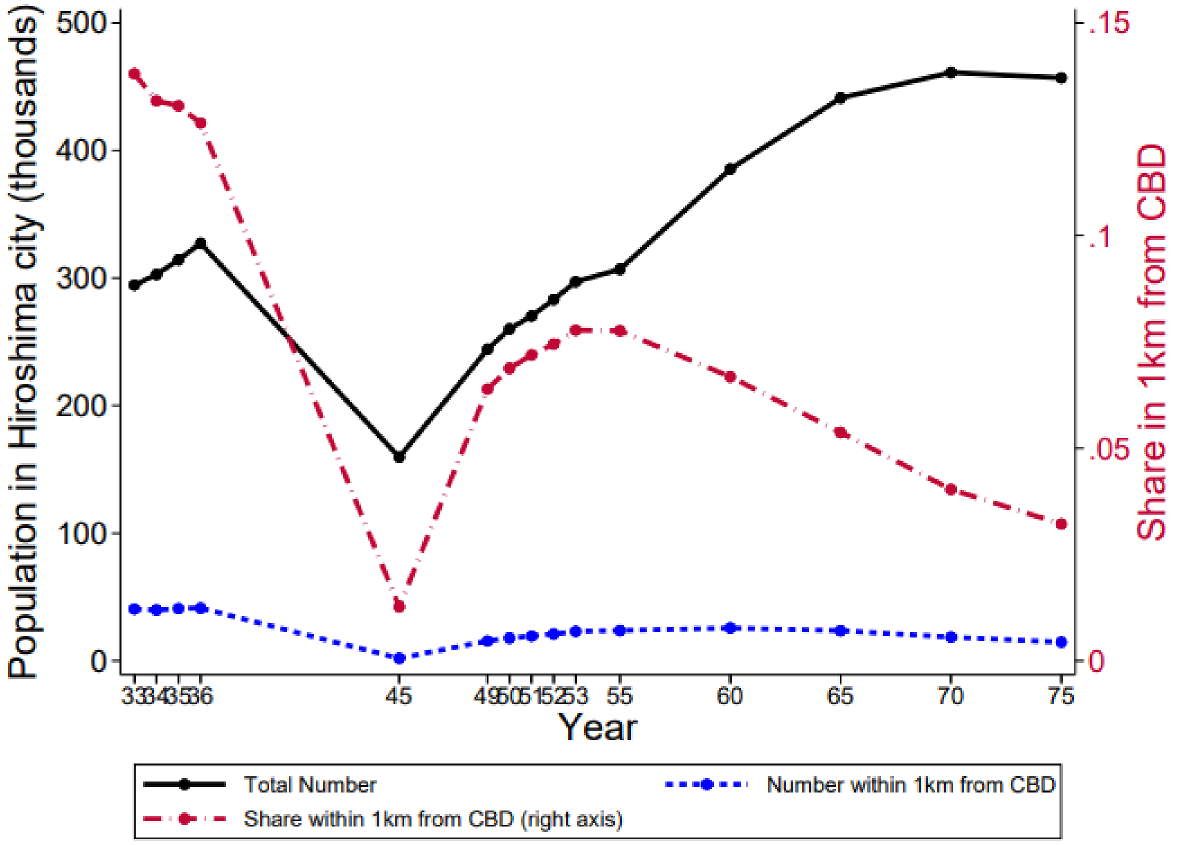
- Population (newly digitized in this paper)
  - 1933-36 Hiroshima-shi tokei sho (広島市統計書)
  - 1945-53 Hiroshima Shisei Yoran (市勢要覧）
  - 1955- Population Census (国勢調査)
  - Block level population in 1945 is estimated using less granular population data and the damage records

- Employment and establishments (newly digitized in this paper)
  - 1938 Hiroshima-shi shoukou gyou keiei chosa (広島市商工業経営調査)
  - 1946 Hiroshima Shisei Yoran (市勢要覧)
  - 1953 Hiroshima chukan jinko chosa (広島昼間人口調査)
  - 1957- Business establishment statistical survey (事業所統計)
  - Block level employment in 1945 is estimated using less granular employment data in 1946, destruction of buildings and establishments in 1938, together
  - We use a less granular level in 1953, 57, 63 and block-level data in 1966 to approximate the block-level employment in 1945-63

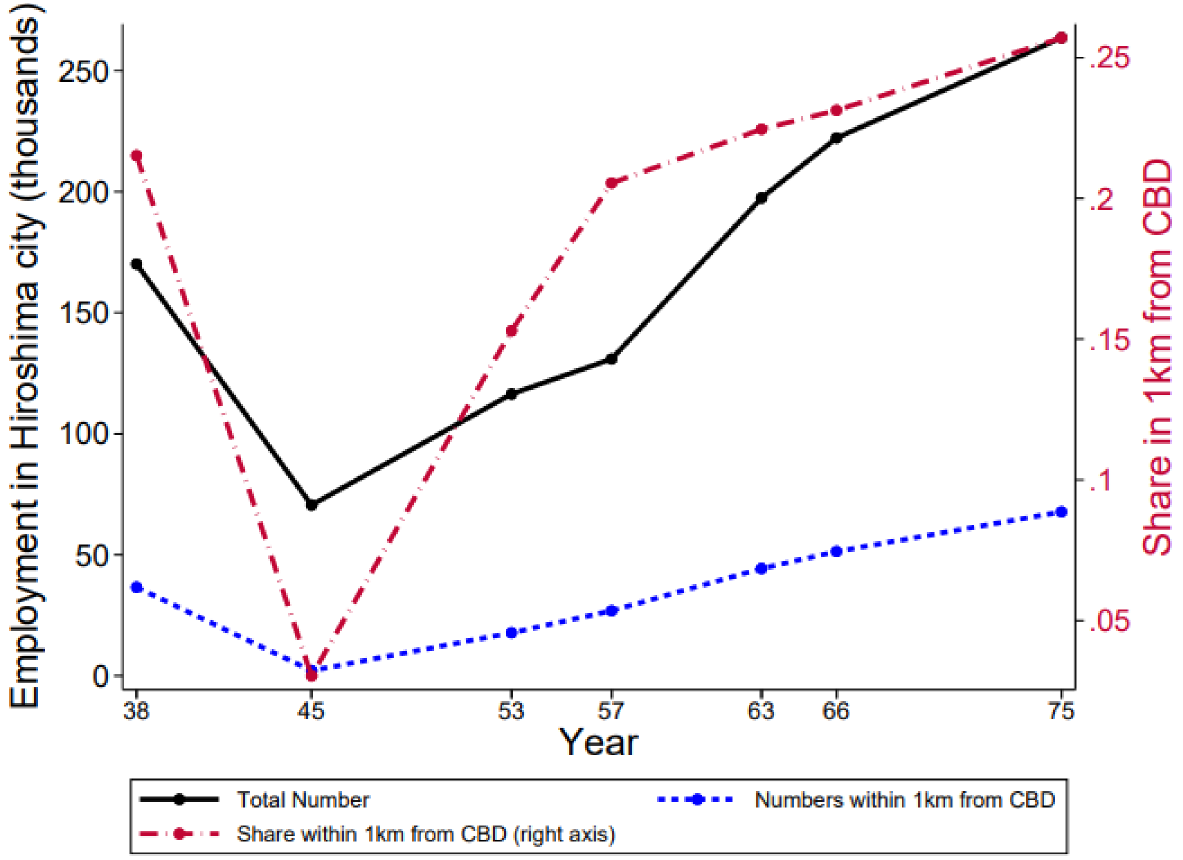
Source of data

- Damage
  - Hiroshima genbaku sensai-shi (原爆戦災誌) on the ratio of death and destroyed buildings
  - Takezaki and Soda (2001) provide the GIS version
- Commuting
  - Microdata of 1987 Person-trip Survey in Hiroshima provided by the Chugoku Region Development Bureau
- Proxies of fundamental locational amenities and productivity
  - Data from the digital national land information by the Ministry of Land, Infrastructure, Transport and Tourism and Hiroshima city government
  - Altitude, slope, distance to water, soil condition, geographical coordinates
  - Distance to the closest station, cultural asset
- Maps
  - Block boundaries as of the bombing (Takezaki and Soda, 2001)
  - We digitized commercial maps published in 1966 and 76 to deal with the redrawing the block boundaries
  - We digitized the transport network in 1950 and 78

Population and employment in Hiroshima

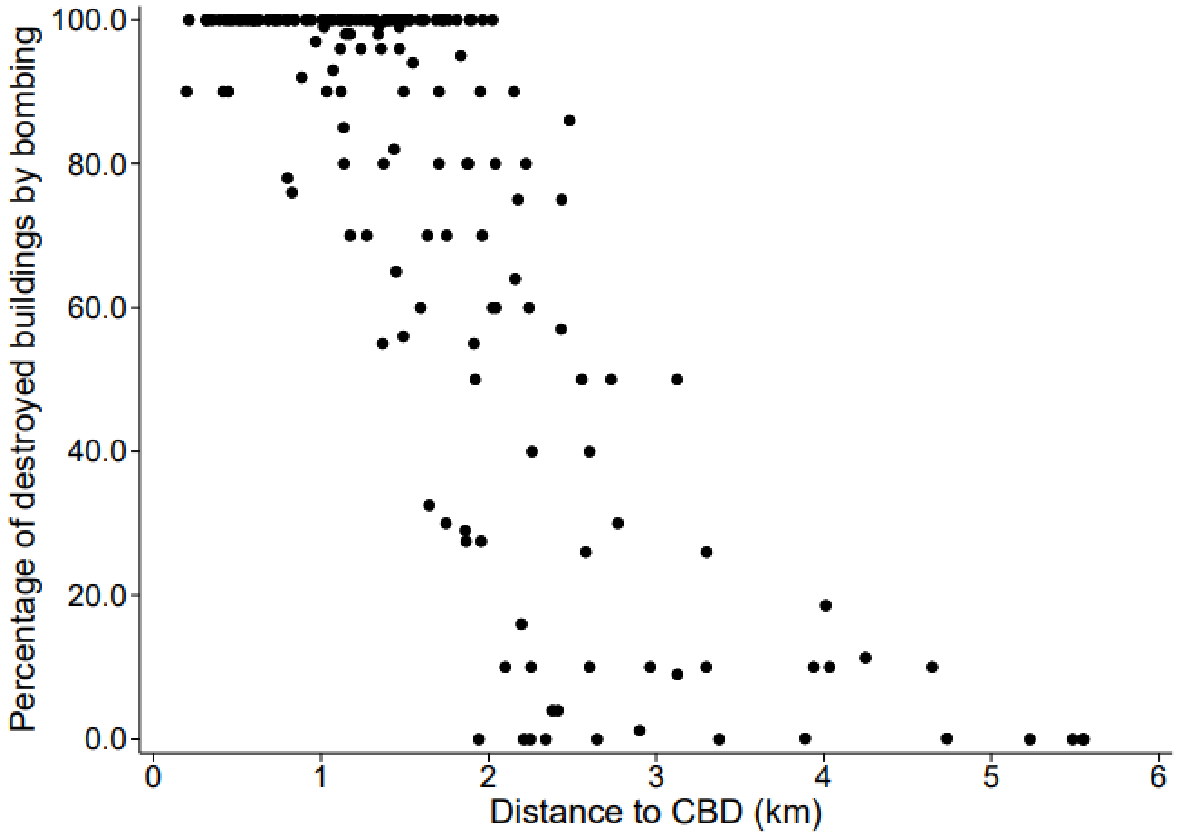


(a) Population

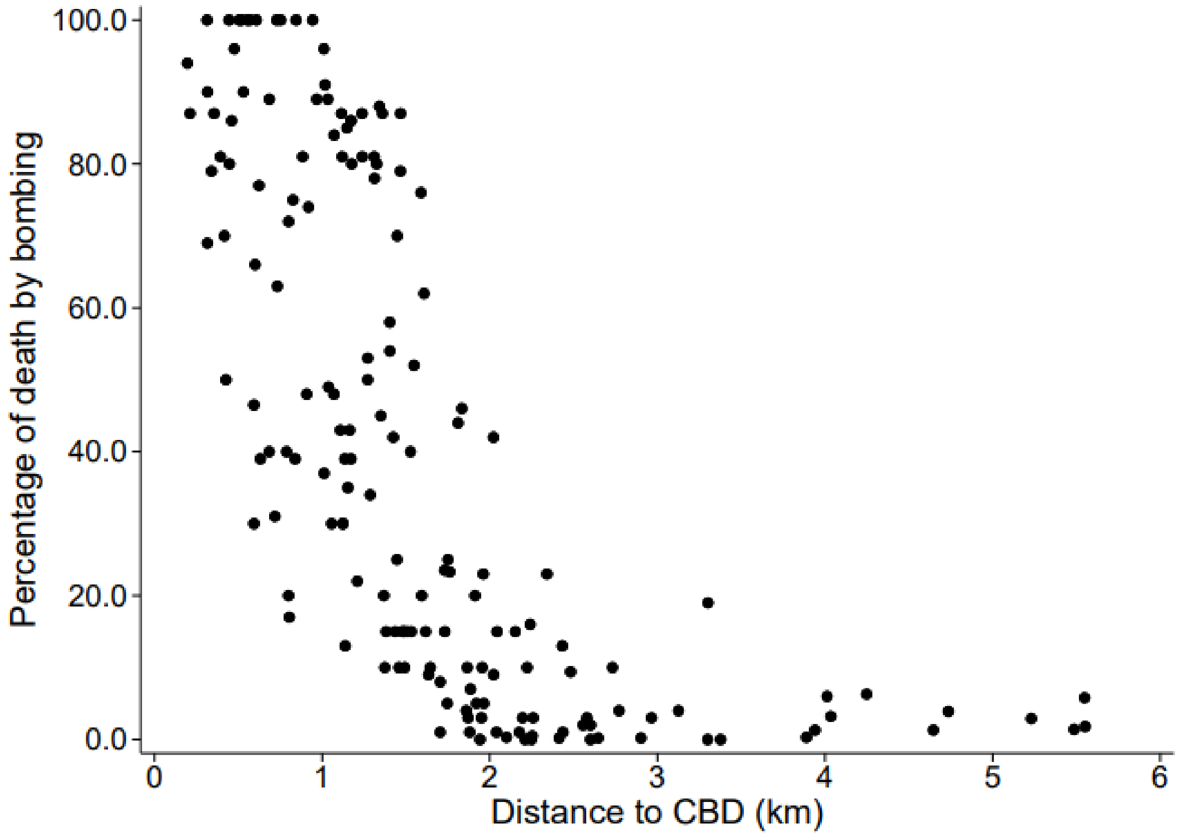


(b) Employment

Damage

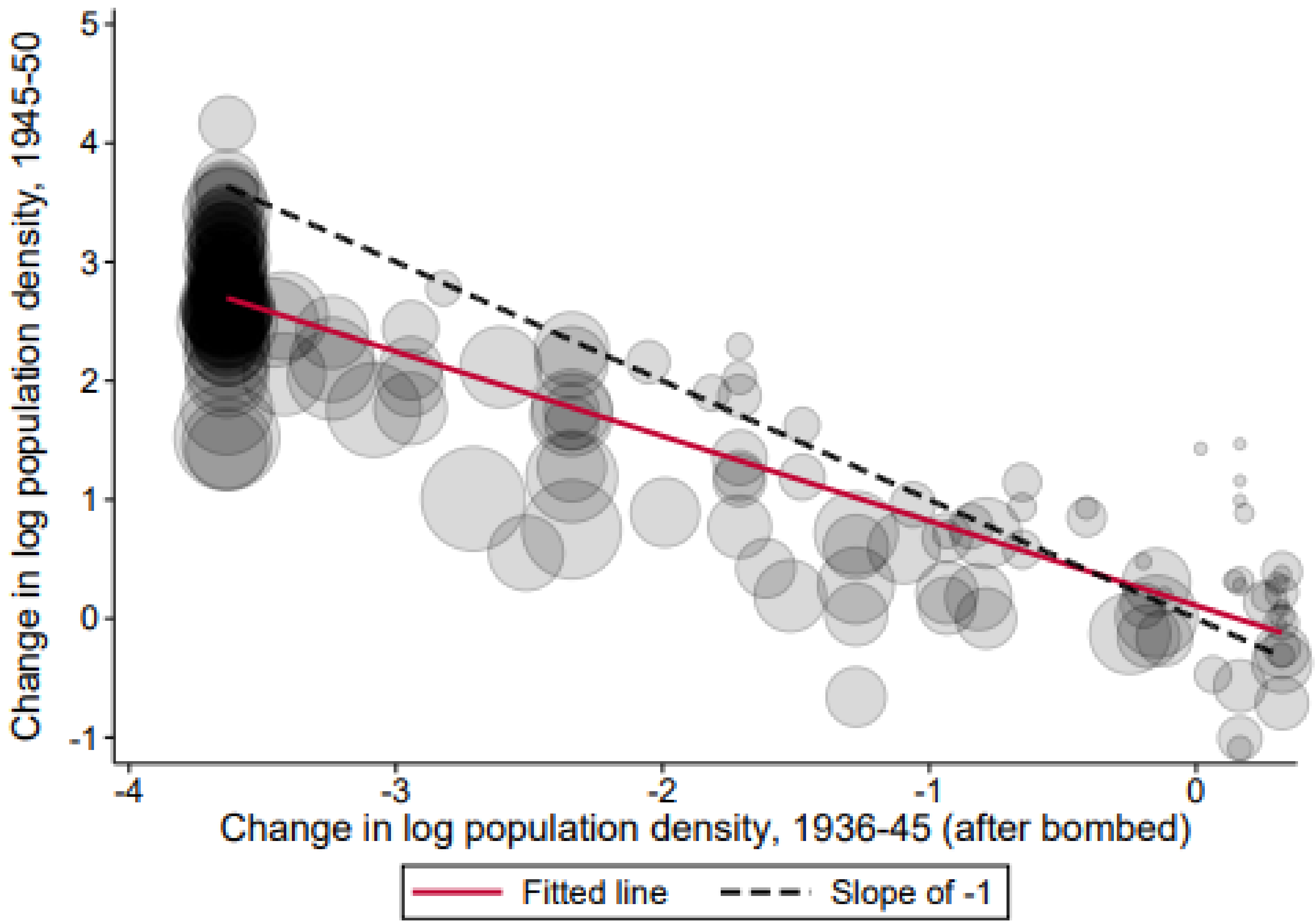


(a) Damage to buildings



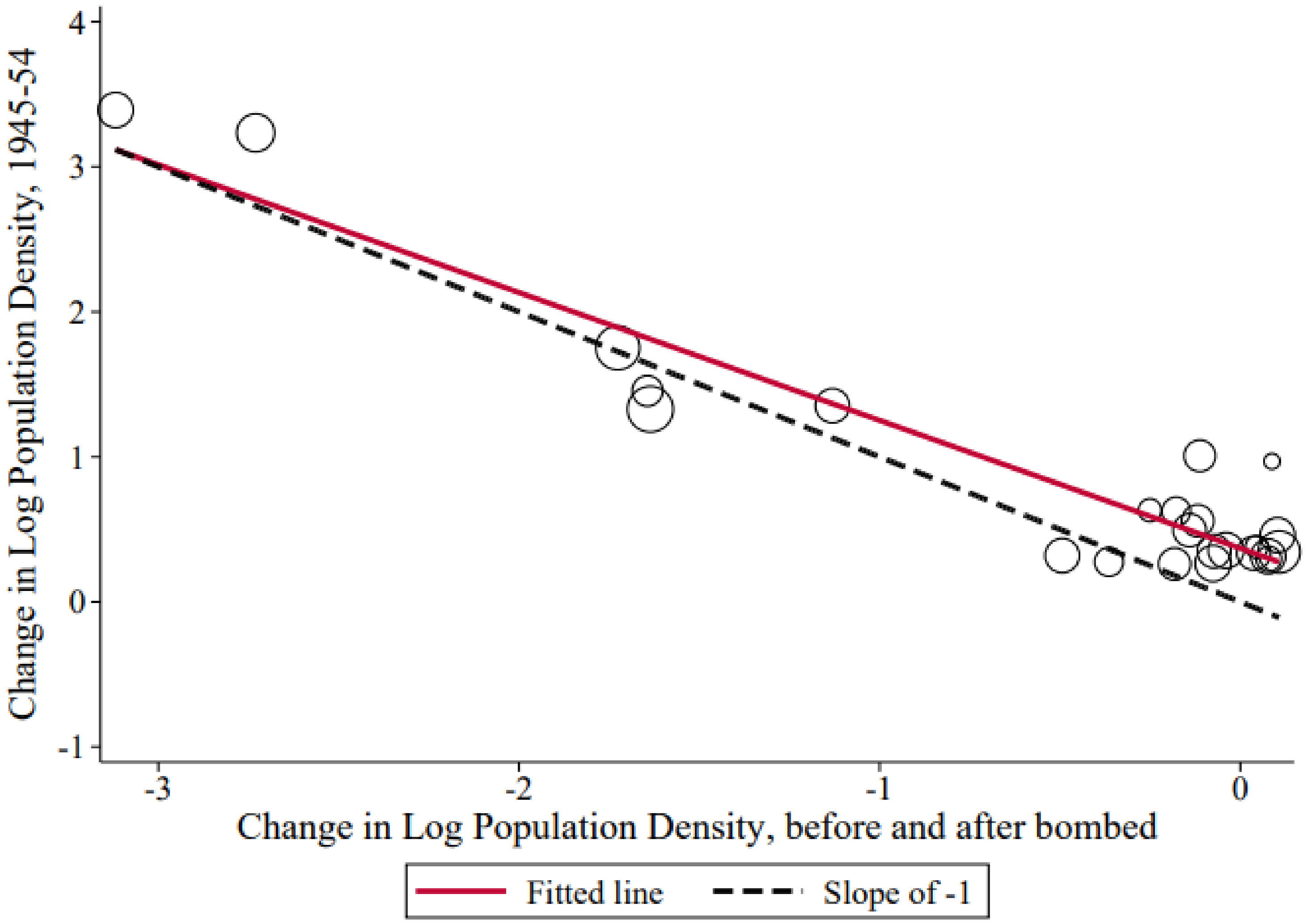
(b) Death rate of people

Hiroshima



Change in log population density, 1945-50
5
4
3
2
1
0
-1
-4
-3
-2
-1
0
Change in log population density, 1936-45 (after bombed)
Fitted line
Slope of -1

Nagasaki



- The bomb hit an outskirt of the city
- We also obtain history independence for Nagasaki

Employment changes

	(1)	(2)	(3)	(4)	(5)	(6)
	Change in log employment density 1945–1950					
Change in log employment density 1938–1945 (γ)	-0.7501[a]	-0.8131[a]	-0.8458[a]	-0.8829[a]	-0.9018[a]	-0.9240[a]
	(0.0363)	(0.0403)	(0.0409)	(0.0533)	(0.0499)	(0.0336)
p-value from testing $\gamma = -1$	0.000	0.000	0.000	0.029	0.051	0.025
Natural location characteristics (first nature)		Yes		Yes	Yes	Yes
Built location characteristics (second nature)			Yes	Yes	Yes	Yes
Pre-war trends in population					Yes	
Within 3 km from the city center						Yes
Number of blocks	174	174	174	174	174	158
R-squared	0.757	0.795	0.775	0.814	0.823	0.877

Note: This table reports the OLS estimation results of estimating equation (1) for employment. The set of control variables is the same as in Table 1 in the main text. In Column (6), we confine the sample to blocks within 3 kilometers of the city center. We report the p-value from testing the null $\gamma = -1$. Heteroskedasticity-robust standard errors in parentheses. [a] indicates significance at the 1 percent level.

Control public housing supply

	(1) Log number of public housing units	(2)	(3)	(4)
		Change in log population density 1945–1950		
Distance to CBD	0.0004[c]			
	(0.0002)			
Change in log population density 1936–1945 (γ)		-0.7270[a]	-0.8403[a]	-0.8875[a]
		(0.0273)	(0.0484)	(0.0472)
Number of public housing units		0.0023	0.0024[c]	0.0019
		(0.0014)	(0.0012)	(0.0026)
p-value from testing $\gamma = -1$		0.0000	0.0012	0.0184
Location characteristics (first and second nature)			Yes	Yes
Number of blocks	22	174	174	158
R-squared	0.234	0.816	0.854	0.866

Note: In Column (1) we regress log number of public housings units on distance to CBD. The number of blocks with public housing units is 22. In Columns (2)–(4), we report the OLS estimates of equation (1) when controlling for the number of public housing units. In Column (2) we do not include other location characteristics, while we include the same set of control variables in Column (3) as in Table 1 in the main text. In Column (4) we focus on 158 blocks within 3 kilometers of the CBD. We report the p-value from testing the null $\gamma = -1$. Heteroskedasticity-robust standard errors in parentheses. [a] and [c] indicate significance at the 1 and 10 percent level, respectively.

Additional reduced form result

	(1)	(2)	(3)	(4)	(5)	(6)
	Log population density in 1950					
	Baseline				Only fundamentals	
	All blocks			Blocks in 3km of CBD	All blocks	Blocks in 3km of CBD
Log population density in 1936	0.4941[a]	0.5222[a]	0.5080[a]	0.5474[a]		
	(0.0415)	(0.0552)	(0.0675)	(0.0808)		
Log population density in 1945	0.0899[a]	0.0553	0.0288	-0.0158		
	(0.0317)	(0.0383)	(0.0400)	(0.0378)		
Log distance to nearest station		-0.0468	-0.0169	-0.0218	-0.1803[b]	-0.1318[c]
		(0.0427)	(0.0491)	(0.0519)	(0.0693)	(0.0704)
Log distance to port		-0.0359	0.8479[c]	0.3643	0.8226	1.2200
		(0.1335)	(0.4463)	(0.8525)	(0.6924)	(1.0585)
Log distance to cultural asset		0.1196[b]	0.1057[c]	0.1287[b]	-0.0133	-0.0214
		(0.0552)	(0.0584)	(0.0546)	(0.0601)	(0.0529)
Fraction of moderately-destroyed buildings		0.0006	-0.0018	0.0017	-0.0082	-0.0051
		(0.0025)	(0.0039)	(0.0041)	(0.0061)	(0.0057)
Log distance to water			0.0734	0.0686	-0.1325[c]	-0.0879
			(0.0462)	(0.0603)	(0.0704)	(0.0819)
Altitude and slope			Yes	Yes	Yes	Yes
Soil conditions			Yes	Yes	Yes	Yes
Latitude and longitude			Yes	Yes	Yes	Yes
Number of blocks	174	174	174	158	174	158
R-squared	0.583	0.599	0.658	0.489	0.412	0.213

Note: We report the OLS estimates of equation (2) in the main text. The controls include the altitude and its square, the slope and its square, a dummy for bad soil conditions, and geographical coordinates (latitude, longitude, and their interaction). Heteroskedasticity-robust standard errors in parentheses. [a], [b] and [c] indicates significance at the 1, 5 and 10 percent level, respectively.

Commuting elasticity

	(1)	(2)	(3)	(4)	(5)	(6)
	Log Commuting Flow		Log(Commuting Flow+1)		Commuting Flow	
Average commuting cost ($\bar{c}_{in}$)	-4.082^{***}	-3.976^{***}	-5.758^{***}	-3.931^{***}	-8.019^{***}	-7.031^{***}
	(0.156)	(0.170)	(0.179)	(0.169)	(0.195)	(0.215)
Estimation	OLS		OLS		PPML	
Number of observations	2,473	1,635	4,356	1,635	4,290	1,635
More than 20 commuters		✓		✓		✓
R-squared/ Pseudo R-squared	0.543	0.522	0.551	0.521	0.764	0.729

Note: We report estimates of gravity equation (14) for commuting by OLS in Columns 1 and 2. In Columns 3 and 4, we use OLS but add 1 to commuting flows so that we do not drop observations with zero commuting flows. We use the PPML in Columns 5 and 6. We use average commuting costs that we computed in mode choice and include origin and destination fixed effects. Note that Column 5 has slightly fewer observations than Column 3 because of computational issues in PPML (Correia et al. 2020). Standard errors in parentheses. ***: Significant at the 1% level.

Estimate the agglomeration parameters

- Population changes between any two periods ⇒ **Overall attractiveness** of each block

$$\Omega_{it} = a_{it}\left(\frac{L_{it}}{S_i}\right)^{\alpha}\prod_{\tau=t+1}^{T}\left[a_{i\tau}\left(\frac{L_{i\tau}}{S_i}\right)^{\alpha}\right]^{\prod_{s=t+1}^{\tau}\rho_s(1-\theta_s)}$$

- Observed population, land endowment and parameters ⇒ **Fundamental advantages a_{it}**

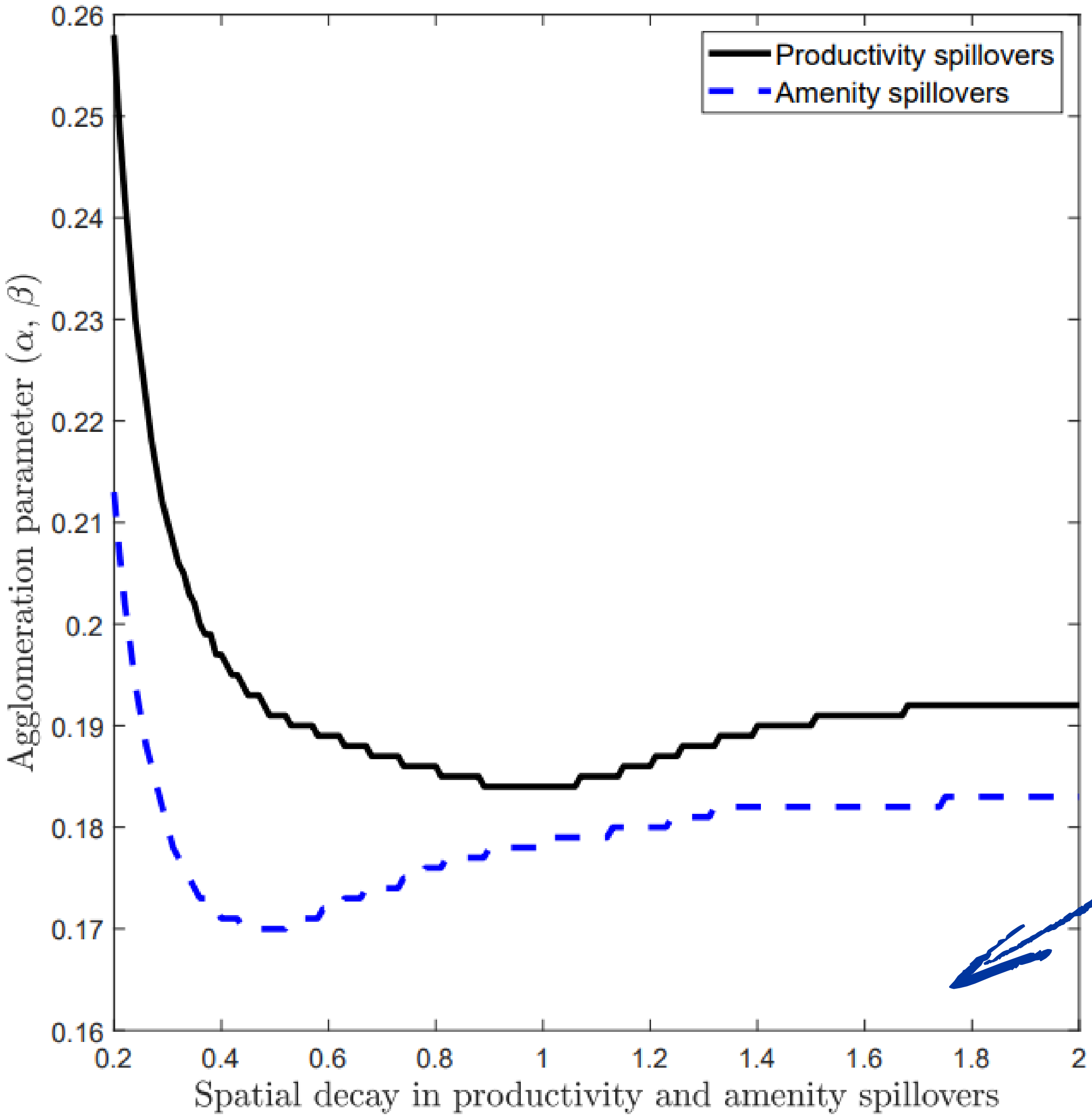
$$\ln a_{it} = \ln a_i^F + \ln a_t^* + \ln a_{it}^{\text{Var}}$$

- Average out the trend terms and take differences between periods ⇒ We focus on the **change in structural error** in fundamentals

$$\mathbb{E}[\Delta \ln(a_{it}/\tilde{a}_t) \times \mathbb{1}_i(k)] = 0$$

  - **Identification**: **changes** in the log structural errors are not correlated with the distance from the city center

Spatial spread of spillovers

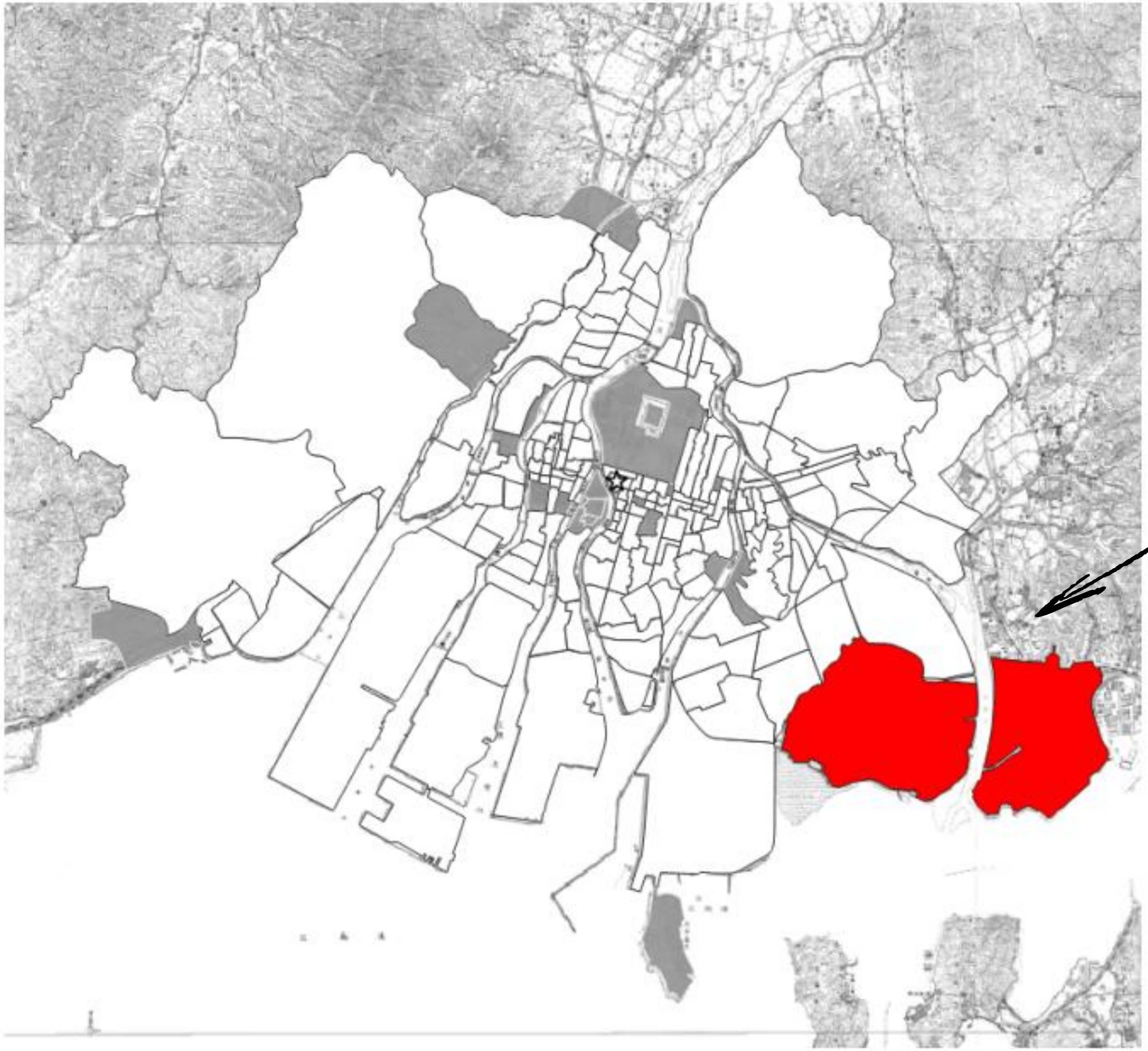


$$A_{it} = a_{it} \left[\sum_{i' \in \mathcal{C}} e^{-\delta \tau_{ii'}} \left(\frac{L_{i't}}{S_{i'}} \right) \right]^{\alpha}$$

$$B_{nt} = b_{nt} \left[\sum_{n' \in \mathcal{C}} e^{-\delta \tau_{nn'}} \left(\frac{R_{n't}}{S_{n'}} \right) \right]^{\beta}$$

Degree of spatial decay, δ

Alternative equilibrium



Highest population and employment density in no recovery equilibrium