History versus Expectations in the Spatial Economy: Lessons from Hiroshima*

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Abstract

This paper studies the relative importance of history and expectations in the spatial economy through the atomic bombing of Hiroshima. Newly digitizing granular data on the distribution of economic activities within the city of Hiroshima, we first demonstrate the startling history-*independence*: the city's center strongly recovered only about five years after being destroyed. We present a dynamic urban economics model that incorporates both history and expectations, allowing us to quantify their relative importance in redevelopment. We find that expectations for rebuilding are self-fulfilling in that they provide a strong incentive to rebuild the city center despite its catastrophic history.

Keywords: agglomeration, history, expectations, quantitative spatial model, atomic bombing

JEL classification: C73, N45, O18, R12, R23

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1 Introduction

The concentration of population and employment increases productivity and welfare through agglomeration economies. Yet, strong agglomeration economies pose a challenge to understanding the spatial distribution of economic activities because they can lead to multiple equilibria (Fujita, Krugman and Venables 1999). The complexity of equilibrium selection often compels researchers to assume away strong agglomeration forces to avoid multiple equilibria in their empirical research (Redding and Rossi-Hansberg 2017), although the presence of multiple equilibria can significantly alter policy implications (Kline and Moretti 2014). A deeper understanding of how equilibrium selection works under multiple equilibria is necessary to analyze the spatial distribution of economic activities while taking into account strong agglomeration economies, which is a core finding in spatial economics.

In their seminal theoretical contributions, Krugman (1991) and Matsuyama (1991) show that *history* and *expectations* dictate which equilibrium realizes. History determines the initial conditions, which may put the economy on the path to a particular equilibrium. However, expectations of individuals that the economy is moving to another equilibrium may become self-fulfilling so that it actually realizes irrespective of history. Empirically, while the importance of history has been extensively analyzed (see, for example Davis and Weinstein 2002; Bleakley and Lin 2012; Allen and Donaldson 2022), we know little about the importance of self-fulfilling expectations because expectations are difficult to observe and distinguish from fundamental characteristics of locations (Lin and Rauch 2022).

This paper analyzes the empirical importance of self-fulfilling expectations in the resurgence of Hiroshima after the atomic bombing. We newly collect granular data on population, employment and fundamental characteristics within Hiroshima. Our reduced-form analysis reveals the strong *path-independence* in Hiroshima: the totally-destroyed city center recovered only five years after the atomic bombing. Our results are not plausibly explained by fundamental location advantages of the city center, suggesting the potential importance of self-fulfilling expectations. To explicitly analyze the role of expectations that are not directly observable, we build and calibrate a novel dynamic quantitative urban model that incorporates both history and expectations. In the model, individuals can switch their residence and workplace while anticipating future productivity and amenities. Both productivity and amenities of each location depend on current and historical employment and population density, as well as fundamental characteristics. Our model of forward-looking location choices can well rationalize the resurgence of population and employment to the city center. To highlight the role of self-fulfilling expectations in the recovery, we also analyze a myopic version of our model, in which individuals relocate to maximize the contemporaneous utility without anticipating future conditions of each location. In this myopic model, expectations play no role and the equilibrium is determined solely by the initial condition. The myopic model cannot rationalize the observed resurgence, suggesting that self-fulfilling expectations are crucial in explaining the recovery of central Hiroshima despite

its catastrophic history.

The atomic bombing in Hiroshima was an unprecedentedly large historical shock to the spatial distribution of economic activities. It reversed the typical monocentric city structure, in which population and employment are concentrated in the city center. In particular, most of the administrative region of Hiroshima city lies within 6 kilometers of the city center, and virtually all structures within 2 kilometers of the center were destroyed by the atomic bombing. Many buildings on the outskirts, however, were not completely destroyed. Some areas on the outskirts even experienced an increase in population due to the inflow of survivors from the city center. Consequently, the atomic bombing reversed the monocentric city structure, leaving the city center with the *lowest* population and employment density. If history determines the equilibrium of realization, the city center of pre-war Hiroshima would be less prosperous in the post-war period. Specifically, the city center could relocate or the city structure could become polycentric (Ahlfeldt, Albers and Behrens 2020). However, after the radioactive contamination was substantially mitigated within a few months of the bombing, the old city center quickly recovered and became the hub of economic activities again.

To formally analyze the recovery of central Hiroshima and its potential causes, we newly collect and digitize historical data on population and employment distribution within Hiroshima from the pre-World War II period to 1975, 30 years after the atomic bombing. Using these data, in Section 3, we conduct a reduced-form analysis on the relationship between the destruction by atomic bombing and the post-war population density. We find strong *path independence*: the influence of the destruction was no longer apparent in the population distribution just five years after the atomic bombing. Moreover, although the city center may recover even without the role of self-fulfilling expectations if it has fundamentally attractive conditions (Davis and Weinstein 2002), our additional results rule out this possibility. First, controlling for observed location characteristics and focusing on a small and homogenous area (c.f., Schumann 2014) do not change our results. Second, we additionally examine Nagasaki, where the atomic bomb hit the outskirts rather than the city center. We observe a rapid and strong recovery in the destroyed outskirts of Nagasaki. Therefore, although the location of the pre-war city center may have been selected based on unobserved fundamental advantages, they would not be a major factor in the recovery of central Hiroshima because the outskirts of Nagasaki could recover despite the absence of such advantages. These findings motivate us to focus on the self-fulfilling expectations in the recovery as the primary driver of recovery, which may have been formed by various factors, including the governmental recovery plans, the anchoring effect of the transportation system, land ownership, and the narrative of rebuilding.

In Section 4 we turn to a structural approach by developing a quantitative urban model that incorporates both forward- and backward-looking aspects of location choices. The structural approach is a powerful tool that allows us to explicitly observe the migration incentive given by self-fulfilling expectations. Following the recent quantitative urban model (Ahlfeldt,

Redding, Sturm and Wolf 2015), a city has the heterogeneous location-specific amenities and productivity. In our model, (i) agents correctly anticipate the future path of the economy when making their location decisions, and (ii) neighborhood amenities and productivity depend on population and employment density. Therefore, the location decisions of individuals hinge on the future changes in population and employment distribution in the city, which define the option value associated with each neighborhood. Our model also incorporates a perspective of backward-looking location decisions, in which amenities and productivity depend on past population and employment density (Allen and Donaldson 2022), and migration is subject to frictions (Caliendo, Dvorkin and Parro 2019). Taken together, our model allows us to evaluate the relative importance of history and self-fulfilling expectations in accounting for the recovery, while remaining agnostic about how the expectations in the recovery were formed.

The model is calibrated in Section 5. We use the data on population, employment and other observed characteristics during the post-recovery period in Hiroshima from 1950 to 1975. We leverage the structure of the model to estimate model parameters and recover unobserved location characteristics. Our key parameters are spillovers in amenities and productivity that determine the value of future returns from location choices. We find strong net agglomeration economies in both amenities and productivity: a high population and employment density today improves current amenities and productivity, respectively. In addition, a higher population density five years ago increases the current value of amenities, while a high employment density five years ago is negatively associated with the current level of productivity. Strong positive agglomeration economies in both amenities and productivity are essential to explaining the change in economic activities in the city, whereas the negative relationship between past employment density and current productivity may be consistent with frictions in floor space supply or innovation activities (c.f., Hornbeck and Keniston 2017). Armed with the model parameters, we assess how well our model can rationalize the data that from 1945 to 1950, people chose to return to the completely-destroyed city center. We demonstrate that our model, in which people make migration decisions while correctly anticipating the recovery of the city center, can rationalize the resurgence. The model accounts for nearly 80 percent of the relative attractiveness of locations as residences and workplaces during the time period.

In Section 6 we highlight that the forward-looking aspects of our model are essential to its success. To this end, we quantitatively compare the performance of models with myopic and forward-looking location choices in explaining the recovery from the bombing. We begin by introducing a myopic model in which people make migration decisions based on static, backward-looking expectations of each location. We compare models using two complementary approaches. First, we demonstrate that, in contrast to our baseline forward-looking model, the myopic model can explain only a much smaller part of the relative attractiveness of each location as a residence and workplace during the recovery period. Second, we simulate the counterfactual population and employment distribution within Hiroshima in 1945, right after the bombing,

when individuals make myopic migration decisions. The counterfactual outcomes of the myopic model fail to predict the observed resurgence of central Hiroshima. Taken together, the inability of the myopic model to account for the recovery suggests that the spatial distribution of economic activities in Hiroshima would be significantly different if only history mattered. Combined with the success of our baseline model with forward-looking behavior to explain the recovery, it suggests that self-fulfilling expectations were crucial for the resurgence of central Hiroshima.

This paper relates to many strands of literature. First, it contributes to the discussion about history versus expectations in equilibrium selection. Krugman (1991) and Matsuyama (1991) show that self-fulfilling expectations can induce a transition from one steady state to another, implying that history can be overcome by expectations.[1] A spatial economy featuring agglomeration economies is a primary example in which equilibrium selection matters because the positive spillovers can lead to multiple equilibria (Fujita et al. 1999; Redding and Rossi-Hansberg 2017). By exploiting the atomic bombing in Hiroshima as one of most catastrophic events in human history and a quantitative model motivated by Krugman (1991) and Matsuyama (1991), we empirically highlight the importance of self-fulfilling expectations in determining equilibrium.[2]

This paper also contributes to the discussion about whether a historical event has a persistent impact on the spatial distribution of economic activities. Previous studies exploiting war-time destruction as a shock often find path independence (Davis and Weinstein 2002, 2008; Brakman, Garretsen and Schramm 2004; Bosker, Brakman, Garretsen and Schramm 2007; Miguel and Roland 2011; Redding and Sturm 2016; Feigenbaum, Lee and Mezzanotti 2022; Harada, Ito and Smith 2022). In particular, the seminal work by Davis and Weinstein (2002) finds that *across-city* population distribution of Japan after WWII converged to the pre-war trend, including Hiroshima and Nagasaki. Yet, path dependency may arise depending on the historical event and the outcome variables of interest, as pointed out in recent reviews (Glaeser 2022; Lin and Rauch 2022).[3]

Our contribution to the empirical literature on path dependence is twofold. First, using newly-digitized data, we revisit the context of the seminal work by Davis and Weinstein (2002) but focus on *within* Hiroshima. The intra-city focus is important because, a priori, path dependence is expected even more plausibly for two reasons. The first reason is that the shock is of greater magnitude. While the atomic bomb reduced the total population of Hiroshima by

[1] Fukao and Bénabou (1993) corrects a mathematical problem in Krugman (1991). See, among others, Rauch (1993), Baldwin (2001), Ottaviano (2001), Oyama (2009), and Barreda-Tarrazona, Kundu and Østbye (2021) for further developments on the idea of Krugman (1991) and Matsuyama (1991) in economic geography.

[2] The self-fulfilling expectations also matter in other important economic contexts with multiple equilibria: bank runs (Diamond and Dybvig 1983); structural transformation in economic development (Murphy, Shleifer and Vishny 1989); and health insurances (Foley-Fisher, Narajabad and Verani 2020).

[3] See, for example, Arthur (1994); Redding, Sturm and Wolf (2011); Bleakley and Lin (2012); Schumann (2014); Siodla (2015); Hornbeck and Keniston (2017); Michaels and Rauch (2018); Kocornik-Mina, McDermott, Michaels and Rauch (2020); Allen and Donaldson (2022); Yamasaki, Nakajima and Teshima (2022); Brooks, Rose and Veuger (2022)

two-thirds, the population in central Hiroshima reached almost zero. The second reason is that our focus on Hiroshima city would substantially mitigate the variation in fundamental advantages due to its small spatial extent and relatively homogeneous location characteristics, which would make multiple equilibria and path dependence more likely (Schumann 2014).[4] Despite these reasons for predicting path dependence, our findings of path independence result despite suggests that self-fulfilling expectations may play a key role in recovery. Our second contribution is to investigate the mechanisms underlying path independence using a quantitative model. An important open question in the empirical literature of path dependence is to understand the conditions under which history matters or does not matter (Lin and Rauch 2022). It has been challenging to analyze the role of self-fulfilling expectations due to the lack of data about expectations and a tractable quantitative model. Combining a reduced-form analysis and a tractable dynamic urban model, we offer a new quantitative insight on this question by highlighting the role of self-fulfilling expectations in overcoming the influence of history.[5]

Our paper also relates to recent research on quantitative spatial models (Redding and Rossi-Hansberg 2017). The model presented in this paper is the first quantitative urban model with the following three key elements. First, people make a forward-looking migration decision with perfect foresight (Desmet, Nagy and Rossi-Hansberg 2018; Caliendo et al. 2019; Balboni 2021; Heblich, Trew and Zylberberg 2021; Kleinman, Liu and Redding 2021; Allen and Donaldson 2022) in order to feature self-fulfilling expectations. Second, we incorporate commuting to account for differences in location as a residential place and a workplace within a city (Ahlfeldt et al. 2015; Dingel and Tintelnot 2020; Tsivanidis 2022). Third, we include history-dependent amenities and productivity and migration frictions to capture the influence of history (Allen and Donaldson 2022).[6] We integrate these elements into one framework while keeping it parsimonious in other aspects because, in our historical context, the availability of data is more limited than in modern developed countries.[7]

Lastly, this paper relates to studies on the recovery of Hiroshima from the atomic bombing. However, there is little econometric analysis on the distribution of economic activities within the city and what can account for the resurgence of the city center (Hiroshima City Government, 1971; 1983). We newly digitize historical resources on population and employment at a spatially

[4]Combined with Japan's geographic heterogeneity across cities, this argument has been invoked to reconcile the path independence result of Davis and Weinstein (2002) with path-dependence results in other studies (Bleakley and Lin 2012; Schumann 2014; Lin and Rauch 2022). See also Rauch (1993) for a related theoretical discussion.

[5]Lin and Rauch (2022) states that "[o]verall, the evidence of self-fulfilling expectations is thinner than evidence of history dependence.... Adapting stylized models such as Krugman (1991) to the data to better understand the importance of history versus expectations might yield important insights." In spirit, this corresponds to what we do in this paper.

[6]In particular, our model extends Allen and Donaldson (2022) by introducing commuting to focus on the internal structure of a city. Furthermore, we set a much lower discount factor for future values compared to Allen and Donaldson (2022) so that expectations play a more important role. This reflects the difference in time-horizon. We consider short periods (every 5 years), while Allen and Donaldson (2022) suppose 50 years for one period since their primary focus is on the long-run impact of history (i.e., the initial conditions).

[7]The parsimony of our model may be useful in data-scarce environments such as historical contexts and developing countries (see, for example Sturm, Takeda and Venables 2022).

granular level to analyze the impact of the atomic bombing at a high spatial resolution. In addition, we present a quantitative economic model to understand the economic mechanisms behind the recovery.

This paper is organized as follows. Section 2 describes the historical background and data. Section 3 introduces the reduced-form analysis and shows the fast and strong resurgence of central Hiroshima after the bombing. Section 4 presents our baseline model. Section 5 calibrates and estimates the model parameters. Section 6 compares our baseline model with the myopic model in which migration decisions are backward-looking. Section 7 concludes.

2 Historical Background and Data

In this section, we briefly describe the history of Hiroshima city and the data of our study. In Subsection 2.1, we summarize the history of the city from the period before the bombing and how atomic bombing changes affect the city. In Subsection 2.2, we describe how we construct a new spatially-granular dataset on population, employment and other characteristics of the administrative Hiroshima city. Appendix A provides further details including summary statistics of the data.

2.1 Historical background

The development of the city of Hiroshima started in the late 16th century, a pre-industrialization era, when Terumoto Mōri, a local samurai lord, built the Hiroshima castle. Hiroshima has been a major city in the region since then. The early 20th century saw a rapid growth of the city: Hiroshima had 310,118 people living there in 1935, making it the seventh-largest city in Japan by population. The growth slowed down and finally reversed as Japan gradually transitioned to a total-war system due to the Second Sino-Japanese war (from 1937) and the Pacific war (from 1941). Prior to the atomic bombing, the city had approximately a population level of 350,000. As the U.S. overwhelmed Japan during World War II (WWII), most major Japanese cities endured extensive non-atomic air raids (Davis and Weinstein 2002). However, since the U.S. desired to preserve Hiroshima as the "best laboratory" to demonstrate the effects of the atomic bomb, the U.S. intentionally refrained from bombing on Hiroshima.[8] Consequently, the atomic bombing was essentially the only direct destruction the city experienced in WWII.

The U.S. Air Force dropped the atomic bomb (*Little Boy*) near the city center of Hiroshima on August 6, 1945. This was the first time in human history that the atomic bomb was used

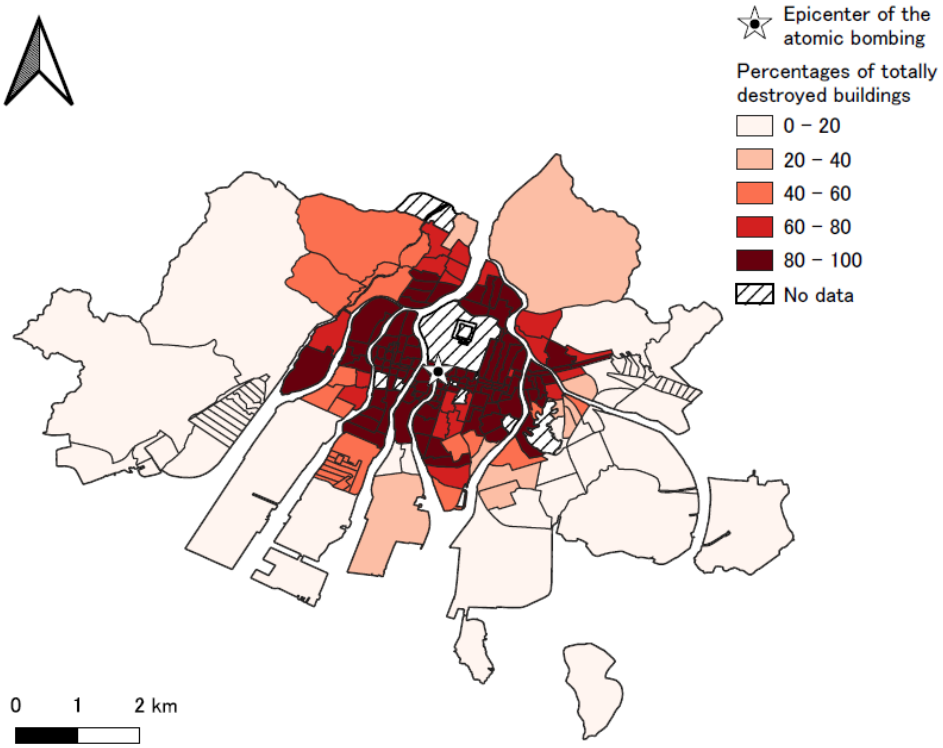
[8]See "Minutes of the second meeting of the Target Committee Los Alamos, May 10-11, 1945" (http://www.dannen.com/decision/targets.html Last accessed on May 14, 2022).

Figure 1: Destruction of the atomic bombing in Hiroshima

(a) Total destruction near the epicenter



(b) Block-level destruction rate of buildings within Hiroshima



Note: Figure (a) illustrates the damage near the epicenter. The photo is by United States Strategic Bombing Survey and provided by The U.S. National Archives & Records Administration. Figure (b) shows the map of Hiroshima city as of the bombing and the block-level data (197 blocks in total) of the fraction of totally destroyed buildings, along with the location of the epicenter (Hiroshima City Government 1971; Takezaki and Soda 2001).

to kill people.[9] The damage to people and buildings was unprecedentedly catastrophic.[10] The city government of Hiroshima estimates that 140,000 people perished by the end of 1945 as a result of the atomic bombing, although it is difficult to determine the exact number.[11] As the atomic bombing caused severe injuries and diseases due to radiation, many of the victims died after 1945, the actual death toll is anticipated to be even higher than this. The death rate was exceptionally high and near 100 percent for those within 1 kilometer from the epicenter. The bomb also destroyed a large number of buildings: 70,147 out of 76,237 buildings in the Hiroshima city were destroyed in excess of fifty percent. The damage tends to be quite severe near the city center, and the majority of buildings within two kilometers of the city center were completely destroyed. The situation in which almost all buildings were destroyed is illustrated in the photo shown as Figure 1a, which was taken near the epicenter of the bombing. Consequently, the population of Hiroshima city dropped to 136,518 in November 1945, which is about one-third of the pre-war population.

However, in contrast to the total destruction in central Hiroshima, the outskirts of the city, by which we mean areas that are about more than 2km away from the city center, experienced relatively moderate destruction. Figure 1b shows the fraction of completely destroyed buildings at the block level (Hiroshima City Government 1971; Takezaki and Soda 2001). While nearly all buildings in the dark-colored areas close to the epicenter were destroyed, the majority of buildings in the light-colored areas away from the epicenter avoided complete destruction, although many of them experienced, to a varying degree, some damages to the building structures. Indeed, the outskirts of Hiroshima experienced a significant increase in population as survivors from the city center escaped to them. Most notably, on November 1, 1945, areas beyond three kilometers from the epicenter had 142 percent of their pre-bombing population.

On August 15, 1945, the war ended when Japan accepted the Potsdam Declaration and surrendered. People initially doubted whether Hiroshima could recover. In particular, radioactive contamination was a major concern immediately after the bombing: rumors circulated that "nothing will grow here for 75 years."[12] However, the serious radioactive contamination caused by the bombing decayed relatively rapidly with time.[13] Furthermore, a large typhoon hit Hiroshima on September 17, 1945 (i.e., about six weeks after the bombing) and it presumably

[9] In Appendix 3.3, we analyze Nagasaki, the last city on which the atomic bomb was detonated, and show that path independence was also observed there despite that the bomb hit different parts of the city: the city center in Hiroshima and the outskirts in Nagasaki.

[10] This damage was even much severer than other cities that endured extensive air raids. For example, the population of Tokyo was approximately 7 million in 1940. During the war, the U.S. air raids on Tokyo killed over 100,000 civilians and damaged approximately 700,000 housing units. Source: https://tokyo-sensai.net/about/tokyoraids/ (In Japanese, last accessed on May 13 2022). While the absolute number is large in Tokyo, the destruction ratio in Hiroshima is substantially greater than in Tokyo due to its smaller population size.

[11] Source: https://www.city.hiroshima.lg.jp/site/english/9803.html (last accessed on November 4, 2022).

[12] Source: https://www.bbc.com/news/world-asia-53660059 (last accessed on March 13 2022).

[13] According to the Hiroshima city government (https://www.city.hiroshima.lg.jp/site/english/9809.html, last accessed on November 4, 2022), the radiation level at the epicenter became 1/1,000th a day after the bombing and 1/1,000,000th a week after.

washed away contaminated substances according to the Atomic Bomb Casualty Commission established by the US, leading to a safe level of radioactivity (Takahashi 2008). Given such evidence, we do not take into account the potential radioactive contamination in analyzing the recovery of Hiroshima because living in Hiroshima was unlikely to cause diseases, at least after this typhoon.[14]

The city government of Hiroshima attempted some early public efforts to aid in the recovery, but a shortage of resources prevented a large-scale action. Indeed, there was no special aid from the central government for Hiroshima until 1949 despite the exceptionally severe damage. Notwithstanding the lack of strong public actions, the Hiroshima city, including its city center, had started to recover strongly due to the private efforts.

In 1955, Hiroshima city had a population level of 357,287, which was already larger than the 1935 population. Hiroshima continued to grow and the city area expanded along the way. Today, Hiroshima city has a population of approximately 1.2 million in 2022, ranking it 10th among all Japanese municipalities and the largest in the *Chugoku* region of Japan.

2.2 Data

We have collected and, when necessary, digitized various information on the economic activity in Hiroshima before and after the war, in addition to other useful data. Here, we provide only a brief overview of the most important data used in this paper (see Appendix A for more details).

Spatial units. The spatial unit of our analysis is mainly block level (*cho-cho-moku*) in Hiroshima city. As our primary definition of geography and city blocks, we use the GIS data of block boundaries as of the bombing constructed by Takezaki and Soda (2001). To make the comparison between the pre-war and the post-war period, we focus on areas that already belonged to Hiroshima city as of the bombing.[15] We additionally digitize the block boundaries as of 1966 and 1976 to account for revisions of the block boundaries by the government. Throughout the paper, the number of blocks is 174 and the average size of blocks is 0.32 square kilometers. This implies that our spatial unit of analysis is generally small, although there is some heterogeneity in the size of blocks. The block tends to be smaller near the city center. The average area size for blocks is 0.04 square kilometers within 1 kilometer from the CBD and 0.13 square kilometers within 3 kilometers from the CBD. In contrast, the average block area is 2.19 square kilometers among blocks more than 3 kilometers away from the CBD.

[14]Note that considering the potential radioactive contamination would, if any, reinforce the main finding of our reduced-form analysis (Section 3) that the city center recovered. Since radioactive contamination was likely to make the city center less attractive, failing to control for it would underestimate the strength of the recovery.

[15]The city boundaries gradually expanded since 1955 through municipal mergers as Hiroshima metropolitan area grew. The administrative Hiroshima city as of 1945 roughly corresponds to the central four wards (*Naka-ku*, *Nishi-ku*, *Minami-ku*, *Higashi-ku*) of the Hiroshima city today. With the expansion of the administrative boundaries and commuting zones of Hiroshima city, it implies that our data concentrate more and more on the central locations as time elapses.

The destruction level by the atomic bombing. Similar to Davis and Weinstein (2002) and Brakman et al. (2004), we primarily use the fraction of totally destroyed buildings as a severity measure of destruction. The block-level destruction rate is reported in Hiroshima City Government (1971). Building on the digitization by Takezaki and Soda (2001), we augment it by consulting Hiroshima City Government (1971) to correct typos in their data and obtain additional information on missing values. Figure 1b in the previous section illustrates the share of completely destroyed buildings in each block on a map.

Population. We collect and digitize the population data at the block level. For the period 1933-1936, we refer to the Statistical Handbook of Hiroshima city (*Hiroshima-shi toukei sho*), which reports population at the block level. For 1945-1953, we refer to the Statistical Abstract of Hiroshima city (*Hiroshima shisei youran*). From 1955, we exploit data from the Population Census. We address changes in the block boundaries by the areal weighting interpolation. For 1945–1950, population is reported in less geographically granular units than blocks, which we address by combining best available block-level information to approximate the block-level population distribution. Details are described in Appendix A.

Figure 2a provides a visualization of the population in Hiroshima over time. The total population in Hiroshima increased prior to the atomic bombing and significantly dropped after the bombing. After WWII, the total population again increased over time. We also observe that the central area of Hiroshima showed a declining share of the population over time. This is suggestive of suburbanization and the development of the outer suburbs of the city that absorbed the population growth of the city, which was a general trend in cities during the post-WWII period (Redding 2021). Note that the declining trend was already observed in the pre-WWII period, suggesting that a lower population share of the center after the WWII does not necessarily mean that the recovery was incomplete.

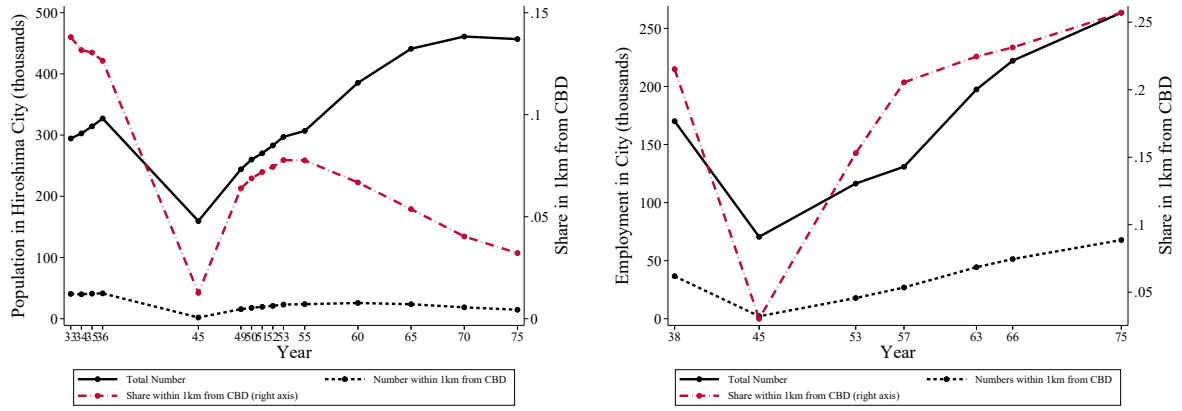
Employment. We collect and digitize employment data at the block level.[16] For the year 1938, we refer to the Survey of Commerce and Industry in Hiroshima city (*Hiroshima-shi shoukougyou keiei chousa*) that records the number of establishments at the block level. The number of commercial buildings right after the bombing is available in the Statistical Abstract of Hiroshima city (*Hiroshima shisei youran*). For 1953, we exploit the Survey on the Daytime Population of Hiroshima (*Hiroshima-shi chukan jinko chosa*). From 1957 to 1975, we use the Business Establishment Statistical Survey (*Jigyousho toukei chousa*). We address changes in the block boundaries by the areal weighting interpolation. For 1953–1963, employment is reported in less geographically granular units than blocks, which we address by combining best available

[16]Throughout this paper, we focus on employment in manufacturing or service sectors and abstract from the agricultural employment. This is relatively a moderate restriction because we focus on an urban area and the agricultural employment is small. Even in 1950, in which the agricultural employment was large in the entire Japanese economy, the Population Census suggests that only less than 10% of workers are in the agricultural sector in the Hiroshima city.

block-level information to approximate the block-level employment distribution. Finally, when employment data is unavailable but establishment data is available, we follow the literature (e.g., Ahlfeldt et al. 2015) to assume that the number of establishments is proportional to the number of employment. Based on the data described above, we also approximate the block level employment every five years from 1950 to 1975 to match the years in which the population data is available. Details are described in Appendix A.

Figure 2b shows the change in employment in Hiroshima city. The total employment dropped significantly in 1945 after bombing, but it increased again post war and number of employment in the central area recovered to the similar level of pre-war period. The share of employment in the central area had been increasing throughout the post-war period, implying the concentration of employment over time.

Figure 2: Change in Population and Employment in Hiroshima City



(a) Population **(b)** Employment

Note: The total number of population and employment of the entire city and within one kilometer from the CBD (left axis), as well as the share of the population and employment living within one kilometer from the CBD (right axis). See Appendix A for data construction.

Commuting. We use the trip-level microdata of the Hiroshima city Person-trip Survey in 1987. We construct a bilateral commuting flow matrix between 73 areas within our sample area.

Locational characteristics. We collect various information on the locational characteristics of each block. In particular, we collect information on the location of train stations, cultural assets, and water area. We also exploit data on the altitude, ruggedness, and the soil condition of each location in a city.

3 Reduced-form Evidence

In this section we analyze population density to illustrate the pattern of destruction and recovery in Hiroshima. Subsection 3.1 describes how the atomic bombing destroyed central Hiroshima and how the city recovered in its subsequent periods. In Subsection 3.2, we conduct a regression analysis of the changes in population distribution and argue that the fundamental advantages of central Hiroshima are unlikely to explain its recovery. Subsection 3.4 discusses the recovery as measured by the employment distribution and land prices, the potential effect of rebuilding policies, and the external validity by examining the case of Nagasaki. Finally, in Subsection 3.5, we highlight that the self-fulfilling expectations in recovery, which may be formed due to factors such as the presence of governmental recovery plans, the anchoring effect of transportation network, property rights, and the popular narrative of rebuilding, may be a primary factor in accounting for the recovery of central Hiroshima.

3.1 Descriptive evidence of the destruction and recovery within Hiroshima

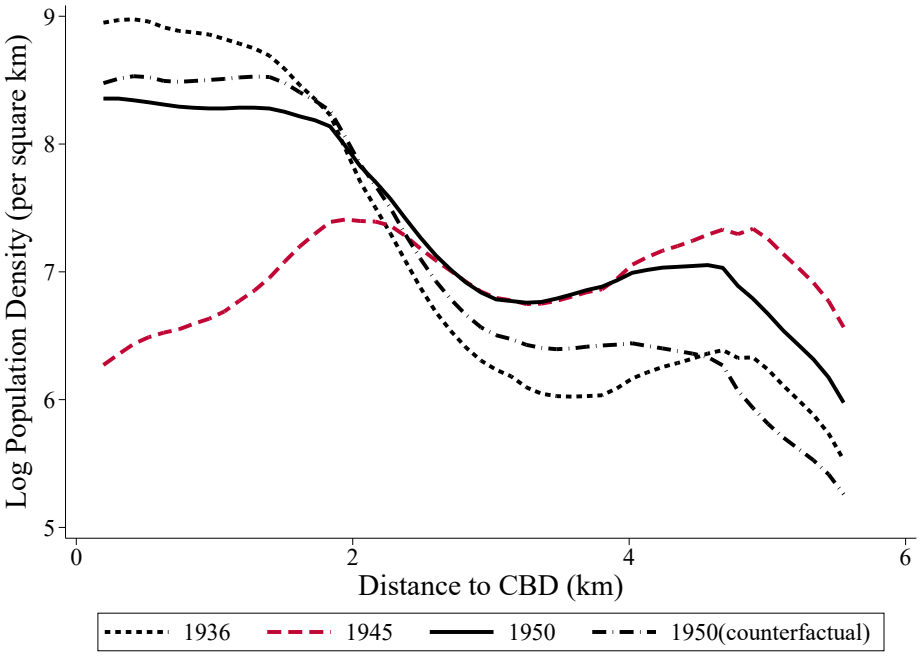
We first graphically illustrate the population distribution within Hiroshima city before and after the atomic bombing. Figure 3 non-parametrically plots the population density of the city of Hiroshima by the distance to the central business district (CBD). We normalize the total population of the city to 100,000 for all years to facilitate comparisons of the inner-city structure across years.

The figure shows that the city structure of Hiroshima completely changed due to the atomic bombing but it quickly recovered to the pre-WWII city structure. In 1936, the city had a typical monocentric city structure. The city center had the highest population density and it decreased as one moved away from the center. Such monocentric city structure is common throughout the world, particularly during historical periods, and Japan is no exception (see, for example Ahlfeldt et al. 2020; Yamagishi and Sato 2022). This monocentric pattern had been completely reversed because the atomic bomb hit the most densely populated city center. Figure 3 shows that, after bombing, the city center became totally destroyed and consequently had the *lowest* population density in the city. In contrast, areas that are about 2 kilometers away from the city center, which avoided the total destruction of buildings (see Figure 1b), became the most crowded places in the city. Areas that are further away from the city center also experienced the significant increase in population density. Indeed, the outskirts experienced an *increase* in population density as many survivors in the city center escaped to the outskirts.[17]

Despite the "reversal" of the monocentric city pattern after the bombing, the monocentric city structure had already re-emerged in 1950, only five years after the bombing. This is quite surprising given that the city center, which was nearly completely destroyed, quickly became the most prosperous place again. While the recovery from the total destruction appears to be robust,

[17] A similar pattern emerges for employment distribution (see Section 3.4).

Figure 3: Population density by the distance to the city center



Note: The figure shows the local polynomial regression of the log population density on the distance to the central business district (CBD) using the block-level data for different years. To eliminate the effect of changes in the total population, we normalize the total population in each year to 100,000. Distances are calculated using the centroid of the each block shape. The CBD is defined as the mid-point of *Kamiya-cho* block and *Hacchobori* block, which are the two prominent areas in the central business district of Hiroshima city both in the pre-WWII and post-WWII periods. The counterfactual population distribution of 1950 is generated from 1936 population distribution, assuming that each block has the annual population growth rate during 1933–1936.

the recovery may not be perfect, as the concentration of the population around the CBD appears to be less dense in 1950 than in 1936. However, this does not necessarily imply that the recovery was incomplete because the city center already had a slow rate of population growth prior to the war. This can be illustrated by the similarity between the actual population distribution in 1950 and the counterfactual one, which was constructed by assuming that there was no atomic bombing and the pre-war population growth rate continued from 1936 until 1950.

If the initial population distribution immediately after the end of the war, which is largely determined by the catastrophic history of the atomic bombing, had a persistent impact, then we would expect a lower population density in the center and a higher population density in the outskirts. The recovery result is analogous to the path-independence result of Davis and Weinstein (2002) for *inter-city* population distribution of Japan after WWII. However, we obtain the recovery in a *within-city* setting of Hiroshima that experienced an extremely larger shock: the complete destruction of the city center.[18] The next section formalizes this point by a regression

[18]Moreover, our results may differ from Davis and Weinstein (2002) in terms of the rate of recovery. In Davis and Weinstein (2002), it took approximately 20 years for the total population of Hiroshima to return to the level predicted by the pre-war trend. In our within-city case, it took only about five years conditional on the location characteristics (see Columns 2 and 3 of Table 1).

analysis.

3.2 Regression analysis of the recovery of central Hiroshima

We now look at the magnitude of the resurgence at a spatially granular level of blocks. We estimate the following regression model analogous to Davis and Weinstein (2002):

$$\ln\left(\frac{\text{Popdens}_{i,t}}{\text{Popdens}_{i,1945}}\right) = \gamma \ln\left(\frac{\text{Popdens}_{i,1945}}{\text{Popdens}_{i,1936}}\right) + \eta X_i + v_i, \tag{1}$$

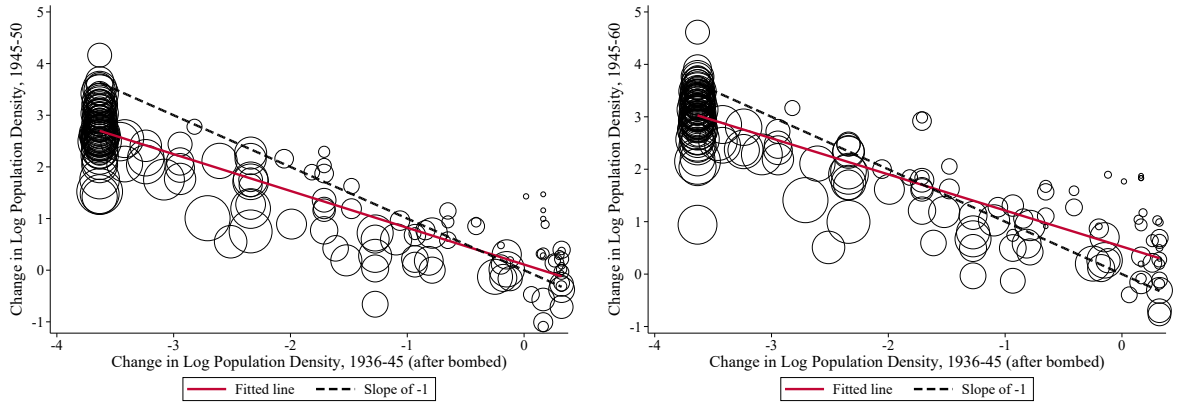
where i is the block and t is the year, and v_i is the error term. In this specification we regress the post-war log population density change rate on the log population change rate induced by the atomic bombing (i.e., the change from 1936 to 1945). If $\gamma = 0$, we have $\ln \text{Popdens}_{i,t} = \ln \text{Popdens}_{i,1945} + \eta X_i + v_i$ so that the log post-war population density is proportional to the log population density right after the bombing, irrespective of the pre-war population density. This is consistent with path dependence, the dominating importance of the historical event (i.e., the atomic bombing) in determining the population distribution. In contrast, if $\gamma = -1$, the population change due to the atomic bombing is completely negated so that $\ln \text{Popdens}_{i,t} = \ln \text{Popdens}_{i,1936} + \eta X_i + v_i$. This is consistent with path independence because the historical event of the bombing no longer matters. A value between 0 and -1 indicates that history matters only partially for the post-war population growth. X_i is the vector of control variables. Throughout Section 3, we keep the analysis descriptive and do not claim causality: The causal interpretation of γ is inessential for our purpose because the estimated coefficient of γ still informs whether the data is better characterized by path dependence or path independence.

We start with a simple case of no control variables. Figure 4 illustrates the relationship between the post-war population density growth rate and that during the bombing period for each block, along with the regression line of (1). The first panel in Figure 4 shows that in 1950, the fitted line is somewhat less steep but already close to the slope of -1, implying that the strong resurgence of the destroyed areas had already occurred only six years after the bombing. The second panel of Figure 4 demonstrats that a similar result is obtained when examining the population distribution in 1960, suggesting that the recovery was essentially completed by 1950. Columns 1 and 4 of Table 1 provide detailed regression results depicted in Figure 4. The coefficient is -0.712 in 1950 and -0.688 in 1960, both of which are statistically distinguishable from zero, thus the complete path dependence is rejected. Although we can also statistically reject $\gamma = -1$ (i.e., perfect path independence) in these regressions, the results suggest a strong recovery just within five years.

The regression specification (1) has been estimated in other contexts and our result is comparable to those estimates. The coefficient around -0.7 in our simple regression is larger in absolute value than Brakman et al. (2004) in their across-city analysis of Germany, suggesting

that the recovery was stronger in our context. On the other hand, the coefficient is somewhat smaller in absolute value than some specifications of Davis and Weinstein (2002, Columns 1 and 3 of Table 3), suggesting that weak path dependence might be observed for the within-city population distribution of Hiroshima.[19] Having said this, we show in the next subsection that, conditional on control variables, we also obtain a coefficient of around -1. Also note the high R-squared despite the fact that we only include the population change from 1936 to 1945 as the explanatory variable, implying a close relationship with the postwar population change.[20] Overall, our results indicate the fast and strong resurgence of central Hiroshima.

Figure 4: Population change due to the atomic bombing and the subsequent population change



(a) Population change in 1945-50 **(b)** Population change in 1945-60

Note: The figures plot change in log of population density from 1945 to 1950 or 1960 to those from 1936 to 1945, which is largely driven by the atomic bombing. Each circle represents a block (i.e., an observation), where the size of the circle is proportional to the population density in 1936. We plot the (unweighted) linear fit between these two variables (solid line) as well as the slope of -1 (dashed line), which would be obtained if the population change during the bombing period is completely reversed in the post-war period.

Locational advantages of the central Hiroshima. An explanation for the fast resurgence of central Hiroshima is that the center had substantially more attractive locational fundamentals, which we investigate in the following. Studies (see, for example Bleakley and Lin 2012; Schumann 2014; Lin and Rauch 2022) have argued that the spatial heterogeneity of geography in terms of climate and topography may be crucial in explaining the history-independence result of Davis and Weinstein (2002) for the *across-city* population distribution in post-WWII Japan. If the damaged locations were innately attractive, people would rebuild there. Although this may be a plausible explanation for the *across-city* population distribution in Davis and Weinstein (2002), we argue below that locational advantages do not appear to play a significant role in the resurgence of central Hiroshima *within* the Hiroshima city.

[19] Column 2 of Table 3 in Davis and Weinstein (2002) reports the coefficient of -0.759, which is close to -0.7.
[20] The high R-squared also suggests that the effect of measurement error is relatively limited in our data.

Table 1: Changes in Population Density

	(1)	(2)	(3)	(4)	(5)	(6)
	Change in log population density 1945 - 1950			Change in log population density 1945 - 1960		
Change in log population density 1936-1945	-0.712	-0.931	-0.979	-0.688	-0.929	-1.007
	(0.026)	(0.100)	(0.097)	(0.030)	(0.101)	(0.117)
p-value from testing $\gamma = -1$	0.000	0.499	0.835	0.000	0.492	0.949
Control variables		✓	✓		✓	✓
Within 3 km from the city center			✓			✓
Number of blocks	174	174	158	174	174	158
R-squared	0.809	0.862	0.880	0.772	0.854	0.862

Note: We report the OLS estimation result of the equation (1). Fundamentals consist of the quadratic of the distance to the nearest station, the distance to the nearest cultural asset, the distance to the nearest water area, the altitude, and the slope. We also include a dummy for a bad soil condition. We also control for the quadratic of the pre-war (1933-1936) population growth rate, the fractions of the half-destroyed, moderately-destroyed, and intact buildings, and the geographical coordinates (the latitude, the longitude, and their interaction). In columns 3 and 6, we confine the sample to blocks within 3 kilometers from the city center, in which fundamental conditions are more homogeneous. We report the p-value from testing the null $\gamma = -1$, meaning that the 1936 population distribution matters for the population in 1950 and 1960 but not the 1945 population distribution. Robust standard errors in parentheses.

Before proceeding with the regression analyses, we first discuss heuristically why the locational advantage of Hiroshima does not appear to account for its resurgence. First, natural conditions within Hiroshima are homogeneous. This is intuitive because our geographic scope is limited and most of the city area lies within up to 6 kilometers of the city center (c.f., Schumann 2014). The majority of Hiroshima city is located in the delta area of *Ota* river, which provides the flat terrain with loose soil. Moreover, the distance to the nearest water area is homogeneous within the city, reflecting the fact that the city is cut through by many branches of *Ota* river and faces the sea to the south.

Second, the key manmade advantages of central Hiroshima prior to WWII were substantially damaged by the bombing. The city center of Hiroshima, areas around *Hacchobori* and *Kamiyacho*, is located next to the Hiroshima castle, which had been a symbol of the city since the samurai period and may be a historical amenity. It was also adjacent to the area called *Nakajimacho*, which developed during the samurai period due to its convenient access to the castle and water transportation. The city center also had convenient access to the tram network. These advantages were lost by the bombing. Hiroshima castle was totally destroyed and *Nakajimacho* was also completely obliterated by the atomic bomb. Although the city center might retain some advantage in the transportation access, the access to workers and jobs would have been substantially worsened as their neighborhoods were completely destroyed and other areas of the city may have had better conditions after the bombing.[21] The resurgence of central Hiroshima despite the loss of many fundamental advantages after the bombing suggests that forces other

[21]For instance, areas around Hiroshima station also provide convenient access to transportation but experienced much less destruction by the bombing, which may make Hiroshima station as the potential new center of Hiroshima city. In a different context, Takano (2022) documents that the central area of Yokohama city moved to such an area after the requisition of the former city center by the US army for nearly ten years.

than fundamental locational advantages may be important in explaining their resurgence.

We now introduce our regression framework to formally assess the role of locational advantages. To this end, we consider the observable characteristics of each block. If such characteristics can explain the post-war population growth, the severeness of destruction would no longer explain the population growth rate, unlike Columns 1 and 4 of Table 1. In contrast, if the resurgence is not driven by fundamental advantages of central Hiroshima, the severity of destruction would retain its explanatory power.

We consider four types of control variables in estimating equation (1). First, we include in the quadratic form the distance to the nearest train station as of 1950, the distance to the nearest cultural asset, the distance to the nearest water area, the altitude and the the ruggedness. Additionally, we include a dummy for a bad soil condition. These variables capture the fundamental locational advantages of the city that can be considered as given after the WWII period.[22] Second, we control for the population growth from 1933 to 1936.[23] The pre-war growth trend is expected to capture unobserved attractiveness of each location. Third, we control for the fractions of half-destroyed, moderately-destroyed, and intact buildings, which we expect to serve as proxies for the initial conditions of each location immediately after the bombing such as the quality of the housing stock and infrastructure after the destruction. Finally, we control for the geographic coordinates in order to account for any unobserved locational characteristics such as wind conditions (c.f., Heblich et al. 2021).

Column 2 and 5 of Table 1 presents the regression results of equation (1) for 1950 and 1960 with the rich set of control variables described above. Compared with columns 1 and 4, coefficient γ is now statistically indistinguishable from -1 even for 1950, suggesting the unimportance of history. This result implies that if any, locations that grew more due to the attractive fundamental conditions might have experienced milder destruction from the atomic bombing, which is in contrast to the center having location advantages and experiencing rapid resurgence. We obtain a very similar estimate for 1960. Columns 2 and 5 thus imply that, conditional on observed fundamentals, the damage due to the atomic bombing no longer matters. This result suggests that the observed fundamental locational advantages of the central Hiroshima do not explain its resurgence.

To further address the concern that the unobserved attractiveness of each location could drive the result, we restrict our sample to blocks within 3 kilometers from the city center. Since the edge of this circle was less damaged and had better access to the undamaged areas, it would be in a better position right after the bombing (see Figure 3). At the same time, these areas have more homogeneous natural conditions and transportation access as we have focused on a smaller area (c.f., Schumann 2014).[24] Columns 3 and 6 of Table 1, however, show that, coefficient γ

[22] While most of the pre-war stations were restored by 1950, no new rails were constructed between 1945 and 1950.

[23] To avoid extreme values due to idiosyncratic reasons or measurement errors, we cap the annualized growth rate at 10 percent in absolute value.

[24] Indeed, Table A.1 suggests that the standard errors of locational characteristics are smaller in this subsample.

is statistically distinguishable from zero but not from -1. This result further suggests that fundamental locational advantages of the city center are unlikely to explain its resurgence.

3.3 When the bomb hit the outskirts of the city: the case of Nagasaki

Our results on Hiroshima suggest that the recovery of central Hiroshima is explained by the destruction level of the atomic bomb; however, the fundamental location advantages do not seem to explain the recovery. To provide further support for this argument, in this subsection, we document the recovery from the bombing in Nagasaki, the second and last city in human history to be destroyed by an atomic bomb.

In Nagasaki, the atomic bomb hit the outskirts of the city (see Figure B.1 for a damage map). This is in contrast to Hiroshima, where the atomic bomb hit the city center. Consequently, the comparison with Hiroshima helps distinguish the fundamental advantages of the pre-war city center, some of which are potentially unobserved, from the level of destruction in explaining post-war population growth. In the Appendix B we analyze the population data in Nagasaki taken from Nagasaki City Government (1983). Figure B.1 displays the damage map of Nagasaki, where we can confirm that the atomic bomb hit the area away from the city center. Figure B.2 demonstrates that heavily-destroyed areas in the outskirts of Nagasaki strongly recovered. In Figure B.2 we show the fitted line from the regression coefficient of equation (1) for Nagasaki. The coefficient of our interest is around -0.88 and is statistically indistinguishable from -1, strongly suggesting the *path-independence* in population distribution within Nagasaki. Therefore, even though the pre-war center of Hiroshima may have been partially determined by unobserved attractive locational characteristics, the recovery of the destroyed outskirt of Nagasaki suggests that they did not play a major role for a strong recovery of the destroyed area.

3.4 Further discussions on the recovery of central Hiroshima

Employment distribution. We have looked at the evolution of the population distribution. However, due to commuting, the population distribution in a city may differ from the employment distribution. As the city center is also the center of employment, the atomic bombing that hit the city center would also alter the employment distribution. In Appendix C we analyze the effect of the atomic bombing on the distribution of jobs using the granular data on the location of establishments in 1938, 1945, and 1966. We find that central Hiroshima recovered in terms of the number of jobs, and the regression results are very similar to those for population.

Land prices. We also investigate the resurgence of central Hiroshima by looking at land prices. A difficulty of this approach is that we do not have comprehensive land price data during our sample period. However, based on the available data, we could investigate the location with the highest land price in the city (see Appendix A for data sources), which could be interpreted as

a central location of the city. Both in 1931 and 1959, the highest land price was observed in the *Hacchobori* area, the city center both before and after the war.[25] Thus, the resurgence of central Hiroshima is also observed in land prices.

The timing of the recovery and public recovery policies. As we have shown in this section, our block-level population data suggests that the recovery was complete in 1950. To shed further light on when the recovery started, we use the population data for 1946, 1947 and 1948 from the Statistical Abstract of Hiroshima as reported by distance from the epicenter of the bombing. Figure A.4 in Appendix shows that the recovery process already started in 1946.

This finding may suggest that public recovery policies had a limited direct impact on the recovery. The Hiroshima city government attempted some early public efforts to facilitate the recovery, but they were not enough to achieve the recovery on their own due to the shortage of resources in Japan. Despite the catastrophic damage and the enormous rebuilding costs, it was not until the enactment of the Hiroshima Peace Memorial City Construction Law in 1949 that Hiroshima could receive special recovery grants from the central government. Consequently, the Hiroshima city could spend only about 1.8 percent of the entire rebuilding budget plan by August 1949 and 3.2 percent by May 1950 (Ohshima 1950). Such serious budged shortage makes it difficult to attribute the early-stage rebuilding to the recovery plan. In addition, even the small budget spending did not seem to be a main factor in explaining the recovery. The primary goal of the Hiroshima city government was to provide housing and during 1946 and 1950, the public sector provided less than 3,000 housing units.[26] This is far short of the more than 70,000 buildings that were at least half-destroyed by the atomic bombing. Public housing is unlikely to be the key to explaining the recovery for two additional reasons. First, public housing tended to be located away from the CBD. Second, controlling for public housing has little effect on our regression results (see Appendix C).

These arguments suggest that the rebuilding policies had at most a limited *direct* impact on the recovery of central Hiroshima. However, we do not rule out the *indirect* impact of the rebuilding policies as a coordination device of expectations. That is, even though underfunded, the presence of the rebuilding policies made people believe that the central Hiroshima would recover, resulting in self-fulfilling expectations for the recovery. As discussed in the next subsection, we think the rebuilding policy may be a good candidate that successfully created self-fulfilling expectations.

[25] Specifically, the block containing the plot with the highest land price is the *Horikawa-cho* block right next to the *Hacchobori* block. Other available evidence on pre-war land prices suggests the similar conclusion (Nozawa 1934; Hayakawa and Nakaouji 1965).

[26] Indeed, the rebuilding plan for housing was 9.7 percent complete by August 1949, which is way faster compared with 1.8 percent for the overall plan (Ohshima 1950). Another primary expenditure was to rebuild damaged infrastructure, such as the water system and trains. While the rebuilding of the infrastructure is important, it did not seem to provide central Hiroshima particular benefits relative to the outskirts because the outskirts also had similar levels of infrastructure.

3.5 Expectations for the rebuilding and their potential causes

Our reduced-form analysis found the resurgence of central Hiroshima within five years after the bombing. In addition, we have demonstrated that it is difficult to explain the recovery by its fundamental location advantages. This raises the following question: why could central Hiroshima recover despite the tragic destruction?

The remainder of this paper emphasizes the role of self-fulfilling expectations in recovery. If people believe that the center will regain its population and employment, then agglomeration economies make the center attractive and people will be motivated to live and work in the center. In this way, expectations of reconstruction can be self-fulfilling. In order to investigate the role of such self-fulfilling expectations, we present a theoretical framework that allows us to quantify them using the available data. This is an important contribution in our context because researchers, in most contexts, cannot directly observe individuals' expectations and beliefs.

Before proceeding, it is important to note that we remain agnostic about why people initially expected that the city center could recover despite its catastrophic history. Answering this question is beyond the scope of this paper due to the empirical difficulty of observing individuals' beliefs during the recovery period and the theoretical complexity of modeling the formation of expectations. We point out several potential factors that may have coordinated people's expectations.

First, the presence of the recovery plan by the government would have facilitated the formation of expectations, while the plan was published in the midst of the recovery and was substantially underfunded (see Section 3.4).[27] Another factor is the physical presence of infrastructure, notably the train (tram) system. While the direct benefit of access to train stations does not seem crucial for the recovery (see Table 1), the presence of the same train network as the pre-war period may have anchored people's expectations toward rebuilding. Land ownership is an additional factor. If people believed that those with land ownership had a strong attachment to that location and some of them would return despite the miserable conditions, people could reasonably anticipate the recovery. However, the importance of this channel may be limited in our context because owner-occupied housing accounted for only around 25 percent of the total housing stock in pre-war Hiroshima and the majority was for rent (Hinokidani and Sumita 1988; Yamagishi and Sato 2022).[28] Finally, the narrative of "rebuilding from the atomic bombing" may have sounded like a powerful success story from the tragedy and been widely shared. As long as people were aware that many others knew this narrative, it led to self-fulfilling "memory-

[27] A related factor is zoning regulation. Yet, its importance was limited in explaining the recovery because the first zoning of Hiroshima after the war was published in 1949. By that time, the recovery was nearly complete. In addition, there were only three types of zones (commercial use, residential use, and manufacturing use) and the center did not receive a distinctively advantageous treatment in zoning relative to other locations.

[28] In terms of business activities, Hiroshima City Government (1983) documents that in a shopping street (*Hondori*) as of 1958, around 28 percent of stores operated in the same location as the pre-war period while the remaining 72 percent started operating after the bombing. Although the majority are newcomers, land ownership may have contributed to forming the expectations for the recovery of business activities.

based" expectations that the city would return to how it was in their memories (Shiller 2017).[29]

Overall, while we conjecture that a combination of the aforementioned factors may have contributed to the formation of the expectations in the recovery, we do not investigate why these expectations were formed in the remainder of this paper. Taking the emergence of such expectations as given, our primary objective is to quantify the importance of their self-fulfilling nature to account for the recovery of central Hiroshima.

4 Theoretical Model

This section presents a parsimonious dynamic quantitative urban model. Our contribution is to develop a framework that enables us to quantitatively distinguish the roles of self-fulfilling expectations and history in the location choices of individuals in a city, which has been a fundamental challenge in stylized theory (see, for example Krugman 1991 and Matsuyama 1991). The model also allows for heterogeneity in location fundamentals and agglomeration forces, and can be matched to available data on the spatial distribution of economic activities in the city.

In particular, the model involves three key elements. First, individuals in a city choose their residence and workplace respectively, which define the equilibrium commuting patterns within a city as in Ahlfeldt et al. (2015). Second, finitely lived workers determine future residential places and workplaces in a forward-looking way, taking into account migration costs and future option values associated with the locations. Third, the model incorporates amenities and productivity spillovers that are dependent on population and employment density in the current period and in the past. With such externalities, there may exist the self-fulfilling prophecy and a multiplicity of transitions that hinge on *both* expectations and the past.[30] These three elements are essential to matching the model to observations in the distribution of economic activities: the separation of workplace and residential place of workers in a city, different patterns of population and employment changes across locations over time, and concentration of jobs in the city center. Our model is the first tractable dynamic quantitative model for the internal structure of the city that possesses these elements in a unified framework. Appendix D provides the details of derivations.

4.1 Model setup

Time is discrete and indexed by t. We consider a single city $\mathcal{C}$ is embedded in the large economy $\mathcal{E}$: $\mathcal{C} \subset \mathcal{E}$. The set of locations in a complementary set $\mathcal{O} = \mathcal{E} \backslash \mathcal{C}$ are the outside of the city. The

[29] Although it is difficult to assess how powerful and widespread such a narrative was, the 1946 Statistical Abstract of Hiroshima was suggestive in stating '...rumors like "nothing will grow here for 75 years" immediately disappeared among people with their burning desire to rebuild...' (p4, translated by the authors).

[30] Allen and Donaldson (2022) introduces this type of local externalities to characterize path dependence in the spatial distribution of economic activities in the U.S. Kleinman et al. (2021) analyzes the properties of the spatial equilibrium when workers determine the future path of mobility in a forward-looking way, taking account of future shocks.

city $\mathcal{C}$ consists of discrete number of locations indexed by i, j, n, ℓ. These locations correspond to blocks and they are differentiated by fundamental productivity, amenities, land endowment and geography. The fundamental productivity and amenities can change over time, while land endowment is unchanged over time.

Individuals in the economy live for a finite time, T. The mass of the population in the economy is $\mathcal{M}$ and it is exogenous. We suppose that there is a potentially large number of people in the whole economy throughout time and $\mathcal{M}$ is constant. Instead, the total population of the city, which is embedded in the whole economy, changes over time through migration flows. This allows us to focus on the distribution of individuals within the city. Individuals are endowed with one unit of labor that is supplied inelastically and they are geographically mobile across locations in a city. They commute from their residential block to their workplace block subject to commuting costs evaluated by their disutility. Individuals outside of the city are prohibited from commuting so individuals living outside of the city ($\mathcal{O}$) work there. Production occurs in every location in the economy and firms produce homogeneous tradable goods that can be freely traded across locations. In every period, an individual may have an opportunity to change their residential block and workplace block in the economy ($\mathcal{E}$). In particular, individuals obtain their chance to change their locations with exogenous probabilities in every period and they decide their locations in a forward-looking way, taking into account future shocks. Their choice of a given location is based on their current real income but also an option value associated with that location. The forward-looking location choices allow us to characterize the transitions of population and employment distribution in the city that hinges on their expectations.

Production. Firms in the economy are competitive and produce homogeneous tradable goods. Firms are myopic, therefore we do not formulate a dynamic problem for firms.[31] Production technology of a representative firm in location $i \in \mathcal{C}$ is:

$$Y_{it} = A_{it} L_{it}, \tag{2}$$

where Y_{it} is production in location i, A_{it} is productivity and L_{it} is employment in location i at time t.[32] Following Allen and Donaldson (2022), the productivity (A_{it}) depends on the current and the previous employment density in the location:

$$A_{it} = a_{it} \left(\frac{L_{it}}{S_i} \right)^{\alpha_1} \left(\frac{L_{it-1}}{S_i} \right)^{\alpha_2}, \tag{3}$$

[31] Given the linear technology and perfect competition, producers always earn zero profit. Thus considering dynamic incentives does not change our arguments as long as firms correctly expect that the future profits are always zero.

[32] While the production technology in (2) uses labor only, this production function is isomorphic to a model with durable investments in local productivity (Allen and Donaldson 2022).

where a_{it} represents the exogenous component in productivity and S_i is the area size of location i that is time invariant.[33] The parameter α_1 controls the contemporaneous productivity spillovers with respect to employment density, and the parameter α_2 controls the effect of lagged employment density on productivity such as durable investments. A positive value of α_1 implies a local agglomeration force that increases productivity, while α_2 captures the historical dependence in productivity spillovers.

In Appendix D.5, we provide two different microfoundations of the spillovers in productivity. As the first microfoundation, we introduce local capital in production that augments labor productivity. The local capital is produced by using local public goods (e.g., roads and water facilities), final goods and land. The current employment density is positively associated with the provision of local capital ($\alpha_1 > 0$). The supply of local public goods and land for the supply of local capital also depends on lagged employment density. In particular, when high employment density in the past induces the depreciation of local public goods and additional transaction costs in land supply, current local capital is negatively associated with lagged employment density ($\alpha_2 < 0$). The second microfoundation is the creation of ideas in production. Suppose incumbent workers who have no opportunity to change their workplace between period $t-1$ to t engage in innovation to improve firms' productivity in period t. In period t, interactions with another worker with a novel idea allow incumbent workers to update their ideas, while ideas of the incumbent workers become obsolete without such interaction. Then, we show that a large number of current workers induce more successful knowledge spillovers ($\alpha_1 > 0$), and more incumbent workers make it difficult to find a worker to interact with for updating their ideas ($\alpha_2 < 0$).

Homogeneous goods are freely tradable in the economy and therefore we normalize their prices to one. The zero profit condition implies that the wage rate at location i in period t is $w_{it} = A_{it}$. Thus the wage rate in any particular location is a function of exogenous productivity, contemporaneous employment density and previous employment density in that location.

Preference. Individuals live for finite periods and have discount factor, $\rho \in (0,1)$. Workers choose where to live and where to work every period. At the end of period t, an individual decides residential place and workplace for the next period $t+1$ (Caliendo et al. 2019). Individuals consume only homogeneous tradable goods and inelastically supply one unit of labor. Their period utility of living in location n and working in location i at period t is

$$\ln u_{int} = \ln B_{nt} + \ln w_{it} - \ln \kappa_{int}, \tag{4}$$

[33] When S_i is time invariant, we can equivalently set the productivity dependent on the employment levels by subsuming $S_i^{-(\alpha_1+\alpha_2)}$ into a_{it}. If the efficient unit of land changes over time given the fixed size of total area, it is isomorphic to the model where a_{it} include such change in land efficiency.

where B_{nt} is the common utility benefit from residential amenities at residential place n in period t, $\kappa_{int} \in [1, \infty)$ is the utility cost due to commuting from n to i and w_{it} is labor earnings in workplace i. The value of amenities in residential place (B_{nt}) depends on current and past population density:

$$B_{nt} = b_{nt} \left(\frac{R_{nt}}{S_n} \right)^{\beta_1} \left(\frac{R_{nt-1}}{S_n} \right)^{\beta_2}, \tag{5}$$

where b_{nt} is an exogenous component in the value of amenities for each location, R_{nt} is population of location n in period t and R_{nt-1} is that in period $t-1$.

In this specification two parameters (β_1, β_2) capture the strength of the net agglomeration effect in the residential place from the current and previous population density. The former parameter (β_1) captures various externalities in the residential place from the current population including congestion of residents, housing prices and consumption amenities. The latter parameter (β_2) captures externalities from the past population including the effect of the stock of housing and amenities.[34] In particular, we provide one microfoundation for both the current and lagged effects of spillovers in amenities in Appendix D.6, which introduces developers of floor spaces with adjustment costs in their investment. In any location outside of the city ($o \in \mathcal{O}$), individuals receive common utility u_{ot} in period t and this is exogenous in every period.

At the end of period t, an individual worker draws idiosyncratic shocks related to location choice in period $t+1$. For an individual worker, the idiosyncratic shock is independently drawn from the time-invariant independent Type-I extreme distribution $F(\varepsilon) = \exp(-\exp(-(\varepsilon + \Gamma)))$ where Γ is Euler-Mascheroni constant. At the end of period t, workers decide their residential place and workplace for the next period taking into account the option value of their location choice $\{V_{int+1}\}$ associated with each workplace and residence pair.

Forward-looking location choice. Workers are forward-looking in making migration decisions subject to the exogenous migration frictions. At the end of period t, the share $\theta_t \in (0, 1]$ among workers in the economy can change their location pairs and the share of $1 - \theta_t$ among workers will stay in the current location choices in the next period $t+1$.[35] If $\theta_t = 1$, all workers are able to change their location pairs and a low value of θ_t leads to the stickiness of workers' mobility in the economy. This Calvo-style migration friction is also adopted in other recent quantitative spatial models to capture the persistence of migration decisions (e.g., Caliendo et al. 2019 Section 5.3; Heblich et al. 2021). Other than such stickiness in the location choices of workers, we do not include additional mobility costs.

Conditional on wage variation and exogenous location characteristics, the mobility of workers is controlled by the parameter of stickiness (θ_t) and the parameter of taste shocks (σ). Both low degree of stickiness and more dispersion in idiosyncratic taste shocks in location choices

[34] Since S_n is time invariant, we can equivalently set the amenities dependent on the population levels by subsuming $S_n^{-(\beta_1+\beta_2)}$ into b_{nt}.

[35] We allow people to choose the same pair of residence and workplace when they can choose other options.

increase workers' mobility in a city. However, we emphasize the difference in interpretations. The parameter of Calvo-style migration friction captures the immobility of workers even if they would like to change their locations. Intuitively, this reflects any physical constraint that prevents workers from relocating. In contrast, the dispersion of taste shocks captures the individual valuation attached to the location pair and controls the sorting of workers. In the present model, we introduce both migration frictions and idiosyncratic shocks since we can take account of both post-war mobility constraints and the sorting of workers in their residential and workplace choices.

Consider an individual ω living in n and working in i at period t. When the worker can move to different location pairs in the next period, she solves the following problem of location choices:

$$v_{int}(\omega) = \ln u_{int} + \max\left\{\rho V_{j\ell t+1} + \sigma\varepsilon_{j\ell t+1}\ ;\ \rho V_{ot+1} + \sigma\varepsilon_{ot+1}\right\} \tag{6}$$

where $V_{j\ell t+1}$ refers to the value function of choosing different pair of residential place ℓ and workplace j in period $t+1$ and V_{ot+1} is the option value of choosing to live in the outside of the city. ρ is the discount factor governing the importance of the future values and σ is a positive constant governing the variance of the idiosyncratic shocks. A large value of σ implies a large variation of idiosyncratic shocks in their location choices. Note that this is a forward-looking migration decision in the sense that at time t, a worker chooses her residence and workplace at $t+1$ expecting the path of the exogenous and endogenous variables. In particular, an individual correctly expects the path of the population distribution $\{R_{it}\}$ and employment distribution $\{L_{it}\}$ that are endogenously determined in equilibrium.

With the idiosyncratic shocks following the extreme distribution and migration frictions, we can express the option value of living in n and working in i assessed in period t by

$$V_{int} = \ln u_{int} + (1-\theta_{t+1})\rho V_{int+1} + \theta_{t+1}\sigma \ln \sum_{d\in\{\mathcal{C}\times\mathcal{C},\, o\}} \exp(V_{dt+1})^{\rho/\sigma}. \tag{7}$$

The first term is the current utility from the location choice of residential place n and workplace i. The second term is the expected value of staying the same location choices in the next period with non-migration opportunity $1-\theta_{t+1}$. The third term is the expected utility for future value when an individual is able to change the location pairs with probability θ_{t+1}. For workers who live outside of the city, we can express their option value by

$$V_{ot} = \ln u_{ot} + (1-\theta_{t+1})\rho V_{ot+1} + \theta_{t+1}\sigma \ln \sum_{d\in\{\mathcal{C}\times\mathcal{C},\, o\}} \exp(V_{dt+1})^{\rho/\sigma}. \tag{8}$$

When workers have opportunity of migration, they can choose any location pairs in economy and therefore the last term of the expected utility for future value is the same as in (7).

Given the idiosyncratic shocks $\{\varepsilon_{j\ell}, \varepsilon_o\}$ are independent and follow the type-I extreme distribution $F(\varepsilon)$, we derive the share of workers that live in n and work in i in the city in the next

period $t+1$ when they have migration opportunity:

$$\lambda_{int+1} = \frac{\exp(V_{int+1})^{\rho/\sigma}}{\sum_{d\in\{\mathcal{C}\times\mathcal{C},\, o\}} \exp(V_{dt+1})^{\rho/\sigma}}, \quad i,n \in \mathcal{C}. \tag{9}$$

The probability λ_{int+1} characterizes the location dynamics of workers in the city for period $t+1$. Workers choose the pair of residential place and workplace with taking into account future changes in commuting costs, wages and residential amenities. Since there is no location-workplace specific migration cost, equation (9) applies to all workers with the migration opportunity in period t. When we focus on migration within a city, bilateral mobility costs in a city are sufficiently small and homogeneous relative to inter-city migration costs. Therefore bilateral mobility costs are assumed away in our model. [36] Further, the share of workers that live in the outside of the city in the period $t+1$ conditional on they can change their locations is given by probability $\lambda_{ot+1} = 1 - \sum_{(j,\ell)\in\mathcal{C}\times\mathcal{C}} \lambda_{j\ell t+1}$.

Using these choice probabilities of workers, we can express the mass of workers in the city who live in n and work in i in period $t+1$:

$$L_{int+1} = (1-\theta_{t+1})L_{int} + \theta_{t+1}\lambda_{int+1}\mathcal{M}. \tag{10}$$

This is the number of commuters within the city. On the right-hand side, the first term is equal to the number of commuters who continue the same location of work and residence and the second term is the total of workers who move from the outside of the city and those who change their locations within the city. The commuting market clears in the city. Therefore, the mass of workers in workplaces becomes:

$$L_{it} = (1-\theta_t)L_{it-1} + \theta_t\mathcal{M}\sum_{n\in\mathcal{C}} \lambda_{int}, \tag{11}$$

where a mass of workers in workplace i is the sum of workers who have no opportunity of location change and those who sort into the workplace in period t. Analogously, the mass of workers in residential places are:

$$R_{nt} = (1-\theta_t)R_{nt-1} + \theta_t\mathcal{M}\sum_{i\in\mathcal{C}} \lambda_{int}. \tag{12}$$

Lastly, the total population in the city in period $t+1$ is given by $L_{t+1} = \sum_{(i,n)\in\mathcal{C}\times\mathcal{C}} L_{int+1}$.

[36] Caliendo et al. (2019) include bilateral migration costs in the context of inter-city (inter-state) migration, which makes the migration (9) dependent on where a worker lives and works.

4.2 Equilibrium

Having the assumptions in our model above, we are in a position to define a forward-looking competitive equilibrium in the economy. The economy starts with the initial distribution of population (R_{i0}) and employment (L_{i0}). The exogenous variables of the model are fundamental productivity (a_{it}) and amenities (b_{nt}) by location, the area size of blocks (S_n), bilateral commuting costs in a city (κ_{int}), the path of stickiness in reallocation of workers (θ_t) and path of the utility outside of a city (u_{ot}). The economy-wide parameters in the model are spillovers in productivity (α_1, α_2), spillovers in amenities (β_1, β_2), a discount factor of workers (ρ), the variance of idiosyncratic shocks in location choices (σ) and a mass of workers in the economy ($\mathcal{M}$). Then, a forward-looking equilibrium can be referenced by the followings:

Definition 1. *Given the exogenous variables of the model and economy-wide parameters, a forward-looking equilibrium is characterized by the sequence of wages* $\{w_{it}\}$*, population* $\{R_{nt}\}$*, employment* $\{L_{it}\}$ *and value functions associated with location choices* $\{V_{int}\}$ *such that (i) value functions of workers for their location choices* $\{V_{int}, V_{ot}\}$ *satisfy* (7) *and* (8) *with* $V_{inT} = \ln u_{inT}$ *and* $V_{oT} = \ln u_{oT}$ *for the last period T, (ii) commuting market clears in the city and the masses of workers in workplaces and residential places are given by* (11) *and* (12)*, and (iii) firms maximize their profits and the zero profit condition leads to a wage rate equal to* (3)*.*

Since productivity and amenities evolves with employment density and population density, we can summarize the transition equilibrium by population and employment and value function adjusted by the value of outside of the city. Equations (7), (8), (11), (12), and (3) constitute $N^2 + 3N$ equations that can be solved for $N^2 + 3N$ endogenous variables. The location choices of people are based on their current real income but also option values associated with the pair of locations, and they determine the future path of location choices taking into account future shocks. In the present model, there are externalities in real income through productivity and amenities with mobility frictions. With small mobility frictions and strong externalities, there may exist the self-fulfilling prophecy and multiplicity of transitions that hinges on the expectations of people. In particular, large values of the spillovers in productivity (α_1) and amenities (β_1) and a large share of mobility (θ_t) may lead to multiple equilibria. In Appendix D, we show the existence of the equilibrium.

While the primary focus of our paper is on the dynamic equilibrium, in the long run, we suppose that the spatial distribution of population and employment is characterized by a steady-state equilibrium, in which population distribution is constant given the exogenous time-varying factors are constant. The steady state equilibrium in this economy exists and it is unique when the net externalities are small in both productivity and amenities. We summarize these results in the following proposition (see Appendix D for details):

Proposition 1. *(i) Given the initial state and exogenous factors, the forward-looking competitive equilibrium such that, for all periods* $t = 1, 2, \cdots, T$*,* $R_{nt} \geq (1 - \theta_t) R_{nt-1}$ *and* $L_{it} \geq (1 -$

$\theta_t)L_{it-1}$, *exists. (ii) The steady-state equilibrium exists when* $\alpha_1 + \alpha_2 \neq \sigma/\rho$ *and* $\beta_1 + \beta_2 \neq \sigma/\rho$. *(iii) A* sufficient *conditions for the unique steady state are negative net spillovers:* $\alpha_1 + \alpha_2 \leq 0$ *and* $\beta_1 + \beta_2 \leq 0$.

Theoretically, there may be multiple steady states and multiple equilibrium paths. Specifically, we have four possibilities. First, there exists a unique steady state and a unique path when high discount rate and relatively small agglomeration forces. In this case, we are not confronted with the problem of history versus expectations. After a shock in the economy, the future payoff of workers jumps to put the transition dynamics on the saddle path converging to the unique steady state. Second case is that there exist multiple steady states but history determines the equilibrium. In this case, a large shock to the history at the initial point leads to completely different steady state. Consequently, we argue history matters in this case. Third, we may have a unique steady state but multiple paths. There is a spiral of paths around the unique steady states and , in this case, expectation matters for the choice of a transition path. Fourth, we may have both multiple steady states and multiple paths, whose characterizations depend on (i) the strength of agglomeration forces in the future payoff, (ii) migration frictions, and (iii) the discount factor.[37] When there are multiple steady states or multiple paths, the discussion of history versus expectations is relevant because which steady state or path realizes matters.

In our calibration, we assume that the economy is in a steady state in the last period and solve the model backwards for the observed changes in population and employment to be on the path to the steady state. In this procedure, our calibration does not require the uniqueness of the steady state nor the unique path to the steady state because it relies only on the *observed* equilibrium path and the steady state. This feature allows us to calibrate the model when there are multiple steady state or paths so that the discussion of history versus expectations is relevant. That said, the multiplicity of equilibrium, by its nature, may pose a challenge in a counterfactual analysis as we need to select one equilibrium out of multiple possible counterfactual equilibria.

5 Quantification of the Model

Our goal in this section is to show how the present model can be matched to the observations in Hiroshima. The quantification proceeds in three steps, and the procedure is sequential. Therefore we discuss it step by step. First, in Subsection 5.1, we determine the model parameters. As we discussed in Section 4.1, our model accommodates two aspects of migration frictions, the dispersion of idiosyncratic taste shocks (σ) and the stickiness of migration decisions (θ_t), and we calibrate them using different information. The dispersion of idiosyncratic taste shocks

[37] For example, in the core-periphery model of new economic geography, low transport costs lead to multiple steady states: one unstable steady state and two stable steady states. In the unstable steady state, we have a uniform population distribution, while in the stable steady state, the population is concentrated in one region. In the dynamics of the core-periphery model, the discount factor affects the rate of convergence of the economy to a stable steady state after a small perturbation. See Baldwin (2001) and Ottaviano (2001) for further discussions.

(σ) is calibrated from the discount factor (ρ) and the commuting elasticity found in the literature because the commuting elasticity in our model is written as ρ/σ. We infer the stickiness (θ_t) from additional data on the mobility of people during the period of study, which informs the share of people who stayed in their residential places so that we can infer how migration decisions were persistent. We also estimate the commuting cost parameter (δ) by exploiting the gravity equation of commuting flows within the city, which holds in a steady state of our model. Finally, the outside utility (u_{ot}) is chosen to match the observed total population of the city.

Given the parameters, in Subsection 5.2, we leverage the structure of the model to back out the composite of amenities and productivity that rationalize the observed population and employment changes over time. Intuitively, changes in population and employment by block allow us to invert option values associated with each location. The option values reflect the attractiveness of each location as a residential place or workplace, which is a function of location fundamentals and agglomeration. In Subsection 5.3, we estimate the key parameters that govern the strength of spillovers in productivity (α_1, α_2) and amenities (β_1, β_2). Given the recovered option values and variation of population density and employment density at different periods, we can recover the unobserved fundamentals in productivity and amenities. For those fundamentals, we define the moment conditions and estimate the parameters. In the estimation, we use the data from 1950 to 1975.

Having fully quantified our model, in Subsection 5.4, we assess how the model can rationalize the recovery of population and employment in the city after the bombing during 1945-50. To this end, we first use the data on population and employment in 1945 and 1950 to back out the location advantages. We then decompose the advantages into two parts: (i) advantages in productivity and amenities explained by the model including spillovers, and (ii) structural residuals. We show that our model performs well in explaining the recovery in the sense that the variation of the first part accounts for a large part of the recovery of population and employment in 1945-50. Appendix E presents details.

5.1 Step #1: Parameter calibration (ρ, σ, θ_t, u_{ot})

Gravity of commuting. The data on commuting flow within Hiroshima can be obtained for 1987. We use this information to estimate the commuting elasticity of workers in the city. To this end, we posit that the economy is in a steady state in the year and bilateral commuting costs (κ_{int}) are a function of bilateral distances (D_{in}), and it takes the form of $\kappa_{int} = \exp(\delta D_{in})$ with positive constant δ. Then, in the steady state, our model derives the gravity equation for commuting:

$$\ln L_{in} = -\delta \frac{\rho}{\sigma} D_{in} + \mathbb{W}_i + \mathbb{H}_n + \xi_{in}, \tag{13}$$

where $\mathbb{W}_i$ and $\mathbb{H}_n$ contain workplace characteristics and residential place characteristics respectively, and ξ_{in} is idiosyncratic error term.[38] Therefore, a composite of three parameters $(\delta\rho/\sigma)$ represents the commuting semi-elasticity of workers to distance.

To estimate (13), we exploit the person trip data in Hiroshima for the year 1987. We use straight-line distances between centroids of block i and n for the bilateral distances (D_{in}). Using them, we estimate (13) by replacing $\mathbb{W}_i$ and $\mathbb{H}_n$ with location indicators. Table 2 presents the estimation results. In Columns 1 and 2, we estimate (13) by ordinary least square (OLS). Column 2 restricts the sample to location pairs with more than 20 commuters, which we expect to mitigate sampling errors. In the data of commuting flows, we observe many zeros. In Columns 3 and 4, we add 1 to all flows (L_{in}) so that taking the logarithm of commuting flows does not drop observations with zero commuters in data. As seen in Column 3, incorporating observations with zero commuters yields a larger coefficient of distance in absolute value. In Columns 5 and 6, we use the Pseudo Poisson Maximum Likelihood (PPML). Our preferred specification is Column 5, which exploits the theoretically desirable properties of the PPML (Santos Silva and Tenreyro 2006). The semi-elasticity of commuting with respect to distance is around -0.40, which implies that an additional one kilometer in the commuting distance is associated with 40 percent decline in commuting flow within a city. In our calibration, we use the coefficient and set $\delta\rho/\sigma = 0.40$.

Table 2: Gravity estimates for commuting

	(1)	(2)	(3)	(4)	(5)	(6)
	Log Commuting Flow		Log (Commuting Flow + 1)		Commuting Flow	
Distance	-0.193	-0.173	-0.331	-0.170	-0.417	-0.260
	(0.009)	(0.010)	(0.013)	(0.010)	(0.015)	(0.016)
Estimation	OLS			OLS	PPML	
Number of observations	2,664	1,636	5,184	1,636	5,112	1,636
More than 20 commuters		✓		✓		✓
R-squared or Pseudo R-squared	0.493	0.468	0.504	0.468	0.650	0.534

Note: We report estiamtes of gravity equation for commuting by OLS (Columns 1 and 2). In Columns 3 and 4, we still use OLS but we add 1 to L_{in} so that we do not have to drop observations with zero commuting flows. We use the PPML for Columns 5 and 6. We use straight line distances centroids of commuting zones used in the survey and include origin and destination fixed effects. We drop the observations with the zero distance (i.e., the workplace and the residence are the same). 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.

Discount factor. In our model the discount factor of workers (ρ) governs the sensitivity of migration decisions to utility differentials. We set $\rho = 0.9$. Given that one period in our calibration corresponds to five years, the value $\rho = 0.9$ implies the annual discount rate of around 2 percent, which is consistent with the discussion of Balboni (2021).[39]

[38] Specifically, $\mathbb{W}_i = (\rho/\sigma)\ln w_i$ and $\mathbb{H}_n = \ln R_n - \ln \sum_j e^{-(\delta\rho/\sigma)D_{jn}} w_j^{\rho/\sigma}$.

[39] If $\rho_{\text{annual}} = 0.98$ is the annual discount rate, we set $\rho = 0.9$ since $\rho_{\text{annual}}^5 \simeq 0.9$. This way of constructing the five-year discount rate assumes that the utility from the period $t+1$ is evaluated five years before, which might

Dispersion of idiosyncratic tastes and the commuting cost elasticity. In the current version, we set $\sigma = 0.15$ to match the commuting elasticity (ρ/σ) of 6, which is similar to the values found in the literature (see, for example, Ahlfeldt et al. 2015; Dingel and Tintelnot 2020). Once we determine the parameter of workers (ρ, σ), we derive the commuting cost elasticity to distances (δ) using estimates from the gravity equation of commuting. This allows us to characterize the commuting costs of workers (κ_{int}). In a future version, rather than taking a value from other studies, we may estimate the parameter of dispersion of idiosyncratic tastes (σ) using additional information and model estimates. In particular, we may use wage variation or mode choice of travel in a city (Tsivanidis 2022).

Migration frictions. Individuals can change their residence and workplace for the period t with probability θ_t. A lower value of the parameter leads to the stickiness of mobility of workers and therefore this migration friction is analogous to the Calvo model of price rigidity. In our calibration, we consider 174 blocks in a city and idiosyncratic taste shocks. Therefore, we suppose that people would change their residence conditional on obtaining the migration opportunity and match the parameter of migration friction to the probability that people change their residence during five years, which corresponds to the length of one period in calibration.

To this end, we consult additional evidence on how people changed their residence in Hiroshima. We first consider the periods after 1955. Referring to the Population Census in 1960, around 86 percent of people stayed in the same residence one year before. Then, we set the parameter $\theta_t = 1 - (0.86)^5 \simeq 0.53$ for periods $t = 1955, 1960, \cdots, 1975$. This implies that individuals may have the opportunity to switch their location choices with a probability 0.53 every five years after 1955, while 47 percent of the total population in the economy must stay in the same residence and workplace for the next five years.[40] For the first period $t = 1950$, available evidence suggests that the mobility rate was substantially higher because the war was likely to induce mobility for various reasons, such as losing jobs or houses and reallocating for military services. The 1949 city population registry in the Statistical Abstract of Hiroshima City suggests that about 20 percent of the population moved out of the city in one year. When we assume that the ratio of the migration between municipalities to the migration within the city is similar to that in the 1960 census, we obtain that the probability of staying in the same residence is around 64 percent. This suggests $\theta_t \simeq 0.9$ for $t = 1950$.

Utility outside the city. We set the outside utility (u_{ot}) for each period to match the total population of Hiroshima city. Formally, we choose the outside value to match the observed total population (Pop_t) and the model-predicted population of the city $(1 - \lambda_{ot})\mathcal{M} = Pop_t$, where

imply a too low discount factor if the migration decision for $t+1$ does not occur exactly five years before but sometime during t and $t+1$. Thus, the annual discount rate consistent with $\rho = 0.9$ might be higher than 2 percent, which is one reason we take a high-end value of ρ_{annual} in Balboni (2021).

[40] Although in a different context, this value is very close to 0.52 used in the model of Heblich et al. (2021).

λ_{ot} is probability to choose outside of the city computed in the model. Since the relative location choice probability in a city does not depend on the outside utility conditional on living in the city, the choice of the outside utility only affects the total population in our model.

5.2 Step #2: Inversion of the option values

When individuals are forward-looking, their location choices depend on current real income and the option value associated with the location. In this step we back out the option values by leveraging the population and employment dynamics of the model. Specifically, the option value of location n as a residential place can be summarized by the continuation value of amenities in the location:

$$\Xi_{nt} = b_{nt} r_{nt}^{\beta_1} r_{nt-1}^{\beta_2} \prod_{\tau=t+1}^{T} \left(b_{n\tau} r_{n\tau}^{\beta_1} r_{n\tau-1}^{\beta_2} \right)^{\rho^{\tau-t} \prod_{s=t+1}^{\tau}(1-\theta_s)}, \tag{14}$$

where $r_{nt} = R_{nt}/S_n$ is population density in period t. Analogously, the option value of location i as a workplace can be written by:

$$\Omega_{it} = a_{it} l_{it}^{\alpha_1} l_{it-1}^{\alpha_2} \prod_{\tau=t+1}^{T} \left(a_{i\tau} l_{i,\tau}^{\alpha_1} l_{i\tau-1}^{\alpha_2} \right)^{\rho^{\tau-t} \prod_{s=t+1}^{\tau}(1-\theta_s)}, \tag{15}$$

where $l_{it} = L_{it}/S_i$ is employment density. The option values (Ξ_{nt}, Ω_{it}) express the attractiveness of each location as residence and workplace, and are composite of amenities and productivity that include both fundamental amenities and productivity (a_{it}, b_{nt}) and the spillovers from past and future population and employment density.[41] When $\theta_t = 1$ for all periods, these option values are reduced to values of amenities (B_{nt}) and productivity (A_{it}). Intuitively, all workers can change locations every period and therefore, the future values of their choice are not attached to the current location choices. In contrast, a small value of the migration opportunity (θ_t) leads to more weight for the future evolution of amenities and productivity in the location since workers are less likely to change their locations. In sum, these option values reflect the value of amenities and productivity by locations when workers choose locations in a forward-looking way.

In equilibrium (11) and (12) imply that (Ξ_{nt}, Ω_{it}) satisfy the change in population and

[41] Equations (14) and (15) imply that our definition of the option values (Ξ_{nt}, Ω_{it}) of each location do not incorporate the convenience of commuting access to other locations. The importance of the commuting access in migration decisions enters in equations (16), which we use to back out (Ξ_{nt}, Ω_{it}).

employment:

$$
\begin{aligned}
R_{nt} - (1-\theta_t)R_{nt-1} &= \sum_i \frac{K_{int}\Xi_{nt}^{\rho/\sigma}}{\sum_j K_{ijt}\Xi_{jt}^{\rho/\sigma}}\left(L_{it} - (1-\theta_t)L_{it-1}\right), \\
L_{it} - (1-\theta_t)L_{it-1} &= \sum_n \frac{K_{int}\Omega_{it}^{\rho/\sigma}}{\sum_j K_{jnt}\Omega_{jt}^{\rho/\sigma}}\left(R_{nt} - (1-\theta_t)R_{nt-1}\right),
\end{aligned}
\tag{16}
$$

where $K_{int} = (\kappa_{int})^{-\rho/\sigma}\prod_{\tau=t+1}^{T}\kappa_{in\tau}^{-(\rho/\sigma)\rho^{\tau-t}\prod_{s=t+1}^{\tau}(1-\theta_s)}$ is the continuation value of commuting costs. Intuitively, equations (16) state that the number of residents that actively choose to live in block n for period t is written as the product of the number of workers that actively choose to live in block i for period t and their conditional choice probability of location n as their residence. We solve the system of equations (16) for option values (Ξ_{nt}, Ω_{it}) conditional on observed population (R_{nt}), employment (L_{it}), commuting costs (K_{int}) and migration frictions (θ_t) and obtain the unique option values.[42]

We recover (Ξ_{nt}, Ω_{it}) as values that rationalize the observed changes in the mass of workers but do not use any information on the unobserved characteristics. Indeed, this step does not require the parameter values of spillovers (α_1, α_2, β_1, β_2) despite that strong spillovers may induce unobserved alternative equilibria. This implies that the possibility of multiple equilibria does not invalidate this step.

5.3 Step #3: Estimation of spillover parameters (α_1, α_2, β_1, β_2)

In Step 2, we obtain option values such that observed changes in population and employment in the city are consistent with equilibrium. We can back out fundamental productivity (a_{it}) and amenities (b_{nt}) by using observed employment and population density, according to the definition of option values (Ξ_{nt}, Ω_{it}). In particular, for each period $t = 1955, 1960, \cdots, 1975$, we derive unique values of fundamentals by location, and these fundamentals are structural residuals in our calibration for the observation to be equilibrium. We assume that the fundamentals consist of location-fixed components, time-trend components and time-varying errors:

$$
\ln a_{it} = \ln a_i^F + \ln a_t^* + \ln a_{it}^{\text{Var}}, \quad \ln b_{nt} = \ln b_n^F + \ln b_t^* + \ln b_{nt}^{\text{Var}},
$$

where $\left(\{a_i^F\}, \{b_n^F\}\right)$ are location fixed productivity and amenities, $\left(\{a_t^*\}, \{b_t^*\}\right)$ are trend of productivity and amenities and $\left(\{a_{it}^{\text{Var}}\}, \{b_{nt}^{\text{Var}}\}\right)$ are stochastic parts of fundamental productivity and amenities. The location fixed productivity and amenities capture the fundamental

[42] The solution is up to scale because equations (16) exploit only the information on the relative migration probabilities across blocks within the city. Since we take the total population of Hiroshima city from data and assume that the outside utility $\ln u_{ot}$ adjusts to rationalize it (see subsection 5.1), we do not need to determine the absolute levels of $\{\Xi_{nt}\}$ and $\{\Omega_{it}\}$ governing the migration condition between Hiroshima city and the outside world. We normalize the geometric mean of $\{\Xi_{nt}\}$ and $\{\Omega_{it}\}$ to one.

advantages of locations and the trend of productivity and amenities reflects the change in their levels over time in the city.

Averaging out the trend terms and taking differences between two periods, we suppose the following moment conditions:

$$\begin{aligned} \mathbb{E}[\Delta \ln \widetilde{a}_{it} \times \mathbb{1}_i(k)] = 0, \\ \mathbb{E}[\Delta \ln \widetilde{b}_{nt} \times \mathbb{1}_n(k)] = 0, \end{aligned} \tag{17}$$

where $\Delta \ln \widetilde{a}_{it} = \Delta \ln \widetilde{a}_{it}^{\text{Var}}$ and $\Delta \ln \widetilde{b}_{nt} = \Delta \ln \widetilde{b}_{nt}^{\text{Var}}$ are change in the idiosyncratic shocks in productivity and amenities adjusted with their geometric means. $\mathbb{1}_n(k)$ is an indicator such that location n is in the grid k. The grid is defined based on the distance from the CBD. Our identification assumption for using the moment condition is that any improvements or declines in the stochastic terms of fundamental productivity and amenities during any five-year period are not systematically correlated to the distance from the city center. While this moment condition accommodates arbitrary location-fixed amenities and productivity, it requires that the systematic change in the gradient of economic activity relative to the distance from the CBD is explained by the mechanisms of the model rather than by systematic changes in the pattern of structural residuals. This identification assumption seems plausible within Hiroshima because the spatial extent of our study is small and all blocks in data would face similar changes in the economic and political environment.[43] All blocks in our sample are located within 6 kilometers from the CBD. To check its robustness, we also estimate the set of parameters using blocks in 3 kilometers to CBD, which are expected to face even more homogeneous conditions and so more likely to satisfy the moment conditions. We use the moment conditions (17) to estimate the set of parameters of agglomeration economies.

In Table 3, we report the efficient GMM estimation results. Column 1 and 2 report our baseline estimates of spillover parameters in productivity (α_1, α_2) and amenities (β_1, β_2) respectively. Overall productivity (A_{it}) in the workplace rises by 0.29 percent when current employment density increases by one percent, but falls by 0.06 percent when employment density increases by one percent in the previous period. The strong agglomeration forces in the workplace rationalize the sustained concentration of employment in the central area of the city. The negative spillovers from the past employment density may capture the congestion effects, such as depreciation in public goods, reduced land supply, and fewer successful matching to achieve innovation (see our microfoundations in Section D.5), implying the possibility of creative destruction (Hornbeck and Keniston 2017). That said, its magnitude is smaller than the positive spillovers from the contemporaneous employment density. A one percent increase in current population density is associated with a 0.19 percent increase in the value of amenities, while a one percent increase in past population density is associated with a 0.15 percent increase in the

[43] We also emphasize that the effect of radioactivity faded away quickly from 1945 (see Section 2.1), and it would be irrelevant for changes in amenities and productivity as our estimation data run from 1950.

Table 3: Generalized Method of Moments estimates for agglomeration parameters

	(1) Productivity	(2) Amenities	(3) Productivity	(4) Amenities	(5) Productivity	(6) Amenities
Elasticity of employment density (α_1)	0.294		0.312		0.196	
	(0.0009)		(0.0019)		(0.0003)	
Elasticity of past employment density (α_2)	-0.065		-0.083		-0.043	
	(0.0010)		(0.0019)		(0.0000)	
Elasticity of population density (β_1)		0.198		0.213		0.132
		(0.0023)		(0.0016)		(0.0082)
Elasticity of past population density (β_2)		0.152		0.116		0.101
		(0.0021)		(0.0018)		(0.0084)
Locations	All blocks		Blocks in 3 km to CBD		All blocks	
Migration frictions (θ_t) after 1955	0.53	0.53	0.53	0.53	0.53	0.53
Parameter ρ/σ	6	6	6	6	9	9

Note: Estimates of the generalized method of moments (GMM) using data for five periods (1955, 60, 65, 70 and 75) and 174 blocks (all blocks) or 158 blocks (blocks in 3 kilometers to CBD). We use the two-step GMM estimation and the standard errors are in parentheses. In Columns 3 and 4, we use blocks in 3 kilometers to CBD. In Columns 5 and 6, we set a large value of commuting elasticity (ρ/σ) compared to the baseline value.

value of amenities. Comparing these estimates, the stronger positive spillovers in amenities from current density are suggestive of the essential role of expectation for future population growth in explaining the change in post-war population distribution in Hiroshima. Other columns in Table 3 show estimates when we restrict locations within 3 kilometers to CBD (Column 3 and 4) and high value of commuting elasticity (Column 5 and 6). Overall, we find strong agglomeration forces (α_1) and a negative effect of previous employment density on wages (α_2) for the spillover effects in workplaces, while positive externalities in neighborhood amenities from both current population density (β_1) and past population density (β_2). These estimates confirm that strong contemporaneous externalities in both amenities and productivity may create a self-fulfilling prophecy, which leads to multiple equilibria. In addition, we find significant effects of past economic activities in both productivity and amenities, implying that history matters in determining the transition path of the economy.[44]

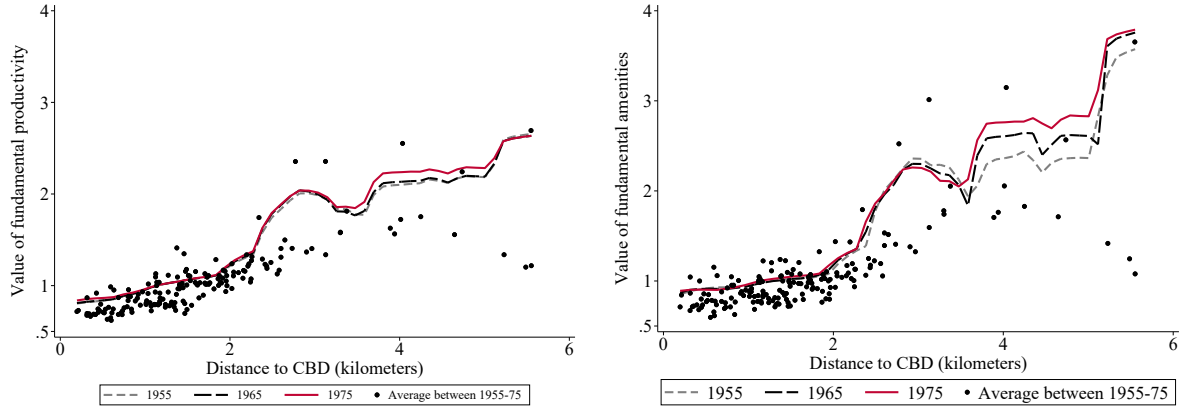
Figure 5 displays the fundamental productivity (a_{it}) and amenities (b_{nt}). The left panel of Figure 5 shows the variation of fundamental productivity for three different years and the average of it over five periods from 1955 to 1975. When there are strong agglomeration forces in the workplace, blocks in the central area show relatively low fundamental productivity since their advantages in productivity are explained by the endogenous part of employment density.[45] In

[44]Our estimates of spillovers in productivity are broadly similar to those in Allen and Donaldson (2022) that uses long-run county-level data of the U.S. However, they find negative contemporaneous spillovers in amenities. This difference may arise from the difference in spatial extent. As we discussed in Appendix D.6, the negative externalities in amenities capture congestion in a local housing market in general. Our estimate implies that such congestion externalities are dominated by positive externalities, including consumption externalities or neighborhood network effects. In a spatially-granular setting such as ours, those positive externalities are likely strong (see, for example Tsivanidis 2022).

[45]Note that the level of fundamentals in our model may be adjusted downward to account for the advantage of smaller blocks. For example, splitting the same block into the two blocks does not change endogenous spillovers, but it is more likely to draw a favorable idiosyncratic shock for one of these locations because we now have two draws. To address this, Figure E.1 in Appendix shows the residualized fundamental amenities and productivity net

particular, we find that fundamental productivity is relatively homogeneous for blocks within two kilometers of the CBD. Among the blocks beyond the area, the fundamental productivity displays large variation. In the right panel of Figure 5, fundamental amenities show a similar pattern to productivity while the difference in the value of amenities between the city center and the outskirts is sufficiently large.[46]

Figure 5: Fundamental productivity and amenities



(a) Productivity **(b)** Amenities

Note: These figures display fundamental productivity (a_{it}) and amenities (b_{nt}) in our calibration for different periods: 1955, 1965 and 1975. Each line shows a polynomial fitted line for them. We also show the average fundamental productivity and amenities from 1955 to 1975, with each point representing a block.

In Appendix E.2, we examine the change in the stochastic terms of fundamental productivity and amenities and their changes over every five years do not exhibit systematic variations with respect to the different band of distances from CBD.

5.4 Accounting for the recovery in 1945-50

We now ask how well our calibrated model can explain for changes in population and employment during recovery period (1945–1950), which were not used for our calibration. To this end, we assess how the endogenous part of location advantages and time-invariant unobserved characteristics can account for changes in population and employment during the phase of recovery of the city from the atomic bombing. Intuitively, we evaluate how much of incentives in the recovery period to work or live in a given location can be explained by our model.

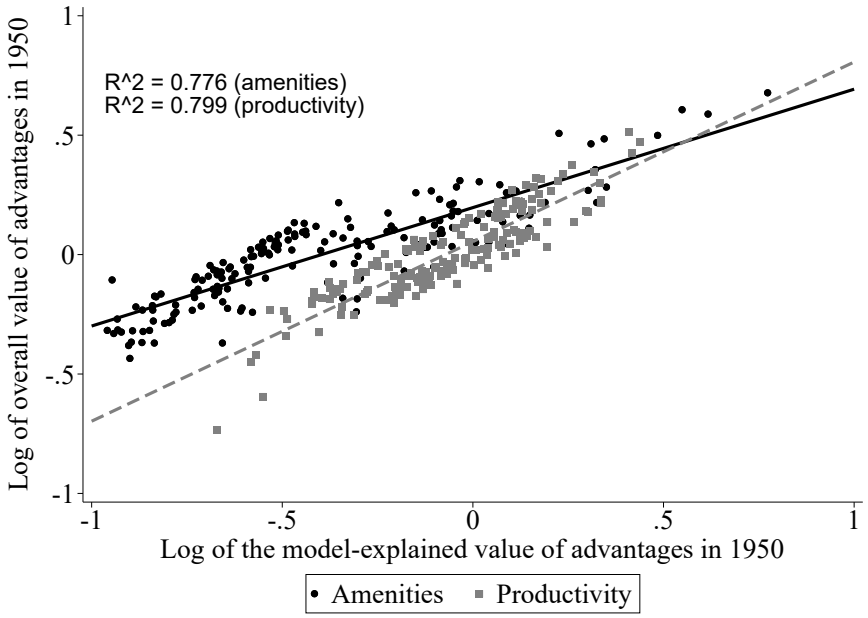
More specifically, we use data on employment and population in 1945 immediately after the bombing and 1950 to back out option values ($\Xi_{n,1950}$, $\Omega_{i,1950}$) by location in 1950 in a similar

of the block size. It shows that the heterogeneity in the fundamental amenities and productivity became substantially smaller after controlling for the block size, but there is still no indication that the city center had better fundamental advantages.

[46]The value of amenities on the outskirts slightly increased from 1955 to 1975, which may reflect suburbanization in Hiroshima during this time period.

manner to Step 2 in Subsection 5.2 (see Appendix E.3 for details). By construction, the option values in our model are a composite of (i) location-fixed advantages, (ii) endogenous terms of spillovers, (iii) future option values associated with the location, and (iv) idiosyncratic shocks. Among them, factors (i)-(iii) capture the location advantages that can be explained by our model and its calibration. In particular, the contemporaneous spillovers of (ii) and (iii) are drivers of the recovery in the location via the forward-looking way of location choices by workers. In contrast, the idiosyncratic terms (iv) are structural residuals in the location advantages and absorb any other characteristics unrelated to the model specification. Therefore, a small role of the idiosyncratic terms compared to other factors in explaining the option values implies that the theory is able to account for the observed recovery of Hiroshima. Note that this analysis does not depend on the potential multiplicity of equilibrium because we use the *observed* population and employment from 1950 and onward, which people with perfect foresight correctly expect in 1945 when making their migration decisions.

Figure 6: The explanatory power of the forward-looking model for the recovery in 1945-50



Note: The figure plots the explained value of amenities and productivity (the horizontal axis) against the total value of amenities and productivity that perfectly rationalize the observed changes in population and employment from 1945 to 1950 (the vertical axis). Each dot represents a block and the black line is the linear fitted line for amenities and the dashed line is for productivity. We also report the R-squared from the simple linear regression of the total value of amenities or productivity on the model-explained value of amenities or productivity.

Figure 6 shows the relationship between the logarithm of overall advantages in productivity ($\ln \Omega_{i,1950}$) and amenities ($\ln \Xi_{n,1950}$) and model based location advantages that conflate (i), (ii) and (iii) discussed above. The large part of the variation in option values of locations in 1950 is explained by the model-based values of location advantages and their R-squared are 0.776 for amenities and 0.799 for productivity, respectively. This relationship is in line with the results of

strong agglomeration forces (Subsection 5.3) and their importance in forward-looking location choices in explaining the population and employment dynamics of the city. In Section 6, we highlight that among model components (i)–(iii), the forward-looking elements play the crucial role in explaining the resurgence of central Hiroshima.

In sum, in this section we calibrate the model using the data on population and employment in Hiroshima. We leverage the structure of the model to recover the option values by locations when people choose locations in a forward-looking way and identify the parameters of spillovers in workplaces and residential places. We then check the performance of our model using the data during the recovery period (1945–1950) of the central area of Hiroshima after the bombing, which was not used for parameter estimation. A key insight from the estimation is that when people correctly expect that the city center would recovery and obtain high population and employment density, the agglomeration in productivity from current employment density and that in amenities from current and past population density are sufficiently large to explain the fast and strong revival of central Hiroshima from 1945 to 1950.

6 History versus Expectations in Hiroshima

Having estimated the model parameters, we have demonstrated that our model, which incorporates both forward- and backward-looking elements in migration decisions, can account for the resurgence of central Hiroshima. We now assess the role of self-fulfilling expectations in explaining the resurgence. For this purpose, Subsection 6.1 introduces a benchmark model that features individuals making myopic migration decisions but is otherwise identical to our baseline model presented in Section 4. Subsection 6.2 conducts the comparison between the forward-looking and myopic models in their ability to explain the recovery from 1945 to 1950. The myopic model is entirely backward-looking and only the history (i.e., the initial condition) determines equilibrium. Consequently, if history matters in explaining the resurgence of Hiroshima, that the myopic model can account for it. In contrast, if the myopic model fails to explain the resurgence, then the forward-looking component of our model, in which people correctly anticipate the resurgence of central Hiroshima when making their migration decisions, is indispensable for explaining the resurgence. This suggests that self-fulfilling expectations are essential for the city's revival.

6.1 The myopic model

As a benchmark, we present a variant of our theoretical model that assumes myopic migration decisions but is otherwise identical to the model in Section 4. Individuals are myopic in the sense that when they have an opportunity to reallocate, they choose where to live and work at period $t+1$ as the best response to the economy at period t. These myopic best-response

dynamics capture the widespread idea that people would migrate from areas with low contemporaneous utility to those with high contemporaneous utility (see, for example, Greenwood 1975; Krugman 1991 Section 2; Fujita et al. 1999) and individuals make their decisions with the belief that the current attractiveness of locations will persist in the future.[47] Under this assumption, expectations play no role because individuals do not consider the variables of future periods. Instead, the history (i.e., conditions at period t) completely determines the dynamics of location choices in the economy (Krugman 1991; Matsuyama 1991). In this sense, the inability to explain the resurgence of central Hiroshima as a result of the myopic migration is suggestive of the importance of the expectations. Note that while the assumption of perfectly backward-looking migration decisions is admittedly strong as a description of reality, we nonetheless make this assumption to obtain a clean benchmark of comparison to tease out the role of the forward-looking elements of migration incentives.[48]

Formally, we operationalize the myopic migration decision as follows. When workers make decisions on locations for the period $t+1$, workers form the static expectation that the future expected utility associated with the workplace and residence pair (j,ℓ) equals the value of the current utility $\ln u_{j\ell t}$. When an individual ω is able to choose the residence and workplace for $t+1$ at the end of period t, she solves the following problem analogous to (6):

$$v_{int}^{\text{Myopic}}(\omega) = \ln u_{int} + \max\left\{\rho \ln u_{j\ell t} + \sigma\varepsilon_{j\ell t+1}\ ;\ \rho \ln u_{ot} + \sigma\varepsilon_{ot+1}\right\}, \tag{18}$$

where we replace the value function in (6) with the period utility at period t. Note that this formulation implicitly assumes that workers ignore any utilities realized in period $t+2$ and onward, which seems natural given the assumed myopia of workers. Equation (18) implies that when making the migration decision for the period $t+1$ at time t, the worker evaluates each location using its current situation at time t but does not take into account its future conditions from $t+1$ and onward. Assuming that the idiosyncratic shocks follow Type-I extreme value distribution, we can derive the probabilities that are analogous to (9), $\{\lambda_{int+1}^{\text{Myopic}}\}$. Specifically, the probabilities are given by:

$$\lambda_{int+1}^{\text{Myopic}} = \frac{u_{int}^{\rho/\sigma}}{\sum_{d\in\{\mathcal{C}\times\mathcal{C},o\}} u_{dt}^{\rho/\sigma}}, \quad i,n \in \mathcal{C} \tag{19}$$

These migration probabilities at time $t+1$ depend only on the period utility at time t, implying that the residence and workplace choice probabilities at period $t+1$ are solely determined by the past. Using these probabilities, for $t = 0,1,...,T-1$, the dynamics of population and

[47] The replicator dynamics used in Fujita et al. (1999) is also a version of the myopic best-response dynamics. More generally, the myopic best-response dynamics is a prominent example of evolutionary dynamics in game theory since it exhibits inertia and myopia (Sandholm 2010).

[48] This approach is analogous to Krugman (1991), in which he first presented a perfectly myopic model in Section 2 and then compared it with the forward-looking model developed in the rest of the paper.

employment are written by:

$$\begin{aligned} L_{it+1} &= (1-\theta_{t+1})L_{it} + \theta_{t+1}\mathcal{M}\sum_{n\in\mathcal{C}} \lambda^{\text{Myopic}}_{int+1}, \\ R_{nt+1} &= (1-\theta_{t+1})R_{nt} + \theta_{t+1}\mathcal{M}\sum_{i\in\mathcal{C}} \lambda^{\text{Myopic}}_{int+1}. \end{aligned} \tag{20}$$

The myopic equilibrium is characterized by the followings. Given the initial employment and population $\{L_{i0}, R_{n0}\}$, total population $\mathcal{M}$, migration opportunities $\{\theta_t\}$, fundamentals $\{a_{it}, b_{nt}\}$ and parameters (α_1, α_2, β_1, β_2), equations (19) and (20) determine the myopic equilibrium $\{L_{it}, R_{nt}\}$. To compute the counterfactual equilibrium, we use parameters and fundamentals that are obtained in our calibration in Section 5. See Appendix F for further details on the myopic model.

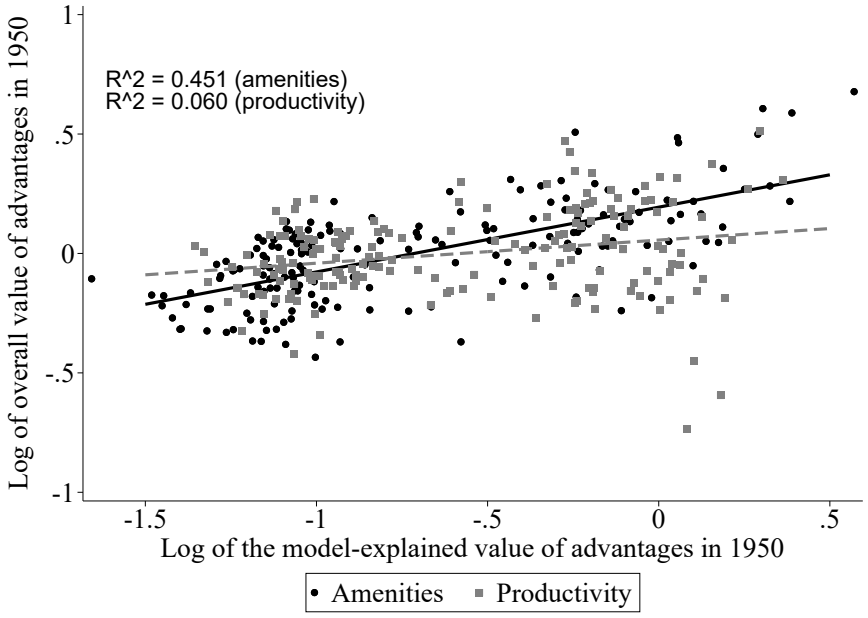
6.2 The role of self-fulfilling expectations in explaining the recovery

We now compare the ability of the forward-looking model presented in Section 4 and the myopic model presented above in Subsection 6.1 to account for the recovery of central Hiroshima, given that this is the most salient feature of our data (see Section 3). We adopt two complementary approaches for this comparison. First, we use the approach described in Subsection 5.4 to determine the extent to which each model can account for changes in population and employment distribution from 1945 to 1950. Second, we simulate the counterfactual Hiroshima in which individuals make myopic migration decisions and compare the results to the observed data, which demonstrates the fast and strong recovery of central Hiroshima. Both approaches suggest that the myopic model is not able to adequately explain the resurgence of Hiroshima. Given that our baseline model featuring a forward-looking way of migration can account for the recovery (Subsection 5.4), we conclude that the self-fulfilling expectations are essential to explain the resurgence of central Hiroshima.

Explanatory power for the recovery period 1945–1950. Using the analogous methodology as Subsection 5.4, we first explore how well the myopic model can explain the data in the recovery period (1945–1950) by analyzing how well the model-based amenities and productivity of each location accounts for the overall amenities and productivity that perfectly rationalize the observed changes in population and employment distribution (see Appendix F.2 for details).

Figure 7 shows the results for the myopic model, analogously to Figure 6 for the forward-looking model. The vertical axis takes the overall advantages (i.e., amenities or productivity) of each location in 1950 that perfectly rationalize the data, and the horizontal axis takes the value of location advantages evaluated by the individuals in the myopic model when deciding on migration for 1950. The myopic model performs significantly worse than the forward-looking model, as evidenced by the flatter fitted lines and the substantially lower R-squared values compared

Figure 7: The explanatory power of the myopic model for the resurgence (1945-1950)



Note: The figure plots the explained value of amenities and productivity by the myopic model (the horizontal axis) against the total value of amenities and productivity that perfectly rationalize the observed changes in population and employment from 1945 to 1950 (the vertical axis). Each dot represents a block and the black line is the linear fitted line for amenities and the dashed line is for productivity. We also report the R-squared from the simple linear regression of the total value of amenities or productivity on the model-explained value of amenities or productivity.

to those in Figure 6.[49] This is particularly the case for productivity: the myopic model can only account for 6 percent of the variation in productivity, whereas the forward-looking model can account for nearly 80 percent. Although the myopic model does a better job of explaining the variation of amenities, it still substantially underperforms the forward-looking model (45 percent compared to 78 percent). It is noted that the poor performance of the myopic model occurs despite the fact that it incorporates flexible fixed amenities and productivity by location. Thus, this inferior performance of the myopic model is attributed to the absence of self-fulfilling expectations.

Counterfactual Hiroshima under myopia. As our second approach to evaluate the performance of the myopic model, we calculate the counterfactual population and employment distribution by assuming that people follow the myopic model starting from 1945. Since we demonstrated in Subsection 5.4 that our forward-looking model fits well the resurgence observed in data, the discrepancy between the myopic model and the observed data suggests that the myopic model performs less well than the forward-looking model. For this counterfactual analysis, we

[49]Note that our comparison considers the commuting access of each location in computing the option values in the forward-looking and myopic models (see also footnote 41). In particular, it takes into account that the destroyed city center may be convenient for commuting access in that the center is not located too far away from most parts of the outskirts.

use the parameter values, fundamental amenities and productivity estimated in Section 5 to fully compute our myopic model. In order to focus on the population and employment within the city, we assume that the total population in the myopic counterfactual scenario matches the observed data.

Figure 8 provides a visualization of population and employment density in the myopic counterfactual scenario. The first panel 8a compares the population density in the myopic equilibrium to the population density observed in 1950. We find that although areas within 2 kilometers of the city center had higher population density than right after the bombing, the monocentric city structure did not re-emerge unlike the observed data. The highest population density is observed in blocks approximately 2 kilometers from the epicenter and areas more than 3 kilometers away from the center, which also had the highest population density right after the bombing. A similar pattern is observed for employment in the second panel 8b. Under the myopic counterfactual scenario the failure of the center to recover is more evident in terms of employment, because the level of employment in the center was lower than it was right after the bombing.

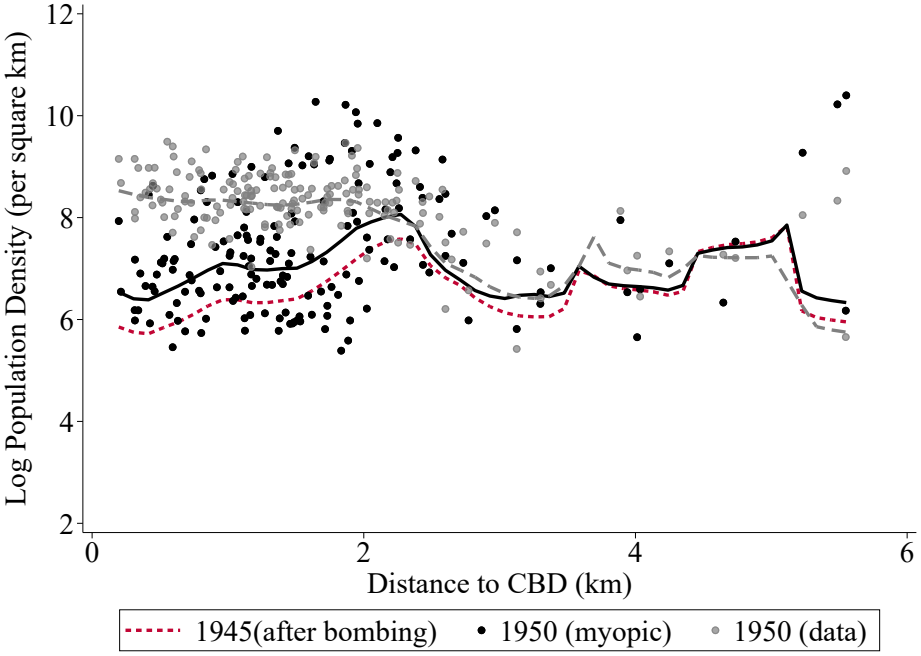
The failure of the resurgence of central Hiroshima under the myopic counterfactual scenario is explained by the backward-looking nature of migration decisions. Since myopic individuals anticipate that the city center would remain as its current state so that the population and employment density remains low in 1950, they suppose that the city center in 1950 is unattractive as residence and workplace in terms of positive contemporaneous spillovers (i.e., $\alpha_1 > 0$ and $\beta_1 > 0$). In addition, taking into account the spillovers from historical population and employment density, those right after the bombing in this case, does not qualitatively alter the attractiveness. First, because $\beta_2 > 0$, the city center is deemed unattractive in terms of historical spillovers. Second, although $\alpha_2 < 0$ indicates that the low employment density in the center after the bombing increases productivity in 1950, the magnitude of these historical spillovers is small enough that it does not overturn the positive contemporaneous spillovers, as measured by the 1945 employment density when people are myopic. Taken together, positive net spillovers both in population and employment density render the central area of Hiroshima unattractive under the myopic counterfactual scenario, which fails to account for the strong incentive to work and reside in the city center during the recovery period.

In addition to failing to account for data from the recovery period (1945-1950), the myopic also fails to account for data from 1950 onward. Figure 9 plots the population density of each location in 1960 and 1975 based on the myopic counterfactual scenario on the horizontal axis and the observed population density on the vertical axis. If the myopic model accounts for the data, then, each observation lies on the 45-degree line (depicted in the dashed line). The size of each dot reflects the population right after the bombing, which is generally small near the city center because of the total destruction.

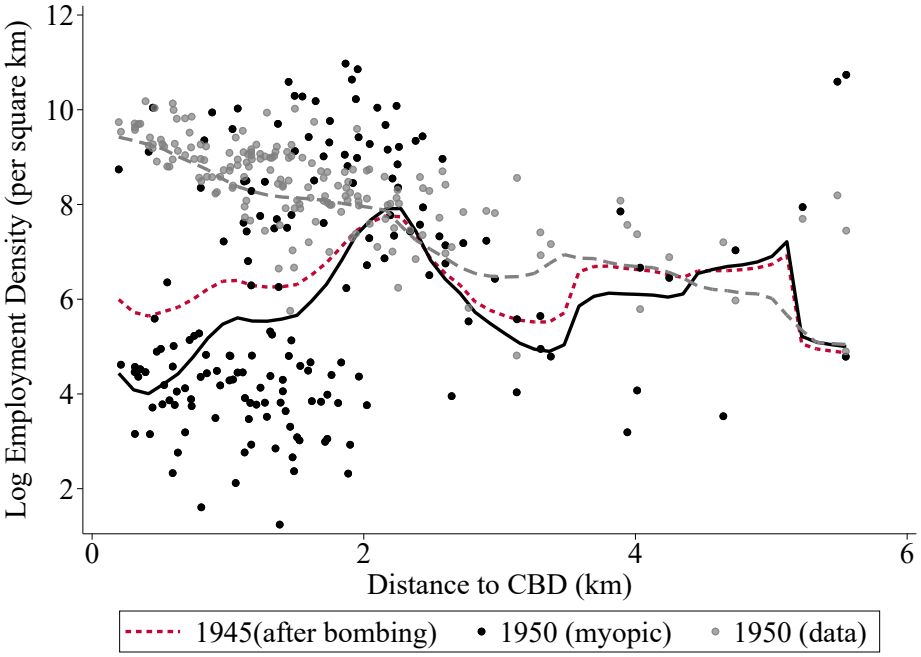
We find that observations substantially deviate from the 45 degree line in both 1960 and 1975, implying that the myopic model fails to account for the data in periods after the initial

Figure 8: The myopic counterfactual scenario and the data in 1950

(a) Population density

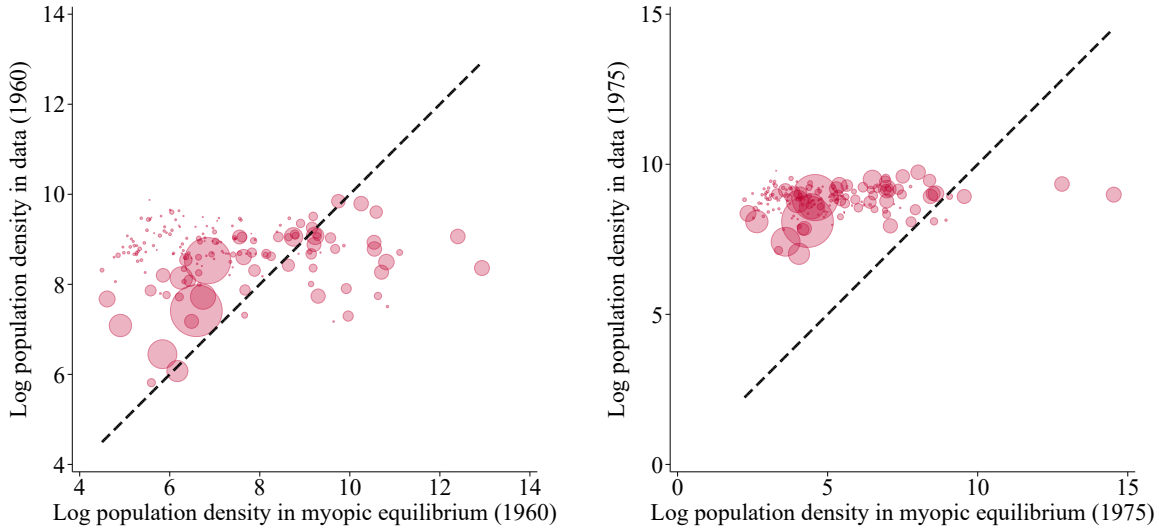


(b) Employment density



Note: Figure 8a plots the results of local polynomial regressions of the log population density on the distance from the city center. We conduct three regressions separately for the 1945 population density in data, the 1950 population density in data, and the 1950 population under the counterfactual scenario. Each dot represents a block. Figure 8b repeats the same analysis for employment density.

Figure 9: Population density when myopic location choice



(a) Population density in 1960

(b) Population density in 1975

Note: This figure plots the log population density in the myopic counterfactual scenario against the log population density in data. Each dot represents a block and the dot size is proportional to the population size in 1945 (i.e., right after the bombing). Figure 9a is for 1960 and Figure 9b is for 1975.

recovery period. There are two additional takeaways. First, a smaller dot tends to appear to the far left of the 45-degree line, indicating that the population density in the data is higher than in the myopic counterfactual scenario. This suggests that the city center with the low initial population keeps failing to recover its population density beyond 1950. Second, the myopic counterfactual scenario has a larger variation in population density across locations, and this variation appears to be increasing over time. Intuitively, because of the net positive externalities, the myopic model implies that initially populated areas are more attractive and vice versa. This implies that the impact of history (i.e., the initial population and employment distribution) would be amplified over time, which is in contrast to the observed data.

Taken together, our findings suggest that the myopic model, which only incorporates a backward-looking element in migration decisions so that only the history determines the equilibrium, cannot account for the observed data: the fast and strong resurgence of central Hiroshima. This failure is in contrast to our forward-looking model, in which individuals make migration decisions while correctly expecting the resurgence of central Hiroshima. Thus, self-fulfilling expectations are necessary to explain the recovery of central Hiroshima from its catastrophic history.

7 Conclusion

This paper studies the relative importance of history and expectations in the spatial economy through the atomic bombing of Hiroshima. By newly digitizing granular data on the distribution of economic activities within the city of Hiroshima, we first establish the striking *path independence* result: the city's center strongly recovered around five years after being completely destroyed. Controlling for observed location characteristics or focusing on homogeneous small areas within the city does not alter this conclusion. Moreover, the destroyed area of Nagasaki also quickly recovered, just like Hiroshima, although the outskirts of the city were destroyed in Nagasaki. This suggests that a factor other than the fundamental advantages of central Hiroshima, such as self-fulfilling expectations, may have contributed to the recovery.

We next develop a dynamic quantitative urban model that incorporates both history and expectations to structurally evaluate the role of self-fulfilling expectations in resurgence. In our model individuals correctly anticipate the recovery of the central area when making their location choices. The model is calibrated with data from Hiroshima during the post-recovery period from 1950 to 1975. We find that the model with forward-looking location choices can well explain the resurgence of central Hiroshima five years after the bombing. In contrast, when myopic individuals make location choices based solely on the status-quo, the model is unable to rationalize the resurgence. This stark contrast suggests that self-fulfilling expectations play a crucial role in explaining the recovery of central Hiroshima despite its catastrophic history.

This paper has highlighted the importance of self-fulfilling expectations in realizing the resurgence of central Hiroshima, implying that expectations may matter in equilibrium selection among multiple equilibria in spatial economic models. However, as discussed in Section 3.5, we have remained agnostic about why people formed the expectations that the center would recover despite its tragic history. We have pointed out that a combination of factors, such as the presence of governmental recovery plans, the anchoring effect of transportation infrastructure, property rights, and the popular narrative of rebuilding, may have contributed to forming expectations in the recovery. These factors are likely to be found to varying degrees in other contexts of studies on the impact of war-time destruction, implying that self-fulfilling expectations on rebuilding caused by these factors may explain the path independence frequently found in these studies while not contradicting the path dependence found in other studies (Glaeser 2022; Lin and Rauch 2022). A more systematic understanding of how self-fulfilling expectations can emerge is insightful for characterizing which spatial equilibrium is realized in a particular context, which is an important next question.

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Appendix to "History versus Expectations in the Spatial Economy: Lessons from Hiroshima"

A Data Appendix **A 1**
- A.1 Basic data . . . A 2
- A.2 Population and employment . . . A 3
- A.3 Other data . . . A 6

B Nagasaki **A 12**

C Further Reduced-form Results **A 14**

D Theoretical Appendix **A 17**
- D.1 Value function . . . A 17
- D.2 Location choice . . . A 18
- D.3 Equilibrium . . . A 19
- D.4 Steady state equilibrium . . . A 21
- D.5 Microfoundations of productivity spillovers . . . A 22
  - D.5.1 Local production capital . . . A 22
  - D.5.2 Innovation by incumbent workers in local firms . . . A 25
- D.6 Microfoundation of amenity spillovers . . . A 26

E Estimation **A 27**
- E.1 Calibration procedure . . . A 27
- E.2 Calibrated amenities and productivities . . . A 31
- E.3 Evaluating the recovery in 1945-50 . . . A 32

F The Myopic Model **A 34**
- F.1 Myopic equilibrium . . . A 34
- F.2 Evaluating how much the myopic model explains 1945-50 recovery . . . A 36

A Data Appendix

This section describe the details of data construction. Subsection A.1 explains the spatial units of our analysis and impact of atomic bombing in our data. Subsection A.2 describes how we construct the data on population and employment. Subsection A.3 presents other data relevant to our analysis, including commuting, location characteristics, land prices and migration rate. Table A.1 provides summary statistics of population, employment, and characteristics of each block, separately for the full sample and blocks within 3 kilometers from the city center.

A.1 Basic data

Maps (spatial units) and sample selection. We use the city block (*cho cho moku*) as our spatial unit of analysis. As our main definition of geography and city blocks, we use the GIS data of block boundaries as of the bombing constructed by Takezaki and Soda (2001). We make several adjustments to create our final sample. First, although Takezaki and Soda (2001) follows the map of officially-published block boundaries (*Hiroshima shin-shi*), it was constructed after the war and a few blocks do not correspond to our population data. We address this issue by suitably aggregating blocks in Takezaki and Soda (2001).[A.1] Second, we drop some blocks that experienced exceptional events that are outside the scope of our model. We first drop blocks that later constitute Hiroshima Peace Memorial Park, Hiroshima-shi Chuo Park, and Hijiyama Park. Second, we drop three blocks that exhibit unusually large changes in population or employment in some periods, which is likely due to idiosyncratic events outside of the model.[A.2] Third, we drop observations that have missing observations in the destruction rate of buildings or the establishment counts in 1938. Finally, to ensure that our geographical scope is small, we drop two blocks whose centroids are more than 6 kilometers away from the city center. In our final sample, there are 174 blocks.

We also digitize the block boundaries as of 1966 and 1976 to deal with changes in the block boundaries. For 1966, we use the map found in the report of the 1965 block-level population of Hiroshima (*Hiroshima-shi machi-betsu jinkou setai shiryou shouwa 40-nen kokusei chosa yori*). For 1976, we use the Hiroshima city map (*Hiroshima shigai chizu*) issued by a private publisher (*Shobun-sya*) in 1976.

The destruction by the atomic bombing. The severeness of destruction can be measured primarily in two ways: the destruction ratio of buildings and the kill ratio of people. Hiroshima City Government (1971), which is our key source of data on the bombing damage, provides both measures at the block level. However, we primarily focus on the building data for two reasons. First, the kill ratio is less reliable because it was extremely difficult to check who was killed in the totally destroyed city. Indeed, Hiroshima City Government (1971) has many missing values on the kill ratio precisely because no reliable data on the kill rate was available. In contrast, the destruction rate of buildings was easier to record even a while after the bombing and hence has way fewer missing values. Second, Hiroshima City Government (1971) records the "immediate" death rate by the bombing, but the definition of the "immediate" is unclear and seemingly inconsistent across blocks in Hiroshima City Government (1971). This is impor-

[A.1] We aggregate two blocks (*Akebomo-machi* and *Kougo kita-machi*) that are recorded in a disaggregated way in Takezaki and Soda (2001). We also combine the *Yaga machi* and *Yaga shin-machi*, and *Funairi minami-machi* and *Funairi kawaguchi-machi*.

[A.2] We drop *Hakushima kita-machi*, *Iwamiya-cho*, and *Toriya-cho*. Although we are not completely sure of why these there blocks exhibit a sudden change in population or employment, we speculate that the presence of schools in *Hakushima kita-machi* and *Iwamiya-cho*, and a very small size of *Toriya-cho* (less than $0.0025 km^2$) made it prone to idiosyncratic shocks.

tant in the context of Hiroshima because many people died many days, months, or even years after the bombing due to the atomic-bomb sickness caused by the radiation. Third, prior studies about the impact of bombing on the city population (Davis and Weinstein 2002; Brakman, Garretsen and Schramm 2004) note that the damage to buildings is a better measure of the damage level than casualties. We base our analysis on the digitization of Hiroshima City Government (1971) by Takezaki and Soda (2001), but we consulted Hiroshima City Government (1971) to (i) correct errors in Hiroshima City Government (1971) or Takezaki and Soda (2001) and (ii) obtain the building destruction rate or the kill rate when they can be credibly inferred from the text information even if they are not reported in the tables.

We plot the building destruction rate against the distance from the CBD in Figure A.1a. The strong heterogeneity within the city is apparent. Blocks within 2 kilometers of the CBD were quite severely destroyed, while those more than 2 kilometers away from the CBD tend to experience much less destruction. See also Figure 1b for the representation of a map. A similar plot for the kill rate is in Figure A.1b. The severest damage tends to concentrate in a smaller area (particularly 1 kilometer from the CBD) and the data has more variation conditional on the same distance from the CBD, partially because the data is noisier.

A.2 Population and employment

Population. We collect and digitize the block-level population data. For 1933–1936, we use the Statistical Handbook of Hiroshima city (*Hiroshima-shi toukei sho*) that reports the population at the block level. For 1945–1953, we use the Statistical abstract of Hiroshima city (*Hiroshima shisei youran*). From 1955, we use the population census data. The time-series data is summarized in Figure 2a.

Two issues must be addressed to make the population data comparable from 1933 to 1975. First, the block boundaries changed over time and the city's shape also changed due to landfills and flood control. Second, prior to 1951, population data is available only at the less spatially-granular level than blocks. We address these issues using various data and construct the block-level population data that are comparable during 1933–1975.

To address these issues, we first base our definition of blocks as of 1945 and focus on block areas that exist from 1945 to 1975. Then, when the block boundary changes since 1945, we evenly distribute the population based on the overlapping area. To address the changes in the size of blocks due to landfills and flood control, we focus on land areas throughout 1945 and 1975. Our focus on the 1945 blocks can allow us to ignore new landfills. However, flood control, especially the redesign of the *ota* river, which started full-scale in 1961 and was almost completed in 1965, is still an issue because some land areas in 1945 were under the river. This implies that some blocks in our data are smaller than their original size as of 1945. To address this, we calculate the percentage change in the area before and after this flood control and multiply by this percentage all population variables prior to 1965, which again implicitly assumes

that the population is evenly distributed within each block.

Second, prior to 1951, population data is available only at a less spatially-granular level than the blocks. To construct the block-level population data in 1945, we combine the block-level information on the rate of totally destroyed buildings from Hiroshima City Government (1971) and the population change ratio from the pre-bombing period to November 1 1945 from the Statistical abstract of Hiroshima city for each distance bin from the epicenter of the atomic bomb. We first calculate the fraction of totally destroyed buildings by the distance to the city center by aggregating the data from Hiroshima City Government (1971). We then regress the population change ratio onto the quadratic function of the fraction of totally destroyed buildings. As seen in Figure A.2a regression model fits the data well. We use this model to predict the population change ratio by using the block-level totally destroyed buildings. Finally, we multiply this ratio with the 1936 block-level population to approximate the block-level 1945 population.

We validate our method of imputing the 1945 population after the bombing using different data. The 1946 edition of *Hiroshima shisei youran* reports in a map the population level before (August of 1945) and after (August of 1946) the bombing for each school district. While we do not know the exact border of school districts, we can compute the population change ratio between the two periods, which we expect to be highly correlated with the population change due to the atomic bombing. We then compare the population change rate of each school district with that of the census block that appears closest to the relevant school district on the map. Figure A.3 shows the scatter plot and the fitted line. We obtain a very high correlation ($\rho \simeq 0.86$) between these two despite the data limitations that the population was measured at different timing and the correspondence of school districts and the block was measured with error.

To construct the block-level population data in 1949 and 1950, we use population data that is recorded at a less spatially granular level, called *shucchojo*, taken from the 1949 and 1950 Statistical Abstract of Hiroshima. *Shucchojo* divides the city into 18 districts based on the administrative area of each branch of the city government office. Assuming that within each *shucchojo*, the population share is the same as 1951, we approximate the block-level population data by multiplying this share by the population of the *shucchojo*.

Our main analysis does not use population data during 1946–1948 because the block-level data is hard to construct. However, the population data in 1946, 1947, and 1948 is available in the Statistical Abstract of Hiroshima City separately for distance categories from the epicenter of the bombing. In Figure A.4, we plot the time series of the population share of areas within 1 kilometer from the epicenter using this data. The figure shows that the recovery process strongly started already in 1946. As we have discussed in Section 3, this might limit the role of the direct impact of public recovery policies in explaining the recovery because Hiroshima city faced an extreme budget deficit and could not take strong policies.

Employment. We collect and digitize the block-level employment data. For 1938, we use the Survey of Commerce and Industry in Hiroshima city (*Hiroshima-shi shoukou-gyou keiei*

chousa) that record the number of establishments at the block level. For 1946, we take from the Statistical abstract of Hiroshima city (*Hiroshima shisei youran*) the number of buildings used for business purposes. For 1953, we use Survey on the Daytime Population of Hiroshima (*Hiroshima-shi chukan jinko chosa*). From 1957 to 1975, we use the Business establishment statistical survey (*jigyousho toukei chousa*). Throughout this paper, we focus on employment in manufacturing or service sectors and ignore the agricultural employment. This is relatively a moderate restriction because we focus on an urban area throughout our sample period.[A.3] Even in 1950, in which the agricultural employment was significant in Japanese economy, the Population Census suggests that only less than 10% of workers are in the agricultural sector in the Hiroshima city. The time-series data is summarized in Figure 2b.

Three issues must be addressed to make the block-level employment data comparable between 1938 and 1975. First, similar to population, the block boundary changed over time. Second, for 1945–1963, the employment information is available only at the less spatially-granular level than blocks. Third, for 1938 and 1945, we know the number of establishments but not the number of workers.

For the first issue, we use the same strategy as the population data to address this issue. We now describe how we address the second issue. We first calculate the number of establishments as of November 1945, which is the time at which our first post-war population data is available. For this, we first take from 1946 Statistical Abstract of Hiroshima City the number of buildings for shops, restaurants, banks, hotels, associations, and entertainment facilities before and after the bombing (August 1946). We also approximate the establishment distribution right after the bombing (August 1945) by multiplying the number of the establishment before the bombing and the ratio of totally destroyed buildings.[A.4] Using linear interpolation, we can approximate the number of establishments for each distance bin as of November 1945 from the numbers as of August 1945 and 1946. Second, we regress the change rate of the number of establishments from the pre-war period to November 1945 on the ratio of totally destroyed buildings and its square. Figure A.2b shows that the regression model exhibits a good fit. Finally, we multiply the number of establishments in 1938 by the predicted change rate using the block-level ratio of the totally destroyed buildings and the estimated regression model shown in Figure A.2b.[A.5]

[A.3] While most of our data already focus on non-agricultural employment, the 1953 data report the total employment including agricultural employment. To adjust for this, we estimate the number of agricultural workers in 1953 using the following procedure. First, we obtain the share of agricultural households from the 1950 Statistical Abstract of Hiroshima. Combined with the number of agricultural workers from the 1950 Population Census, we estimate that about the half of the agricultural household members are counted as working. This allows us to calculate the fraction of agricultural workers in the overall population. We multiply it by the 1953 block-level population to approximate the agricultural employment in 1953.

[A.4] We compute the average fraction of totally destroyed buildings for each bin from the block-level data of the fraction of totally destroyed buildings (Hiroshima City Government 1971), using the 1938 number of establishments as weights.

[A.5] The predicted model yields a negative change rate in the number of establishments for 100% total destruction rate. To address this, we use the change rate predicted for the 99% destruction rate for blocks with the 100% destruction rate.

To construct the block-level employment distribution for 1950–1963, we rely on employment distribution that is recorded at a less spatially granular level (*shucchojo*). Since our 1957 employment data aggregates seven peripheral districts into one, we define it as the "others" district and use 12 *shucchojo* areas. In principle, each *shucchojo* district is aggregated up from blocks.[A.6] The number of workers at the *shucchojo* level is available for 1953, 1957, and 1963.[A.7] To calculate the employment at the block level, we multiply the number of workers in the *shucchojo* and the employment share of that block in 1966. This procedure assumes that the employment share *within* the *shucchojo* district is approximated by the 1966 distribution, but allows for the employment changes across *shucchojo* districts. Finally, to approximate the employment distribution in 1950, we assume that the employment distribution in 1950 is the same as in 1953 except for the total number of workers, which we scale down by the growth rate in the total population.

Finally, we need to construct the block-level employment data from the block-level establishment data. Following prior studies (e.g., Ahlfeldt, Redding, Sturm and Wolf 2015), we assume that the number of employment is proportional to the number of establishments. To determine the total size of employment in 1938 and 1945, we multiply the total population by the labor force participation rate in 1936, which is 44.2% according to the 1936 Statistical Handbook of Hiroshima city (*Hiroshima-shi toukei sho*).[A.8]

A.3 Other data

Commuting. We use the trip-level microdata of the 1987 Hiroshima city person-trip survey. The 1987 person trip survey was for residents of the Hiroshima metropolitan area. It was large-scale (about 7% of the population was surveyed) and representative. To further enhance the representativeness based on residence, age, and gender, we use the sampling weights provided in the survey. The unit of observation is a trip and for each trip, it collects information on the origin, destination, and transportation mode(s). It also asks individual characteristics, including residence, workplace, age, gender, industry, and occupation. We construct a bilateral commuting matrix between 73 areas within our sample area, using individual-level information on the residence and the workplace. The 73 areas are constructed by suitably aggregating blocks. We measure the bilateral distance by the distance of the centroids of two areas.

Location characteristics. We collect various information on the locational characteristics of each block. We first explain the natural locational characteristics: altitude, ruggedness and soil

[A.6] There are a few exceptions in which a block overlaps multiple *shucchojo* districts. In this case we assume that a block belongs to the district in which more of the block residents live.

[A.7] Similar to the block-level data, we have also adjusted the shrink in the area of *shucchojo* districts by defining the area change of each district before and after the *ota* river flood control. We multiply the original employment by this area change rate to obtain the *shicchojo* level employment in 1953, 1957, and 1963.

[A.8] In our structural estimation, however, the total employment equals the total population because our model assumes that everyone works. We normalize the total population to the total employment.

condition. The altitude and the ruggedness are taken from the Digital National Land Information[A.9]. For each $250m \times 250m$ squares, the data record the average altitude and the average degree of slopes. We assign the value at the centroid of each block. Second, we obtain the location of water areas separately for the pre-war and post-war periods. We use the digital map of Takezaki and Soda (2001) for the pre-war period and the Basic National Land Information data for the post-war period. Finally, we take the soil condition from the Land Classification Basic Investigation.[A.10] We use the data on the surface strata and assign the soil condition to each block using the centroid location.

We now explain our data on the non-natural locational characteristics. We collect information on the location of train stations in 1950 from the Digital National Land Information[A.11] and the list of cultural assets (*bunkazai*) in the city from the Hiroshima Metropolitan Area and Hiroshima Prefecture Open Data Portal Site.[A.12] Finally, we digitize the location and the number of units of each public housing from 1949 and 1950 Statistical abstract of Hiroshima city (*Hiroshima shisei youran*).[A.13] The data cover all public housing units constructed in Hiroshima from 1946 to 1950.

Land prices. We obtain the location with the highest unit land price within Hiroshima city.[A.14] For 1931, this is reported in the 1931 Statistical Yearbook of Hiroshima City. For 1959, the National Tax Agency reports the location with the highest land price in each prefecture.[A.15] Since the highest land price in Hiroshima prefecture was in Hiroshima city, we know that this place also had the highest land price in Hiroshima city.

Migration rate. In order to assess the degree of mobility friction, we use the information on migration rates. Our primary data source is the 1960 population census. It asks whether a respondent changed their address, including moving within the same municipality. In densely populated areas of Hiroshima prefecture, 85.9% of prime-age people say they did not.[A.16] Converting this into a 5-years interval, we calculate the rate of moving within five years is $\theta \simeq 0.53$. However, this migration probability seems too small for the period right after the war. Many

[A.9]Source: https://nlftp.mlit.go.jp/ksj/gml/datalist/KsjTmplt-G04-d.html, in Japanese. Last accessed on September 9, 2022

[A.10]Source is map with a scale of 1 to 50,000; https://nlftp.mlit.go.jp/kokjo/inspect/landclassification/land/l_national_map_5-1.html, in Japanese. Last accessed on September 7, 2022.

[A.11]Source: https://nlftp.mlit.go.jp/ksj/gml/datalist/KsjTmplt-N05-v1_3.html, in Japanese. Last accessed on September 7, 2022.

[A.12]Source: https://hiroshima-opendata.dataeye.jp/resources/9843, last accessed on September 9, 2022.

[A.13]In some cases, the location information in the data does not allow us to pin down the block the public housing is located in. We still assign the single block based on our best guess on the location of that public housing.

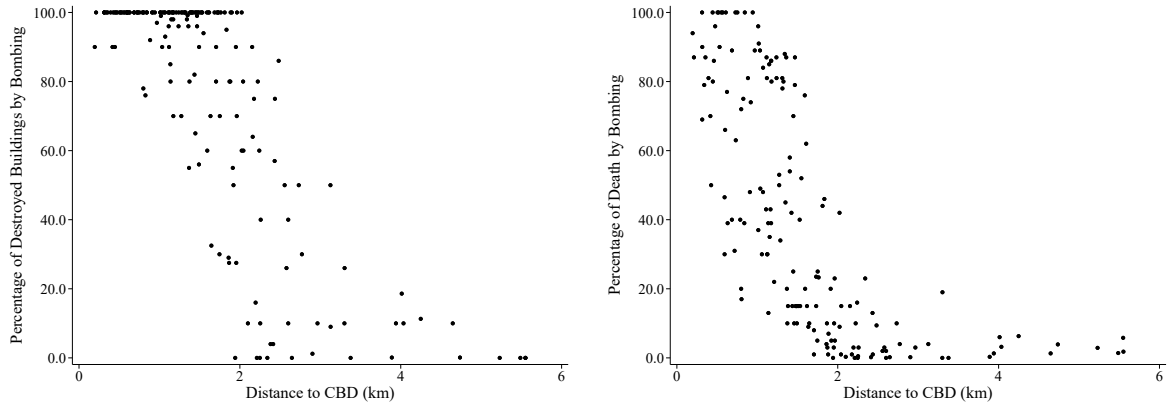
[A.14]In Japan, to our knowledge, digitized comprehensive land price data in the pre-WWII period is available only in Tokyo and Kyoto (Yamagishi and Sato 2022).

[A.15]This can be found in Weekly Tax Communication (*Shukan zeimu tsushin*), volume 444, issue of February 22, 1960.

[A.16]Here, the prime-age means between the ages of 15 and 59. Data source: https://www.e-stat.go.jp/stat-search/files?page=1&layout=datalist&toukei=00200521&tstat=000001036867&cycle=0&tclass1=000001038047&tclass2val=0, in Japanese. Last accessed on September 8, 2022.

people reallocated for wartime reasons and they would have lower mobility costs (e.g., lower attachment to their current residence, higher probability of intending job switching). According to the city population registry (reported in *Hiroshima shisei youran*), more than 50 thousands of people moved out of Hiroshima city in 1949. Since the population of Hiroshima city at the end of 1948 was about 24 thousands (1952 *Hiroshima shisei youran*), this implies the annual migration rate of 21% even if intra-city migration is ignored. We assume that the relative frequency of intra-city migration and inter-city migration right after the war is similar to that in 1960.[A.17] This suggests the annual rate of staying of 0.64, corresponding to the rate of moving within five years $\theta \simeq 0.9$. Note that our migration rate is primarily based on the migration data of 1949. This might understate the migration rate if the mobility right after the war is even higher than the 1949 migration rate.

Figure A.1: Damage to buildings and Death of people



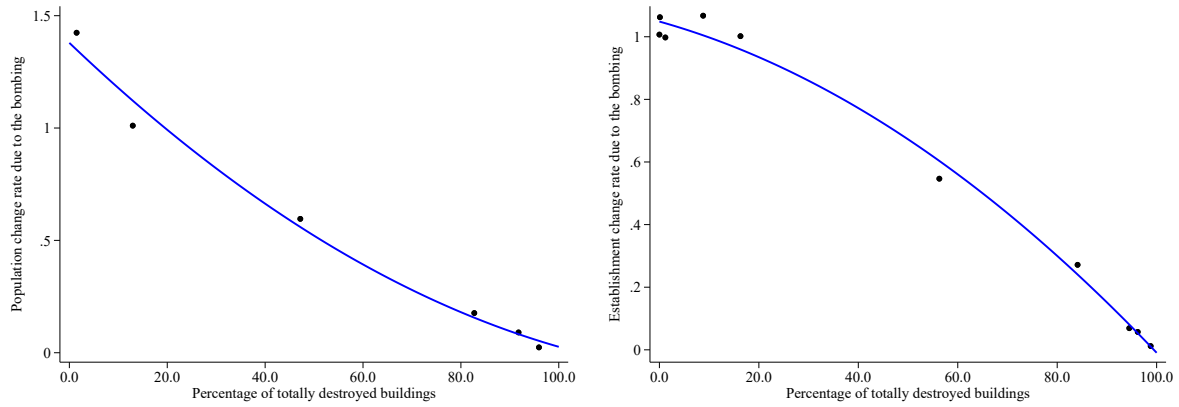
(a) Damage to Buildings

(b) Death Rate of People

Note: The left panel plots percentage of totally destroyed buildings by the atomic bombing in each block. The right panel plots percentage of people killed by the atomic bombing in each block. Source is Hiroshima City Government (1971).

[A.17]For the prime-aged people, this ratio in the densely-populated area of Hiroshima prefecture is around 7:10, implying that the annual migration rate is roughly 0.36.

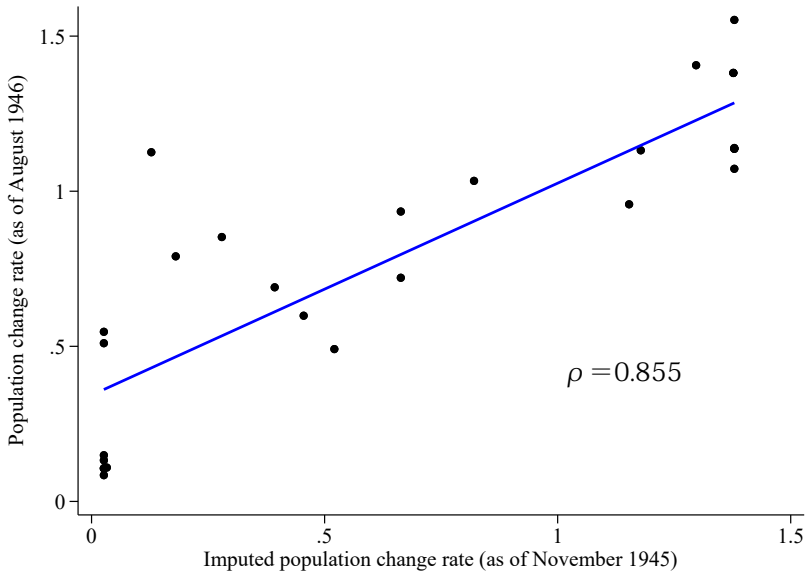
Figure A.2: The population and establishment change on the rate of totally-destroyed buildings



(a) Population change **(b)** Establishment change

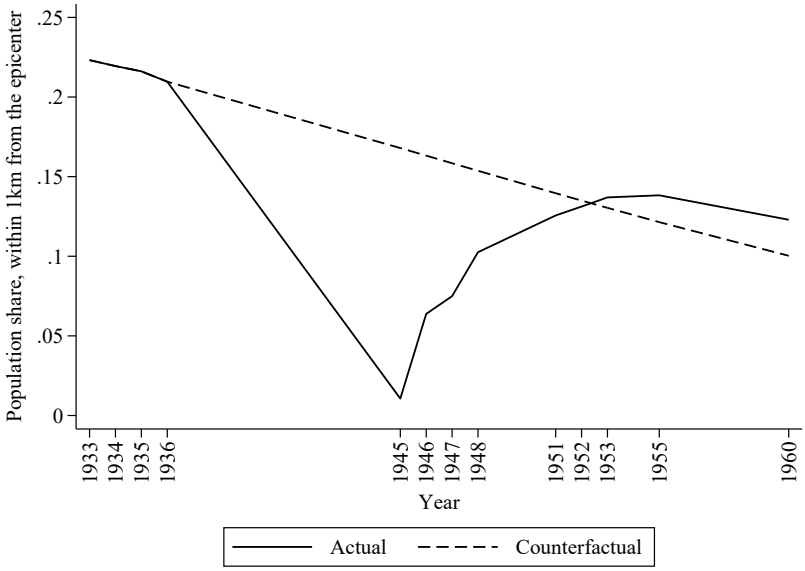
Note: The left panel shows the scatter plot of the percentage of totally destroyed buildings and the population change rate due to the bombing, for distance categories from the epicenter (within 1km, 1-1.5km, 1.5-2km, 2-2.5km, 2.5-3km, more than 3km away). The population change rate is taken from the 1946 Statistical Abstract of Hiroshima City and the destruction rate of each category is a population-weighted average of the block-level destruction rate from Hiroshima City Government (1971). The right panel shows the scatter plot of the percentage of totally destroyed buildings and the establishment change rate due to the bombing, for distance categories from the epicenter (0.5km grids up to 5km). The establishment change rate is taken from the 1946 Statistical Abstract of Hiroshima City and the destruction rate of each category is a establishment-weighted average of the block-level destruction rate from Hiroshima City Government (1971). In both panels, we fit the quadratic model and plot it.

Figure A.3: Validation of our 1945 population data with alternative population data in 1946



Note: We validate our method of imputing the 1945 population after the bombing using different population data taken from the 1946 edition of *Hiroshima shisei youran* at the school district level. On the horizontal axis, we show our predicted population change rate as of November 1945 based on the imputed destruction rate of buildings for each school district. On the vertical axis, we show the population change rate as of August 1946, taken from the data. We also plot a linear regression line. We obtain a very high correlation ($\rho \simeq 0.855$) between these two despite the data limitations that the population was measured at different timing and the potential measurement errors in imputing the destruction rate of buildings for the school district.

Figure A.4: Actual and counterfactual population share within 1km from the epicenter



Note: This figure shows the population share of areas within 1km from the epicenter of the atomic bombing. For 1945–1948, we observe the population in the Statistical Abstract of Hiroshima. For the remaining years, we aggregate the block-level population to the distance bins from the epicenter according to the definition of Hiroshima City Government (1971). The counterfactual population share extrapolates the pre-war linear trend to the post-WWII period, analogous to Figure 2 of Davis and Weinstein (2002).

Table A.1: Summary statistics

	Full sample			Within 3km from the CBD		
	mean	sd	count	mean	sd	count
Population 1936	1880	2153	174	1642	1103	158
Population 1936 per $1km^2$	23761	14104	174	25752	13138	158
Population 1945	917	2927	174	459	916	158
Population 1945 per $1km^2$	3566	5496	174	3374	5158	158
Population 1950	1495	2683	174	1026	1091	158
Population 1950 per $1km^2$	11877	6616	174	12583	6374	158
Population 1960	2215	3648	174	1537	1689	158
Population 1960 per $1km^2$	16725	8548	174	17737	8188	158
Population 1975	2625	5423	174	1501	2694	158
Population 1975 per $1km^2$	12758	5046	174	13065	4906	158
Employment 1938	978	835	174	949	626	158
Employment 1938 per $1km^2$	42517	41449	174	46512	41422	158
Employment 1945	405	1056	174	259	420	158
Employment 1945 per $1km^2$	5507	8035	174	5602	8072	158
Employment 1953	669	965	174	505	465	158
Employment 1953 per $1km^2$	7358	6083	174	7909	6099	158
Employment 1966	1277	1516	174	1060	792	158
Employment 1966 per $1km^2$	18499	17408	174	20111	17463	158
Employment 1975	1515	1880	174	1211	993	158
Employment 1975 per $1km^2$	21017	21948	174	22821	22243	158
Block area (km^2)	.321	.971	174	.132	.39	158
Distance to the CBD (km)	1.66	1.06	174	1.4	.652	158
Distance to the nearest station (m)	336	319	174	285	232	158
Distance to the nearest water area (m)	248	229	174	226	185	158
Distance to the nearest cultural asset (m)	808	637	174	684	412	158
Altitude (m)	5.91	14.4	174	4.25	7.56	158
Average slope (degree)	.814	2.4	174	.611	2.07	158
Dummy of bad soil condition	.96	.197	174	.981	.137	158
Latitude	34.4	.0104	174	34.4	.00917	158
Longitude	132	.0167	174	132	.0123	158
Annual population growth rate 1933–1936	1.03	.0355	174	1.03	.0344	158
Rate of total destroyed Building	74.5	35.4	174	81.1	29.8	158
Rate of half-damaged buildings	18.6	26	174	15.2	23.6	158
Rate of mildly-damaged buildings	6.65	17.7	174	3.38	12.1	158
Rate of intact building	.685	3.99	174	.316	1.66	158
Observations	174			158		

B Nagasaki

Throughout the paper, we focus on Hiroshima: the first city hit by the atomic bomb in our history. This section briefly discusses Nagasaki, the second and last city that experienced an atomic bombing as of the writing of this paper. We can compare Nagasaki with Hiroshima based on existing resources, despite a lack of detailed data for Nagasaki.

The case of Nagasaki is useful to distinguish the role of war-time destruction from the locational fundamentals because the atomic bomb hit a different part of the city. In Hiroshima, we have shown in Section 3 that central Hiroshima experienced a significant population decrease while the outskirts experienced a population increase because the atomic bomb hit the city center of Hiroshima. In contrast, as shown in the damage map of Nagasaki in Figure B.1, the atomic bomb hit the outskirts of the city of Nagasaki and the epicenter is more than 2 kilometers away from the city center. Consequently, the city center of Nagasaki, areas to the south-east of the Nagasaki station, was damaged relatively mildly. Some outskirts of Nagasaki experienced destruction and a decrease in population, while the center, which experienced less destruction, experienced an increase in population as people escaped *into* the center (Inami 1953). Therefore, in contrast to Hiroshima in which the monocentric city structure was reversed, the concentration in the center was augmented by the bombing in Nagasaki.

This contrasting pattern of the population change after the atomic bombing might allow us to distinguish between the importance of the destruction due to the bombing and the fundamental characteristics. If the destruction rate determines the post-war population growth, then the outskirts should experience a substantial increase in the population. In contrast, if being the (pre-war) city center is what matters in explaining the post-war population growth of central Hiroshima, then we would not expect the recovery of the pre-war population distribution in the outskirts of Nagasaki.

To investigate the post-war population growth in Nagasaki after the bombing, we use the population data in May 1945 (pre-bombing), October 1945 (post-bombing), and March 1954 at the school district level, taken from Nagasaki City Government (1983). Similar to the equation (1) in Section 3, we estimate the following equation:

$$\ln\left(\frac{\text{Popdens}_{i,1954}}{\text{Popdens}_{i,1945oct}}\right) = \gamma \ln\left(\frac{\text{Popdens}_{i,1945oct}}{\text{Popdens}_{i,1945may}}\right) + v_i. \tag{B.1}$$

The interpretation of γ is the same as equation (1): $\gamma = 0$ suggests the complete path dependence and $\gamma = -1$ suggests the complete path independence. The unit of observation is the school district i and there were 24 school districts.[B.1]

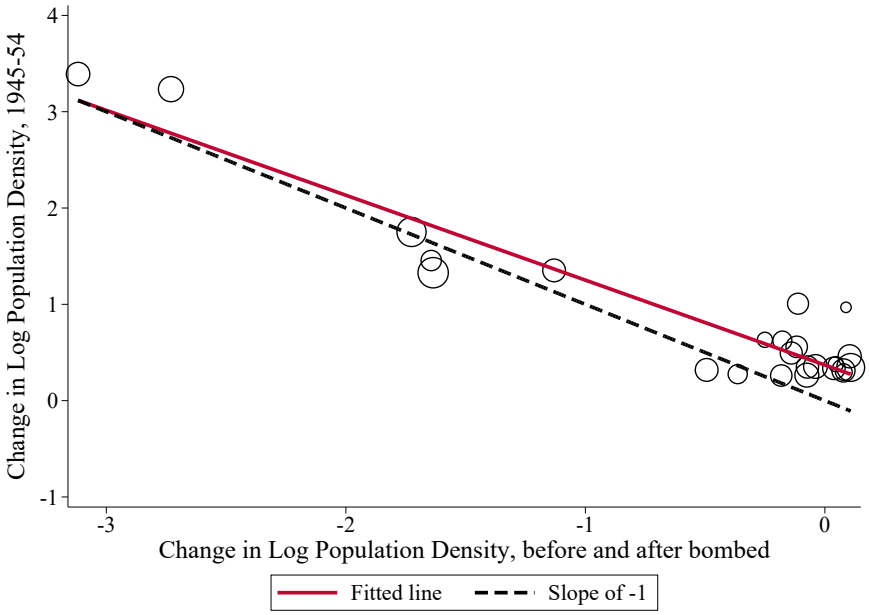
[B.1] Strictly speaking, we cannot calculate population density because we have no information on the size of each school district. However, this does not prevent us from implementing (B.1) as long as the size does not change throughout our sample period. We do not include control variables because Nagasaki City Government (1983) does not show a map of school districts and we could not collect precise locational characteristics.

Figure B.1: Map of Physical Damages Caused by the Atomic Bombing (Nagasaki)



Note: This map of Nagasaki shows the epicenter of the bombing in Nagasaki, as well as major facilities and the extent of the damages to structures. This map is provided by the Atomic Bomb Disease Institute, Nagasaki University.

Figure B.2: Change in Population Density (Nagasaki)



Note: The figures plot change in the log of population density from 1945 to 1954 to those from May 1945 to October 1945 in Nagasaki. Each circle represents a school district (i.e., an observation), where the size of the circle is proportional to the population density in May 1945. We plot the (unweighted) linear fit between these two variables (solid line) as well as the slope of -1 (dashed line).

Figure B.2 shows the estimation result. Despite the fact that the atomic bomb hit a different part of the city, the figure looks very similar to the case of Hiroshima in Figure 4. The estimated slope of the fitted line is -0.882 with a standard error 0.101. While we can strongly reject the null of $\gamma = 0$, we cannot reject the null of $\gamma = -1$ at the conventional level. Therefore, similar to Hiroshima, we obtain evidence of the path-independence within Nagasaki.

This evidence from Nagasaki suggests that the population distribution in the city would resemble the pre-war one, even if the atomic bomb hit a different place in the city. Combined with the result from Hiroshima, it is difficult to explain the recovery if it is driven by the fundamental advantages of the city center or the outskirts of the post-war Japanese cities. This underscores the importance of self-fulfilling expectations on the recovery, rather than the fundamental locational characteristics, to explain the recovery after the atomic bombing.

C Further Reduced-form Results

Employment. We repeat the same reduced-form analysis as Section 3 for employment data in 1938, 1945, and 1966. Figure C.1 shows the scatter plot of the log employment change rates in the same way as Figure 4 for population data. Similar to the population, we find that areas that experienced a significant decline in employment due to the bombing had a high employment growth rate in the post-war period. Moreover, the magnitude of this recovery is close to, albeit not exactly, the case of the complete path independence shown in the dashed line.

Table C.1 reports the regression results of the equation (1) for employment, in the same manner as Table 1 for population. Column 1 reports the result of the simple regression in Figure C.1. We find the coefficient around -0.86, which indicates a stronger recovery than the case of the population in Table 1 (around -0.7). Adding control variables, column 2 shows that the coefficient is now almost -1, i.e., the path independence. The path independence result after adding control variables is the same as the case of population. Finally, column 3 shows that focusing on blocks within 3km from the epicenter, which is expected to have more homogeneous locational characteristics, still implies path independence. This is again similar to the pattern in the case of the population in Table 1.

Table C.1: Change in employment density

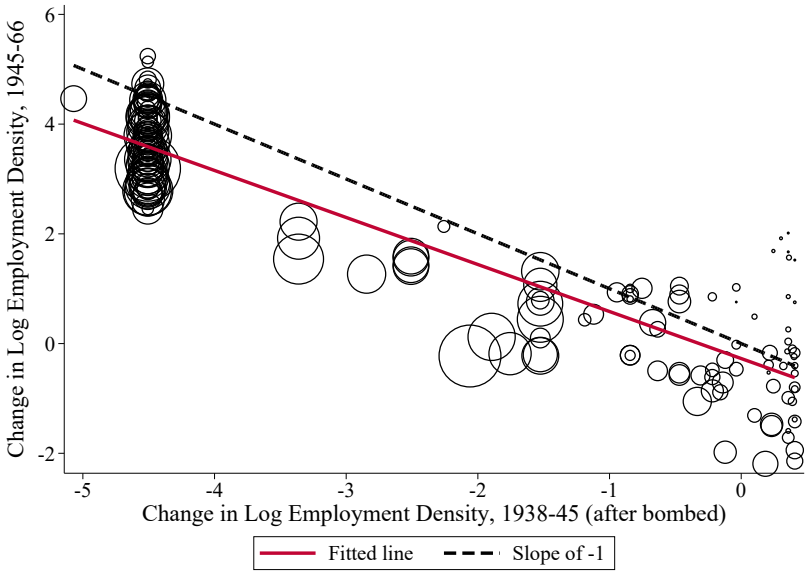
	(1)	(2)	(3)
	Change in log employment density 1945-66		
Change in log employment density 1938-45	-0.8571[a]	-0.9978[a]	-0.9420[a]
	(0.0324)	(0.0586)	(0.0642)
p-value from testing $\gamma = -1$	0.000	0.970	0.368
Control variables		✓	✓
Within 3km from the city center			✓
Number of blocks	174	174	158
R-squared	0.828	0.892	0.915

Robust standard errors in parentheses

[c] $p < 0.1$, [b] $p < 0.05$, [a] $p < 0.01$

Note: We report the OLS estimation result of the equation (1) for employment density. Fundamentals consist of the quadratic of the distance to the nearest station, the distance to the nearest cultural asset, the distance to the nearest water area, the altitude, and the slope. We also include a dummy for a bad soil condition. We also control for the quadratic of the pre-war (1933-1936) population growth rate, the fractions of the half-destroyed, moderately-destroyed, and intact buildings, and the geographical coordinates (the latitude, the longitude, and their interaction). In columns 3, we confine the sample to blocks within 3km from the city center, in which fundamental conditions are more homogeneous. We also test the null that $\gamma = -1$ (i.e., the complete path independence) and report its p-value.

Figure C.1: Change in employment density



Note: The figures plot the log employment change rate from 1945 to 1966 to log employment change rate from 1938 to 1945. Each circle represents a block (i.e., an observation), where the size of the circle is proportional to the employment density in 1938. We plot the (unweighted) linear fit between these two variables (solid line) as well as the slope of -1 (dashed line).

Public housing. To assess how much the recovery of central Hiroshima was driven by governmental policies, we explore the role of public housing, which was a primary policy target right after the war.

Table C.2: Units of public housing and distance to the CBD

	(1) Log units of public housing	(2) Units of public housing
Distance to the CBD	0.4491^{b}	0.7732^{a}
	(0.1889)	(0.1641)
Estimation method	OLS	PPML
Number of blocks	22	174
R-squared Pseudo R-squared	0.234	
Pseudo R-squared		0.268

Robust standard errors in parentheses
^{c} $p < 0.1$, ^{b} $p < 0.05$, ^{a} $p < 0.01$

Note: We investigate the relationship between public housing provision during 1946–1950 and the distance to the CBD. In column 1, we regress the log number of public housing units on the distance to the CBD. To deal with the issue that the log transformation forces us to drop blocks with zero public housing units, column 2 uses the Poisson regression model following Santos Silva and Tenreyro (2006)

In Table C.2, we investigate where the public housing was supplied. We find that public housings were more likely to be supplied in locations away from the CBD. In column 1, we estimate a simple linear regression of the log units of housing on the distance to the CBD and find a positive significant coefficient. However, public housing was supplied only in a limited set of blocks and hence many blocks had zero public housing units, but the log outcome variable forces us to drop such observations. To deal with this, in column 2, we adopt the Poisson Pseudo Maximum Likelihood (PPML) estimator suggested by Santos Silva and Tenreyro (2006). We actually find a large coefficient and so our conclusion is strengthened.

Thus, if any, public housing would relatively promote the growth of the outskirts of the city and does not contribute to the recovery of central Hiroshima. This can be formalized in a regression framework by controlling for the number of public housing units on top of our main reduced-form regressions in Table 1. Table C.3 reports the results, showing that controlling for public housing does not change our conclusion.

Table C.3: Change in population density (controlling for public housing)

	(1)	(2)	(3)
	change in log population density 1945-50		
Change in log population density 1936-45	-0.7270[a]	-0.9453[a]	-0.9839[a]
	(0.0270)	(0.0986)	(0.0992)
p-value from testing $\gamma = -1$	0.000	0.580	0.871
Control variables (other than public housing)		✓	✓
Within 3km from the city center			✓
Number of blocks	174	174	158
R-squared	0.816	0.866	0.880

Robust standard errors in parentheses
[c] $p < 0.1$, [b] $p < 0.05$, [a] $p < 0.01$

Note: We report the OLS estimation result of the equation (1) for population density, while controlling for the number of units of public housing in each block for all specifications. Fundamentals consist of the quadratic of the distance to the nearest station, the distance to the nearest cultural asset, the distance to the nearest water area, the altitude, and the slope. We also include a dummy for a bad soil condition. We also control for the quadratic of the pre-war (1933-1936) population growth rate, the fractions of the half-destroyed, moderately-destroyed, and intact buildings, and the geographical coordinates (the latitude, the longitude, and their interaction). In columns 3, we confine the sample to blocks within 3km from the city center, in which fundamental conditions are more homogeneous. We also test the null that $\gamma = -1$ (i.e., the complete path independence) and report its p-value.

D Theoretical Appendix

This section provides detailed derivations in the model.

D.1 Value function

When an individual ω is able to change the location choices, she solves the problem of location choice:

$$v_{int}(\omega) = \ln u_{int} + \max\left\{\rho V_{j\ell t+1} + \sigma\varepsilon_{j\ell t+1}\ ;\ \rho V_{ot+1} + \sigma\varepsilon_{ot+1}\right\} \tag{D.1}$$

The idiosyncratic taste shocks $\{\varepsilon_{j\ell t+1}, \varepsilon_{ot+1}\}$ are drawn from the time invariant independent Type I extreme distribution:

$$F(\varepsilon) = \exp(-\exp(-(\varepsilon+\Gamma))), \quad f(\varepsilon) = \exp(-(\varepsilon+\Gamma))F(\varepsilon)$$

where γ is Euler-Mascheroni constant: $\gamma \equiv -\int_0^\infty \ln x e^{-x} dx$. We have distribution functions:

$$G_{j\ell t+1}(s) = \text{Prob}[\rho V_{j\ell t+1} + \sigma\varepsilon_{j\ell t+1} \le s] = \exp\left(-\exp\left(-\left(\frac{s-\rho V_{j\ell t+1}}{\sigma} + \Gamma\right)\right)\right),$$
$$G_{ot+1}(s) = \text{Prob}[\rho V_{ot+1} + \sigma\varepsilon_{t+1} \le s] = \exp\left(-\exp\left(-\left(\frac{s-\rho V_{ot+1}}{\sigma} + \Gamma\right)\right)\right)$$

Therefore, $\rho V_{j\ell t+1} + \sigma\varepsilon_{j\ell t+1}$ follows Gumbel distribution with mean $\rho V_{j\ell t+1} - \sigma\gamma$ and scale parameter σ. The large value of σ leads to large variation. Let

$$V^*_{t+1} \equiv \max\left\{\rho V_{j\ell t+1} + \sigma\varepsilon_{j\ell t+1}\ ;\ \rho V_{ot+1} + \sigma\varepsilon_{ot+1}\right\}$$

Then, we have

$$H_{t+1}(s) = \text{Prob}[V^*_{t+1} \leq s] = \prod_{(j,\ell)} G_{j\ell t+1}(s) \times G_{ot+1}(s) \tag{D.2}$$

which corresponds to the maximum of the Gumbel random variables. It can be shown that this also follows the Gumbel distribution with mean

$$\mu_{t+1} = \mathbb{E}_{t+1}[s] = \sigma \ln\left(\sum_{(j,\ell)} \exp(V_{j\ell t+1})^{\rho/\sigma} + \exp(V_{ot+1})^{\rho/\sigma}\right)$$

Therefore, we have value functions:

$$\begin{aligned} V_{int} &= \ln u_{int} + (1-\theta_{t+1})\rho V_{int+1} + \theta_{t+1}\mu_{t+1}, \\ V_{ot} &= \ln u_{ot} + (1-\theta_{t+1})\rho V_{ot+1} + \theta_{t+1}\mu_{t+1}. \end{aligned} \tag{D.3}$$

D.2 Location choice

We transform the variable such that $z = \varepsilon + \gamma\sigma$. Suppose that an agent can switch the location. Then, the probability that an individual chooses location pair of workplace j and residential place ℓ in period $t+1$ is:

$$\lambda_{j\ell t+1} = \int_{-\infty}^{\infty} \left(\prod_{(j',\ell')} \exp\left(-e^{-\frac{1}{\sigma}\left(z+\rho V_{j\ell t+1} - \rho V_{j'\ell' t+1}\right)}\right) \exp\left(-e^{-\frac{1}{\sigma}\left(z+\rho V_{j\ell t+1} - \rho V_{ot+1}\right)}\right)\right) \frac{1}{\sigma} e^{-\frac{z}{\sigma}} dz$$

Letting $s = e^{-z/\sigma}$,

$$\begin{aligned} \lambda_{j\ell t+1} &= \int_0^{\infty} \exp\left(-s \sum_{\iota\in\{(j',\ell'),o\}} \exp\left(-\frac{1}{\sigma}\left(\rho V_{j\ell t+1} - \rho V_{\iota t+1}\right)\right)\right) ds \\ &= \left[\frac{\exp\left(-s\sum_{\iota\in\{(j',\ell'),o\}} \exp\left(-\frac{1}{\sigma}\left(\rho V_{j\ell t+1} - \rho V_{\iota t+1}\right)\right)\right)}{-\sum_{\iota\in\{(j',\ell'),o\}} \exp\left(-\frac{1}{\sigma}\left(\rho V_{j\ell t+1} - \rho V_{\iota t+1}\right)\right)}\right]_0^{\infty} \\ &= \frac{\exp(V_{j\ell t+1})^{\rho/\sigma}}{\sum_{\iota\in\{(j',\ell'),o\}} \exp(V_{\iota t+1})^{\rho/\sigma}} \end{aligned} \tag{D.4}$$

Analogously, the probability that workers live in outside of the city is:

$$\lambda_{ot+1} = \frac{\exp(V_{ot+1})^{\rho/\sigma}}{\sum_{\iota \in \{(j',\ell'),o\}} \exp(V_{\iota t+1})^{\rho/\sigma}} \tag{D.5}$$

An individual can change the residential place and workplace with the exogenous probability, $\theta_t \in (0,1)$. Using the probabilities of location choice, the mass of workers choosing location i as a workplace and location n as a residential place in period $t+1$ can be expressed by:

$$\begin{aligned} L_{int+1} &= (1-\theta_{t+1})L_{int} + \theta_{t+1}\lambda_{int+1}L_t + \theta_{t+1}\lambda_{int+1}(\mathcal{M} - L_t) \\ &= (1-\theta_{t+1})L_{int} + \theta_{t+1}\lambda_{int+1}\mathcal{M} \end{aligned} \tag{D.6}$$

We can use the same idea to derive the dynamics of population (11) and employment (12):

$$R_{nt+1} = \sum_{i \in \mathcal{C}} L_{int+1} = (1-\theta_{t+1})R_{nt} + \theta_{t+1}\sum_{i \in \mathcal{C}} \lambda_{int+1}\mathcal{M} \tag{D.7}$$

and

$$L_{it+1} = \sum_{n \in \mathcal{C}} L_{int+1} = (1-\theta_{t+1})L_{it} + \theta_{t+1}\sum_{n \in \mathcal{C}} \lambda_{int+1}\mathcal{M} \tag{D.8}$$

Total population in the city is

$$L_{t+1} = \sum_{(i,n) \in \mathcal{C}\times\mathcal{C}} L_{int+1} = (1-\theta_{t+1})L_t + \theta_{t+1}(1-\lambda_{ot+1})\mathcal{M} \tag{D.9}$$

D.3 Equilibrium

Let $\widetilde{V}_{int} = V_{int} - V_{ot}$ and $\widetilde{u}_{int} \equiv u_{int}/u_{ot}$. Bellman equation implies

$$\widetilde{V}_{int} = \ln \widetilde{u}_{int} + (1-\theta_{t+1})\rho \widetilde{V}_{int+1} \tag{D.10}$$

Iterating this, we obtain

$$\begin{aligned} \widetilde{V}_{int} &= \ln \widetilde{u}_{int} + \sum_{\tau=t+1}^{T} \rho^{\tau-t} \left(\prod_{s=t+1}^{\tau} (1-\theta_s) \right) \ln \widetilde{u}_{in\tau} \\ &= \ln \left(\widetilde{u}_{int} \prod_{\tau=t+1}^{T} \left(\widetilde{u}_{in\tau}\right)^{\rho^{\tau-t}\prod_{s=t+1}^{\tau}(1-\theta_s)} \right) \\ &= \ln \left(C_{int} L_{it}^{\alpha_1} L_{it-1}^{\alpha_2} R_{nt}^{\beta_1} R_{nt-1}^{\beta_2} \prod_{\tau=t+1}^{T} \left(C_{in\tau} L_{i\tau}^{\alpha_1} L_{i\tau-1}^{\alpha_2} R_{n\tau}^{\beta_1} R_{n\tau-1}^{\beta_2} \right)^{\rho^{\tau-t}\prod_{s=t+1}^{\tau}(1-\theta_s)} \right) \end{aligned} \tag{D.11}$$

where $C_{int} \equiv \frac{a_{it}b_{nt}}{S_i^{\alpha_1+\alpha_2}S_n^{\beta_1+\beta_2}}\kappa_{int}^{-1}u_{ot}^{-1} > 0$. The probability (D.4) can be expressed as

$$\lambda_{int} = \frac{\exp(\pi\widetilde{V}_{int})}{\sum_{j,\ell}\exp(\pi\widetilde{V}_{j\ell t})+1} \tag{D.12}$$

where $\pi = \rho/\sigma$. Therefore, we obtain population in location n:

$$R_{nt} = (1-\theta_t)R_{nt-1} + \theta_t\sum_i \frac{\exp(\pi\widetilde{V}_{int})}{\sum_{j,\ell}\exp(\pi\widetilde{V}_{j\ell t})+1}\mathcal{M} \tag{D.13}$$

and employment in location i:

$$L_{it} = (1-\theta_t)L_{it-1} + \theta_t\sum_n \frac{\exp(\pi\widetilde{V}_{int})}{\sum_{j,\ell}\exp(\pi\widetilde{V}_{j\ell t})+1}\mathcal{M} \tag{D.14}$$

The equilibrium is characterized by $\{R_{nt}, L_{it}\}$ solving (D.11), (D.13) and (D.14) jointly.

We show the existence of the forward-looking competitive equilibrium in which population and employment satisfy $R_{nt} \geq (1-\theta_t)R_{nt-1}$ and $L_{it} \geq (1-\theta_t)L_{it-1}$ given θ_t. To simplify the notation, we suppose $(1-\theta_t)\rho \to 0$. Yet, our following augment can be applied for the general case. When $(1-\theta_t)\rho \to 0$, the forward-looking equilibrium is characterized by $(\{R_{nt}\}, \{L_{it}\})$ solving the system of equations:

$$\begin{aligned}
R_{nt} &= (1-\theta_t)R_{nt-1} + \sum_i \frac{C_{int}^{\pi}R_{nt}^{\tilde{\beta}_1}R_{nt-1}^{\tilde{\beta}_2}}{\sum_\ell C_{i\ell t}^{\pi}R_{\ell t}^{\tilde{\beta}_1}R_{\ell t-1}^{\tilde{\beta}_2}}(L_{it} - (1-\theta_t)L_{it-1}), \\
L_{it} &= (1-\theta_t)L_{it-1} + \sum_n \frac{C_{int}^{\pi}L_{it}^{\tilde{\alpha}_1}L_{it-1}^{\tilde{\alpha}_2}}{\sum_j C_{jnt}^{\pi}L_{jt}^{\tilde{\alpha}_1}L_{jt-1}^{\tilde{\alpha}_2}}(R_{nt} - (1-\theta_t)R_{nt-1})
\end{aligned} \tag{D.15}$$

where $\tilde{\alpha}_1 \equiv \alpha_1\pi$, $\tilde{\alpha}_2 \equiv \alpha_2\pi$, $\tilde{\beta}_1 \equiv \beta_1\pi$ and $\tilde{\beta}_2 \equiv \beta_2\pi$.

We suppose that $R_{nt} \geq (1-\theta_t)R_{nt-1}$ and $L_{it} \geq (1-\theta_t)L_{it-1}$ for any $\{\theta_t\}$. Therefore, we characterize the equilibrium in which population and employment are increasing given the friction of mobility. This is in line with our quantification in the next section. Letting $\boldsymbol{z} = (\boldsymbol{R}, \boldsymbol{L})$ be a vector of population and employment and we define the operator $J(\boldsymbol{z})$ such that ι-th element $J_\iota(\boldsymbol{z})$ corresponds to the right-hand side of (D.15). When $R_{nt} \geq (1-\theta_t)R_{nt-1}$ and $L_{it} \geq (1-\theta_t)L_{it-1}$, we can define the convex subset of $\mathbb{R}_{++}^{2N}$ where the operator J is mapping from the subset to itself. The operator J is continuous mapping. Therefore, by Brouwer's fixed-point theorem, there exist forward-looking equilibrium such that they satisfy $R_{nt} \geq (1-\theta_t)R_{nt-1}$ and $L_{it} \geq (1-\theta_t)L_{it-1}$.

D.4 Steady state equilibrium

If the steady state equilibrium exists, it is stationary steady state where all variables in the model are not changing over time. In such stationary steady state, probabilities (D.4) can be written as:

$$\lambda_{in} = \widetilde{u}_{in}^{\pi} \bar{V}^{-1} = C_{in}^{\pi} L_i^{\tilde{\alpha}\pi} R_n^{\tilde{\beta}\pi} \bar{V}^{-1}, \tag{D.16}$$

where we let $\pi \equiv \rho/\sigma$, $\bar{V} \equiv \sum_{(j,\ell)} (\widetilde{u}_{j\ell})^{\pi} + 1$, $\tilde{\alpha} \equiv \alpha_1 + \alpha_2$ and $\tilde{\beta} \equiv \beta_1 + \beta_2$. The conditional probabilities that workers commute to i given residential place n become:

$$\lambda_{i|n}^{L} = \frac{\lambda_{in}}{\sum_{j \in \mathcal{C}} \lambda_{jn}} = \frac{\tilde{a}_{in} L_i^{\tilde{\alpha}\pi}}{\sum_{j \in \mathcal{C}} \tilde{a}_{jn} L_j^{\tilde{\alpha}\pi}} \tag{D.17}$$

where $\tilde{a}_{in} \equiv (\bar{a}_i/\kappa_{in})^{\pi} > 0$. Analogously the conditional probabilities that workers live in n given workplace i become:

$$\lambda_{n|i}^{R} = \frac{\lambda_{in}}{\sum_{\ell \in \mathcal{C}} \lambda_{i\ell}} = \frac{\tilde{b}_{in} R_n^{\tilde{\beta}\pi}}{\sum_{\ell \in \mathcal{C}} \tilde{b}_{i\ell} R_{\ell}^{\tilde{\beta}\pi}} \tag{D.18}$$

where $\tilde{b}_{in} \equiv (\bar{b}_n/\kappa_{in})^{\pi} > 0$.

Summarising, the steady state equilibrium is characterized by variables $\{R_n, L_i, \Phi_i, \mathrm{Y}_n\}$ solving the system of equations:

$$\begin{aligned} R_n^{1-\tilde{\beta}\pi} &= \sum_i \tilde{b}_{in} \Phi_i^{-1} L_i, \quad \Phi_i = \sum_n \tilde{b}_{in} R_n^{\tilde{\beta}\pi}, \\ L_i^{1-\tilde{\alpha}\pi} &= \sum_n \tilde{a}_{in} \mathrm{Y}_n^{-1} R_n, \quad \mathrm{Y}_n = \sum_i \tilde{a}_{in} L_i^{\tilde{\alpha}\pi} \end{aligned} \tag{D.19}$$

To exploit the result of Allen, Arkolakis and Li (2020), we consider the following matrix $\mathbf{C}$ and $\mathbf{D}$ that summarize the parameters from the left and right-hand sides of the system of equations, respectively:

$$\mathbf{C} = \begin{bmatrix} 1-\tilde{\beta}\pi & & & \\ & 1 & & \\ & & 1-\tilde{\alpha}\pi & \\ & & & 1 \end{bmatrix}, \quad \mathbf{D} = \begin{bmatrix} 0 & -1 & 1 & 0 \\ \tilde{\beta}\pi & 0 & 0 & 0 \\ 1 & 0 & 0 & -1 \\ 0 & 0 & \tilde{\alpha}\pi & 0 \end{bmatrix}$$

Matrix $\mathbf{C}$ is diagonal matrix and invertible when:

$$\alpha_1 + \alpha_2 \neq \frac{\sigma}{\rho}, \quad \beta_1 + \beta_2 \neq \frac{\sigma}{\rho} \tag{D.20}$$

and steady state equilibrium exists when these conditions are hold. Then, we define matrix $\mathbf{\Gamma} = |\mathbf{D}\mathbf{C}^{-1}|$. Using the results in Allen et al. (2020), the system of equations has a unique

up-to-scale solution if *all* eigenvalues of the matrix $\mathbf{\Gamma}$ are no larger than one. In our case the *sufficient* conditions for a unique up-to-scale solution are:

$$\frac{|\tilde{\beta}\pi| + 1}{|1 - \tilde{\beta}\pi|} \leq 1, \quad \frac{|\tilde{\alpha}\pi| + 1}{|1 - \tilde{\alpha}\pi|} \leq 1$$

These conditions are hold if and only if:

$$\tilde{\beta} = \beta_1 + \beta_2 \leq 0, \quad \tilde{\alpha} = \alpha_1 + \alpha_2 \leq 0 \tag{D.21}$$

The net agglomeration in productivity ($\alpha_1 + \alpha_2$) and net neighborhood externality in amenities ($\beta_1 + \beta_2$) are negative so that congestion force is dominating the agglomeration force in *both* workplace and residential place to ensure the unique up-to-scale solution. To see this intuitively, consider the special case of no net externalities: $\tilde{\alpha} = \tilde{\beta} = 0$. In this case, u_{in} in the steady state is constant so that the period utility of each workplace-residence pair is insensitive to the distribution of workers and residents. This problem is essentially a discrete-choice problem over alternatives whose utilities are constant, leading to the unique distribution of workers and residents. It turns out that this conclusion pertains in the presence of congestion forces.

The level of the solution is pinned down by the total population in the city, and we obtain a unique stationary steady state. We make two remarks. First, the sufficient condition in (D.21) holds under any bilateral commuting cost κ_{in} and the dispersion of idiosyncratic tastes σ. Second, (D.21) is just a sufficient condition for the uniqueness of the steady state and not necessary: the steady state can be unique in the presence of agglomeration economy, either in terms of productivity ($\tilde{\alpha}$) or residential amenities ($\tilde{\beta}$).

D.5 Microfoundations of productivity spillovers

In this section we present microfoundations of productivity spillovers.

D.5.1 Local production capital

Capital in final good production. The production function is given by

$$y_{it} = A_{it} k_{it}^{\nu_1} l_{it}, \quad \nu_1 \in (0, 1) \tag{D.22}$$

where k_{it} stands for local production capital (e.g., floor space) and ν_1 governs the decreasing returns to scale in its contribution to labor productivity. A_{it} is the productivity of location i, including contemporaneous agglomeration economies from employment density in period t, and firms take it as given. As in our main model in Section 4, we assume that the technology is linear in its labor, so that the equilibrium wage $w_{it} = A_{it} k_{it}^{\nu_1}$. Firms also choose their local

capital input taking its unit price r_{it} as given, leading to

$$r_{it} = \nu_1 A_{it} l_{it} k_{it}^{\nu_1 - 1} \tag{D.23}$$

Since the production technology is linear in labor, at this profit maximizing point, firms earn negative profits may stop operating if the cost of local capital is incurred by them. To simplify the discussion, we assume that firms do not exit, possibly because they receive a lump-sum transfer from the government or other sources that covers the cost of local capital. Alternatively, firms may earn positive profits in equilibrium and have no incentive to exit when they can exert a monopsonic power in the labor market and set a lower wage than the marginal revenue: $w_{it} = A_{it} k_{it}^{\nu_1} / (1 + m_{it})$, which is isomorphic to the perfect competition case with A_{it} multiplied by $1/(1 + m_{it})$.[D.1]

Local capital supply. Capital is supplied locally in each location. The production technology of the supplier is given by:

$$k_{it} = Q_{it} \left(\frac{n_{it}}{\nu_2} \right)^{\nu_2} \bar{S}_{it}^{1-\nu_2}, \quad \nu_2 \in (0, 1) \tag{D.24}$$

where Q_{it} is the efficiency of production of local capital, n_{it} is input of numeraire (final goods) and $\bar{S}_{it}$ is land used for business. The supplier of local capital decide input of numeraire given commercial land ($\bar{S}_{it}$). The local capital supplier bid for commercial land and absentee land owner extract all profit from the suppliers, implying that firms earn zero profit in equilibrium. Therefore, the first order conditions of profit maximization imply:

$$n_{it} = \nu_2 r_{it} k_{it} \tag{D.25}$$

Plugging (D.25) into (D.24), we obtain:

$$k_{it} = Q_{it}^{1/(1-\nu_2)} r_{it}^{\nu_2/(1-\nu_2)} \bar{S}_{it} \tag{D.26}$$

This is supply of capital in location i, and plugging (D.23) into this yields:

$$k_{it} = Q_{it}^{1/(1-\nu_1\nu_2)} (\nu_1 A_{it} l_{it})^{\nu_2/(1-\nu_1\nu_2)} \bar{S}_{it}^{(1-\nu_2)/(1-\nu_1\nu_2)} \tag{D.27}$$

We now specify how the efficiency of local capital supply (Q_{it}) and land allocation for commercial use ($\bar{S}_{it}$) are related to the employment of the previous period. First, efficiency is related to the infrastructure invested by the government. If infrastructure depreciates more when firms use it intensively in period $t-1$, while infrastructure increases more when the

[D.1] In particular, since the local labor supply curve has the iso-elastic form with elasticity ρ/σ when $\theta_t = 1$, m_{it} equals ρ/σ so that markup rate is constant and common across all locations.

government's investment is increasing based on production in period $t-1$. This time difference is intuitive since replacing infrastructure takes time. Then, we can argue

$$Q_{it} = \bar{Q}_i (L_{it-1})^{\psi_1},$$

where parameter ψ_1 can take positive or negative value and $\bar{Q}_i$ is time-invariant quality. Next, commercial land use is also related to a land allocation by government or absentee landowners based on economic activities in the previous period. Intuitively, more economic activities in period $t-1$ induce land allocation to business. On the other hand, land for commercial use can be negatively associated with employment in the previous period through lot size adjustment costs, as suggested by the empirical findings of Yamasaki, Nakajima and Teshima (2022). Intuitively, more workers in period $t-1$ may imply a smaller lot size and that increases development costs or adjustment costs of land for large-scale construction, limiting the efficient land allocation toward business. In sum, we can write:

$$\bar{S}_{it} = S_i (L_{it-1})^{\psi_2},$$

where S_i is land endowment and parameter ψ_2 can be negative or positive.

Equilibrium wages. Substituting these into the wage equation $w_{it} = A_{it} k_{it}^{\nu_1}$ yields:

$$w_{it} = \bar{A}_{it} (L_{it})^{\nu} (L_{it-1})^{\psi} (S_i)^{\eta}, \tag{D.28}$$

where $\bar{A}_{it} \equiv \nu_1^{\frac{\nu_1\nu_2}{1-\nu_1\nu_2}} A_{it}^{\frac{1}{1-\nu_1\nu_2}} \bar{Q}_i^{\frac{\nu_1}{1-\nu_1\nu_2}}$ and we let parameters

$$\nu = \frac{\nu_1\nu_2}{1-\nu_1\nu_2}, \quad \psi = \frac{\nu_1}{1-\nu_1\nu_2}\psi_1 + \frac{\nu_1(1-\nu_2)}{1-\nu_1\nu_2}\psi_2, \quad \eta = \frac{\nu_1(1-\nu_2)}{1-\nu_1\nu_2}$$

Manipulating this, we have:

$$w_{it} = \tilde{A}_{it} \left(\frac{L_{it}}{S_i}\right)^{\nu} \left(\frac{L_{it-1}}{S_i}\right)^{\psi}, \tag{D.29}$$

where $\tilde{A}_{it} = \bar{A}_{it} S_i^{\eta-\nu-\psi}$. The wage is increasing in current employment density (L_{it}/S_i) because more employment implies more local capital supply and it enhances labor productivity. The effect of previous employment density (L_{it-1}/S_i) depends on the sign of parameters (ψ_1, ψ_2). If both are negative, more past employment reduces productivity because it reduces the quality of public infrastructure through depreciation and the land supply for period t is reduced due to increased frictions. Assuming that the firm profit goes outside of the economy, the rest of the model behaves the same as our main model in Section 4 with A_{it} is given by the right-hand-side of (D.29).

D.5.2 Innovation by incumbent workers in local firms

The technology of final good producers is linear in labor, $y_{it} = A_{it}L_{it}$ where L_{it} is total employment. Productivity of firms in location i is determined by:

$$A_{it} = (\phi_{it} - \delta_A)(L_{it})^{\chi}\bar{A}_{t-1}, \tag{D.30}$$

which has three different components. First, productivity grows at rate $\phi_{it} - \delta_A$. ϕ_{it} is innovation between period $t-1$ and t and δ_A is obsolete rate of previous idea. Second, there is scale effects in innovation and parameter χ captures the return to employment size in knowledge spillovers. Third, all firms can access the productivity frontier of the last period, $\bar{A}_{t-1} = \max_i A_{it-1}$. In the following, we discuss how we determine innovation, ϕ_{it}.

The innovation ϕ_{it} is equal to the average units of a blueprint of innovators in location i. In period t, only incumbent workers who stay in the location from the period $t-1$ can do innovation since it requires experience in the local firms. Among workers in i at period t, incumbent workers who do not have an opportunity of moving are $(1-\theta_t)L_{it-1}$. Each incumbent workers have one unit of the blueprint of ideas at the end of period $t-1$, $\varphi_{it-1}^{Old} = 1$.

At the beginning of period t, *all* workers in location i draw new blueprints from Pareto distribution with support $[1,\infty)$. Specifically, units of blueprints are drawn from $1-\varphi^{-\varrho}$ and its average is $\frac{\varrho}{\varrho-1}$. Intuitively, all workers of L_{it} in location i including both incumbent and movers have new ideas relative to the incumbent ideas, and they acquire the average size of innovating ideas $\varphi_{it}^{New} = \frac{\varrho}{\varrho-1}$.

Incumbent workers of $(1-\theta_t)L_{it-1}$ can update their ideas or keep their obsolete ideas. To update their ideas, they need to meet workers who draw new ideas (i.e., all workers who have more than one unit of blueprints in period t), and their matching function is given by:

$$\mathcal{P}((1-\theta_t)L_{it-1}, L_{it}) = z_{it}((1-\theta_t)L_{it-1})^{\varpi}(L_{it})^{\varpi_2}, \tag{D.31}$$

where z_{it} controls matching efficiency and parameters are $\varpi_1 \in (0,1)$ and $\varpi_2 \in (0,1)$ as in standard matching function. Then, the share of incumbent workers who update their blueprints is:

$$s_{it}^{New} = \frac{\mathcal{P}((1-\theta_t)L_{it-1}, L_{it})}{(1-\theta_t)L_{it-1}} = z_{it}((1-\theta_t)L_{it-1})^{\varpi_1-1}(L_{it})^{\varpi_2} \tag{D.32}$$

Then, the average units of blueprints per incumbent worker become:

$$\phi_{it} = s_{it}^{New}\varphi_{it}^{New} + (1-s_{it}^{New})\varphi_{it-1}^{Old} = 1 + \frac{z_{it}}{\varrho-1}((1-\theta_t)L_{it-1})^{\varpi_1-1}(L_{it})^{\varpi_2} \tag{D.33}$$

Plugging this into (D.30) and setting $\delta_A = 1$, we obtain productivity in location i:

$$A_{it} = \frac{z_{it}}{\varrho-1}((1-\theta_t)L_{it-1})^{\varpi_1-1}(L_{it})^{\varpi_2+\chi}\bar{A}_{t-1} \tag{D.34}$$

Productivity depends on matching efficiency (z_{it}), the number of incumbent workers who have blueprints for innovation, a mass of workers in period t and the technology frontier in the previous period ($\bar{A}_{t-1}$). In particular, this is decreasing in the number of incumbent workers since they are imperfectly updating their obsolete blueprints and more incumbent workers lead to a small share of updating their blueprints. In contrast, this is increasing in the current number of workers since more workers lead to a large number of matching for updating blueprints of incumbent workers and directly increase productivity through scale effects. Lastly, matching efficiency can absorb any characteristics in location i. Among them, it is natural to assume that a small area is associated with higher matching efficiency. Therefore, we can write the right-hand side of (D.34) as a function of employment density.

D.6 Microfoundation of amenity spillovers

Consider supply of local amenities. In each location there are homogeneous absentee landlords and each of them own unit of land and develop local amenities including housing and other general amenities on the unit of land. In location n they solve:

$$\max_{C_{nt}, C_{nt+1}, x_{nt+1}} u(C_{nt}) + \rho u(C_{nt+1}) \tag{D.35}$$

subject to

$$\begin{aligned} h_{nt+1} &\leq \left(\frac{(1-\varsigma_n)h_{nt}}{\eta}\right)^{\eta} \left(\frac{X_{nt+1}}{1-\eta}\right)^{1-\eta} \\ C_{nt} + \frac{C_{nt+1}}{1+r_{t+1}} &+ \mathcal{O}(x_{nt+1}, h_{nt})h_{nt} \leq \frac{Q_{nt+1}h_{nt+1}}{1+r_{t+1}} \end{aligned} \tag{D.36}$$

$u(\cdot)$ is concave function such that CRRA utility function and log utility. The stock of amenities in the unit of land at period t is h_{nt}. The landlords live for two periods and choose consumption and investment in the first period (x_{nt+1}). In the budget constraint investing x_{nt+1} units of numeraire requires adjustment costs $\mathcal{O}(x_{nt+1}, h_{nt})$ per unit of current stock of housing. Specifically, we posit the function for the investment and adjustment costs:

$$\mathcal{O}(x_{nt+1}, h_{nt}) = \left(\frac{x_{nt+1}}{\psi h_{nt}}\right)^{\psi}, \tag{D.37}$$

where we assume that $\psi > 1$ therefore the investment costs are convex function of investment. This is a traditional functional form of investment costs in macroeconomics (see, for example Baxter and Crucini 1993). The production technology is decreasing return to investment, $\eta \in (0,1)$. Q_{nt} refers value of amenities in period t relative to consumption goods.

First, we suppose that $(1+r_{t+1})\rho = 1$ and consumption is constant over time. Let ξ_H and ξ_X refer Lagrangian multiplier corresponding to the constraints, respectively. First order

conditions for the problem imply:

$$\frac{\xi_X}{\xi_H} = \frac{1}{\rho Q_{nt+1}} = (1-\eta)\frac{h_{nt+1}}{x_{nt+1}}\left(\frac{x_{nt+1}}{\psi h_{nt}}\right)^{1-\psi} \tag{D.38}$$

Then, we obtain:

$$Q_{nt+1} \propto h_{nt+1}^{\frac{\psi}{1-\eta}-1} h_{nt}^{-\frac{\psi\eta}{1-\eta}-(\psi-1)} \tag{D.39}$$

We suppose that each household require one unit of amenities. Therefore, in equilibrium, the total mass of amenities are $H_{nt+1} = R_{nt+1}$ and $H_{nt} = R_{nt}$. Then, we can express the value of amenities in n at period $t+1$ by:

$$Q_{nt+1} \propto \left(\frac{R_{nt+1}}{S_n}\right)^{\frac{\psi}{1-\eta}-1}\left(\frac{R_{nt}}{S_n}\right)^{-\frac{\psi\eta}{1-\eta}-(\psi-1)}. \tag{D.40}$$

This is increasing in population density in period $t+1$ due to congestion in housing market. In contrast, the price is decreasing in population density in period t. Intuitively, the large stock of housing in period t leads to a lower marginal cost of investment in period $t+1$. This turns to be the positive spillover effects of current population density (R_{nt}/S_n) on the benefit from the local amenities.

This microfoundation predicts $\beta_2 > 0$, which we find in Section 5. In contrast, this microfoundation predicts $\beta_1 < 0$ while we empirically find $\beta_1 > 0$ in Section 5. We think $\beta_1 > 0$ in our data captures agglomeration economies not included in this microfoundation, such as the variety expansion of goods and residential amenities (e.g., safety). Studies (e.g., Tsivanidis 2022) also find the substantial improvement in residential amenities by high population density.

E Estimation

In the model we have following parameters: the set of fundamental parameters is (α_1, α_2, β_1, β_2, σ, ρ), time-varying parameters of labor mobility $\{\theta_t, u_{ot}\}$, location-specific unobserved characteristics $\{a_{it}, b_{nt}\}$ and frictions $\{\kappa_{int}\}$. We follow multiple steps to estimate these structural parameters.

E.1 Calibration procedure

Step # 1: Gravity Equation for Commuting

In the steady state, the mass of commuters from n to i in a city is

$$L_{in} = \lambda_{in}\mathcal{M} \propto \left(\frac{\bar{a}_i \bar{b}_n}{\kappa_{in}} L_i^{\alpha_1+\alpha_2} R_n^{\beta_1+\beta_2}\right)^{\pi} \mathcal{M} \tag{E.1}$$

This gravity equation holds once the economy reaches the stationary steady state equilibrium because the commuting pattern in previous periods is the same as the current commuting pattern.

We introduce the following parametrization of the bilateral commuting costs: $\kappa_{in} = e^{\delta D_{in}}$, where D_{in} is observed bilateral resistance and $\delta \in (0, \infty)$ is commuting cost elasticity. In the steady state, the equilibrium commuting flow from n to i within a city becomes:

$$L_{in} = \lambda_{i|n}^{L} R_n = \frac{w_i^{\pi} e^{-\pi\delta D_{in}}}{\sum_j w_j^{\pi} e^{-\pi\delta D_{jn}}} R_n \tag{E.2}$$

Manipulating this, we obtain the gravity equation for commuting in the steady state:

$$\ln L_{in} = -\delta\pi D_{in} + \mathbb{W}_i + \mathbb{H}_n \tag{E.3}$$

where $\mathbb{W}_i$ and $\mathbb{H}_n$ are:

$$\mathbb{W}_i \equiv \pi \ln w_i, \quad \mathbb{H}_n \equiv \ln \frac{R_n}{\sum_j w_j^{\pi} e^{-\pi\delta D_{jn}}} \tag{E.4}$$

In turn, we estimate the following gravity equation:

$$\ln L_{in} = -\delta\pi D_{in} + \mathbb{W}_i + \mathbb{H}_n + \nu_{in}, \tag{E.5}$$

where ν_{in} is the idiosyncratic error term and we replace $\mathbb{W}_i$ and $\mathbb{H}_n$ by residential place and workplace indicators. We use D_{in} measured by the straight line distance between block i and n. See Table 2 in main text for estimation results.

Step # 2: Back Out Continuation Value of Productivity and Amenities

The probability of location choices (D.12) becomes: $\lambda_{int} = \lambda_{ot} \exp(\pi \widetilde{V}_{int})$. Then, (D.13) and (D.14) can be expressed by:

$$R_{nt} - (1-\theta_t) R_{nt-1} = \lambda_{ot}\theta_t \left(\sum_i \exp(\pi \widetilde{V}_{int}) \right) \mathcal{M} \tag{E.6}$$

$$L_{it} - (1-\theta_t) L_{it-1} = \lambda_{ot}\theta_t \left(\sum_n \exp(\pi \widetilde{V}_{int}) \right) \mathcal{M} \tag{E.7}$$

We also use following notations for the values of outside option:

$$v_t = (u_{ot})^{-\pi} \prod_{\tau=t+1}^{T} (u_{o\tau})^{-\pi \prod_{s=t+1}^{\tau}(1-\theta_s)}, \tag{E.8}$$

and the values of commuting costs:

$$K_{int} = (\kappa_{int})^{-\pi} \prod_{\tau=t+1}^{T} \kappa_{in\tau}^{-\pi\rho^{\tau-t}\prod_{s=t+1}^{\tau}(1-\theta_s)} \tag{E.9}$$

Our focus in this step is to back out the continuation value of amenities and productivity:

$$\Xi_{nt} = (b_{nt} r_{nt}^{\beta_1} r_{nt-1}^{\beta_2}) \prod_{\tau=t+1}^{T} (b_{n\tau} r_{n\tau}^{\beta_1} r_{n\tau-1}^{\beta_2})^{\rho^{\tau-t}\prod_{s=t+1}^{\tau}(1-\theta_s)} \tag{E.10}$$

$$\Omega_{it} = (a_{it} l_{it}^{\alpha_1} l_{it-1}^{\alpha_2}) \prod_{\tau=t+1}^{T} (a_{i\tau} l_{i,\tau}^{\alpha_1} l_{i\tau-1}^{\alpha_2})^{\rho^{\tau-t}\prod_{s=t+1}^{\tau}(1-\theta_s)} \tag{E.11}$$

Then, (E.6) and (E.7) become:

$$R_{nt} - (1-\theta_t) R_{nt-1} = \lambda_{ot}\theta_t v_t \mathcal{M} \Xi_{nt}^{\pi} \sum_{i \in \mathcal{C}} K_{int} \Omega_{it}^{\pi}, \tag{E.12}$$

$$L_{it} - (1-\theta_t) L_{it-1} = \lambda_{ot}\theta_t v_t \mathcal{M} \Omega_{it}^{\pi} \sum_{n \in \mathcal{C}} K_{int} \Xi_{nt}^{\pi}. \tag{E.13}$$

Substituting (E.13) into (E.12) yields:

$$R_{nt} - (1-\theta_t) R_{nt-1} = \sum_i \frac{K_{int}\Xi_{nt}^{\pi}}{\sum_j K_{ijt}\Xi_{jt}^{\pi}} \left(L_{it} - (1-\theta_t) L_{it-1}\right) \tag{E.14}$$

Analogously, we obtain

$$L_{it} - (1-\theta_t) L_{it-1} = \sum_n \frac{K_{int}\Omega_{it}^{\pi}}{\sum_j K_{jnt}\Omega_{jt}^{\pi}} \left(R_{nt} - (1-\theta_t) R_{nt-1}\right) \tag{E.15}$$

Solving (E.14) and (E.15) together conditional on observations of population and employment $\{R_{nt}, L_{it}\}$ and parameter $\{\theta_t\}$, we obtain $\{\Xi_{nt}, \Omega_{it}\}$. Given $\rho/\sigma > 0$, this system of equations is solved for unique solutions $\{\Xi_{nt}, \Omega_{it}\}$ up to scale if $L_{it} - (1-\theta_t) L_{it-1} \geq 0$ and $R_{nt} - (1-\theta_t) R_{nt-1} \geq 0$ hold. This step does not require the parameter values of agglomeration.

Step # 3: Estimation of Parameters $(\alpha_1, \alpha_2, \beta_1, \beta_2)$

Step 2 derive $\{\Xi_{nt}, \Omega_{it}\}$ consistent with observed data to be an equilibrium given value of $\{\theta_t\}$. By construction, in the last period T

$$\Xi_{nT} = b_{nT} r_{nT}^{\beta_1} r_{nT-1}^{\beta_2} \tag{E.16}$$

Given the population density $\{r_{nT}, r_{nT-1}\}$ and parameters (α_1, α_2, β_1, β_2), inversion of this leads to fundamental amenities $\{b_{nT}\}$. In period $T-1$ we have:

$$\Xi_{nT-1} = b_{nT-1} r_{nT-1}^{\beta_1} r_{nT-2}^{\beta_2} \Xi_{nT}^{\rho(1-\theta_T)} = b_{nT-1} r_{nT-1}^{\beta_1} r_{nT-2}^{\beta_2} \left(b_{nT} r_{nT}^{\beta_1} r_{nT-1}^{\beta_2}\right)^{\rho(1-\theta_T)} \tag{E.17}$$

Given population density, parameter ρ, θ_T and fundamental amenities $\{b_{nT}\}$, we can invert this for the fundamental amenities in previous period $\{b_{nT-1}\}$. We continue this process and obtain the sequence of fundamental amenities: $\{b_{nt}\}_{t=2,\cdots,T}$. For the productivity, we can decompose $\{\Omega_{it}\}_{t=1,2,\cdots,T}$ to obtain the sequence of fundamental productivity $\{a_{it}\}_{t=2,\cdots,T}$.

The fundamental amenities and productivity ($\{a_{it}\}$, $\{b_{nt}\}$) are uniquely given. These fundamentals are structural residuals in our calibration for the observation to be equilibrium. We assume that the fundamentals consist of location fixed components, time fixed components and variant term:

$$\ln a_{it} = \ln a_i^F + \ln a_t^* + \ln a_{it}^{\text{Var}}, \quad \ln b_{nt} = \ln b_n^F + \ln b_t^* + \ln b_{nt}^{\text{Var}}$$

where ($\{a_i^F\}$, $\{b_n^F\}$) are location fixed productivity and amenities, ($\{a_t^*\}$, $\{b_t^*\}$) are trend of productivity and amenities and ($\{a_{it}^{\text{Var}}\}$, $\{b_{nt}^{\text{Var}}\}$) are stochastic part of fundamental productivity and amenities. The location fixed productivity and amenities capture the first nature advantages of locations and trend of productivity and amenities reflect the change in levels over time. Averaging out the trend yields:

$$\begin{aligned}
\ln \tilde{a}_{it} &\equiv \ln a_{it} - \frac{1}{N}\sum_i \ln a_{it} = \ln \tilde{a}_i^F + \ln \tilde{a}_{it}^{\text{Var}}, \\
\ln \tilde{b}_{nt} &\equiv \ln b_{nt} - \frac{1}{N}\sum_n \ln b_{nt} = \ln \tilde{b}_n^F + \ln \tilde{b}_{nt}^{\text{Var}},
\end{aligned}$$

where $\tilde{a}_i^F \equiv a_i^F / \bar{a}^F$, $\tilde{b}_n^F \equiv b_n^F / \bar{b}^F$, $\tilde{a}_{it}^{\text{Var}} \equiv a_{it}^{\text{Var}} / \bar{a}_t^{\text{Var}}$ and $\tilde{b}_{nt}^{\text{Var}} \equiv b_{nt}^{\text{Var}} / \bar{b}_t^{\text{Var}}$ are variables adjusted with geometric mean. Then, taking the difference between periods and we suppose the following moment conditions:

$$\begin{aligned}
&\mathbb{E}\left[\Delta \ln \tilde{a}_{it} \times \mathbb{1}_i(k)\right] = 0, \\
&\mathbb{E}\left[\Delta \ln \tilde{b}_{nt} \times \mathbb{1}_n(k)\right] = 0,
\end{aligned} \tag{E.18}$$

where $\Delta \ln \tilde{a}_{it} = \Delta \ln \tilde{a}_{it}^{\text{Var}}$ and $\Delta \ln \tilde{b}_{nt} = \Delta \ln \tilde{b}_{nt}^{\text{Var}}$ are change in the idiosyncratic shocks in productivity and amenities between period $t-1$ and t and $\mathbb{1}_n(k)$ is an indicator such that location n is in the grid k.

The grid is defined based on the distance from CBD as in Ahlfeldt et al. (2015). Our identification assumption is that any improvements or declines in the stochastic shocks over any six years period are unrelated to the distance from the city center. We use the moment conditions

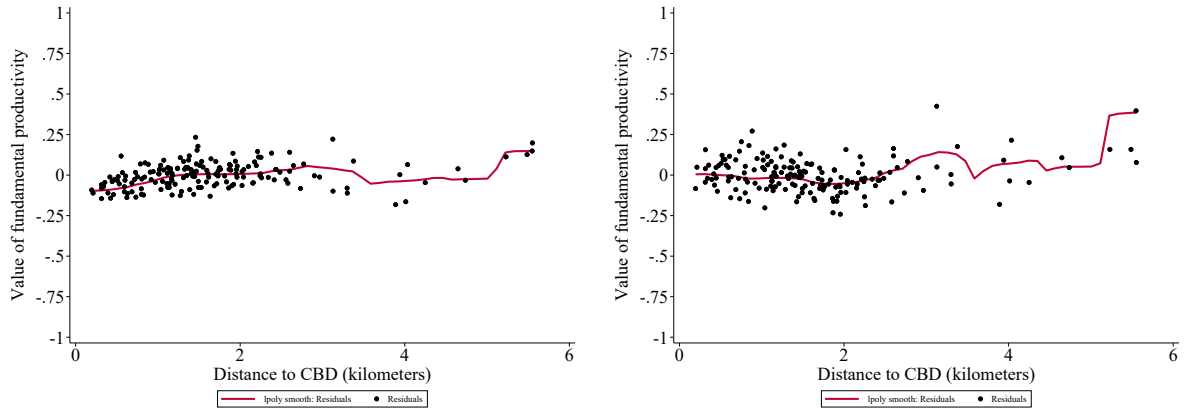
(E.18) to estimate the set of parameters of agglomeration economies (α_1, α_2, β_1, β_2).

E.2 Calibrated amenities and productivities

In this section, we present additional discussions on the amenities and productivity in our calibrated model. Figure E.1 presents the estimated location-specific amenities and productivity adjusted for the block size. Specifically, we regress our estimate of the log of the location-specific productivity and amenities on the log area size, and we plot the residuals of the regressions. Figure E.1a shows the result for productivity and Figure E.1b shows the result for amenities. It shows that both are not strongly related with the distance from the CBD, which is in contrast to Figure 5 showing that productivity and amenities are lower in areas closer to the CBD. Therefore, the lower fundamental values of areas around the city center in Figure 5 may be an artifact of the smaller block size around the center. As discussed in footnote 45, other things being equal, a smaller block is likely to have higher population and employment density because the idiosyncratic preferences in our model is i.i.d. irrespective of the block size. Thus, the location-specific productivity and amenities may be smaller in smaller blocks to offset such a small-block advantage.

To graphically illustrate the changes in residuals of fundamental amenities ($\Delta \ln \tilde{b}_{nt}$) and productivity ($\Delta \ln \tilde{a}_{it}$) in the city, Figure E.2a displays the changes in residuals of fundamental amenities for different periods, 1955-60 and 1965-70. During the early period, the changes are show small variation across locations in the city and this confirms that the idiosyncratic part of the fundamental location advantages in amenities is less important to explain the population changes during this period. In the later period, 1965-70, we observe that the residuals increase their values in the area close to CBD while drop in the periphery. This is consistent with the suburbanization that proceeds not because of the fundamental locational advantages in the periphery but expectation of the change in population move toward the periphery. Figure E.2b presents the changes in residuals of productivity. Compared to those of amenities, their variation is relatively small in the city for both periods. This implies that idiosyncratic shocks in fundamental productivity do not account for the variation of employment distribution in the city and this is reassuring for our identification assumption.

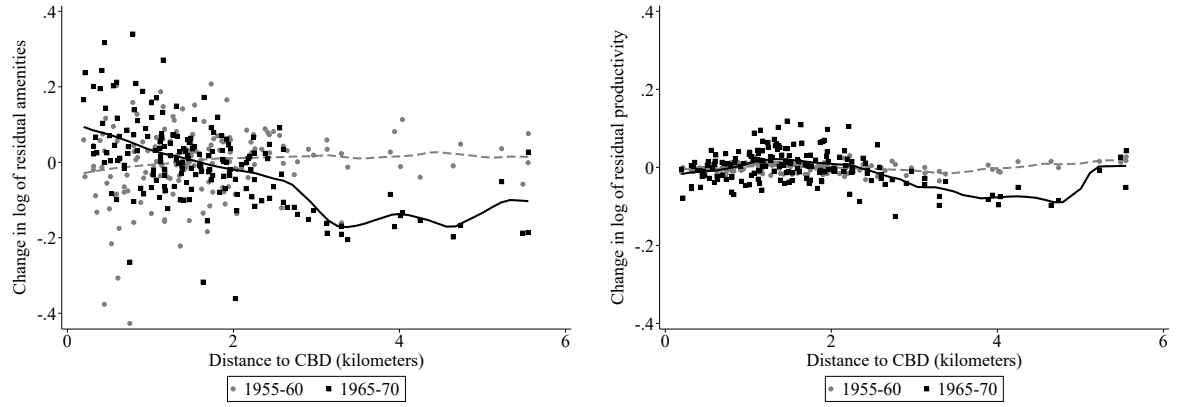
Figure E.1: Fundamental productivity and amenities (accounting for block size heterogeneity)



(a) Productivity **(b)** Amenities

Note: These figures display fundamental productivity ($\bar{a}_i$) and amenities ($\bar{b}_n$) in our calibration, after netting out the block size using the residual of the linear regression of the fundamentals on the block size. Each line shows a local polynomial fitted line for them.

Figure E.2: The population and establishment change on the rate of totally-destroyed buildings



(a) Change in fundamental amenities **(b)** Change in fundamental productivity

Note: These figures show change in fundamental amenities ($\Delta \ln \tilde{b}_{nt}$) and productivity ($\Delta \ln \tilde{a}_{it}$) for two periods, 1955-60 and 1965-70. Each point represents different blocks and lines are local polynomial regressions.

E.3 Evaluating the recovery in 1945-50

Having estimated model parameters (α_1, α_2, β_1, β_2) by exploiting the data from 1950 to 1975, we can evaluate how much the model explains the population and employment change from 1945 to 1950 after the atomic bombing. Although our model can be perfectly fitted to the data by using the structural residuals, but the model better explains the recovery during the period 1945–50 when our calibration results for the period rely less on the structural residuals. To

evaluate the model's performance, we consider the following steps which share the basic ideas in our model inversion.

Step 1. Using the data on population and employment $(R_{nt}, R_{nt-1}, L_{it}, L_{it-1})$ for $t = 1950$ (period 1) and $t-1 = 1945$ (period 0), we solve the following $2N$ equations to obtain $(\Xi_{n,50}, \Omega_{i,50})$ for the year 1950:

$$\begin{aligned} R_{n,50} - (1-\theta_{50})R_{n,45} &= \sum_i \frac{K_{in,50}\Xi_{n,50}^{\rho/\sigma}}{\sum_j K_{ij,50}\Xi_{j,50}^{\rho/\sigma}}\left(L_{i,50} - (1-\theta_{50})L_{i,45}\right) \\ L_{i,50} - (1-\theta_{50})L_{i,45} &= \sum_n \frac{K_{in,50}\Omega_{i,50}^{\rho/\sigma}}{\sum_j K_{jn,50}\Omega_{j,50}^{\rho/\sigma}}\left(R_{n,50} - (1-\theta_{50})R_{n,45}\right). \end{aligned} \tag{E.19}$$

The inverted $(\Xi_{n,50}, \Omega_{i,50})$ provide the attractiveness of residence and workplace that perfectly rationalizes the observed recovery pattern from 1945 to 1950.

Step 2. Suppose that the forward-looking migration describes the recovery data. Then, the inverted value of $(\Xi_{n,50}, \Omega_{i,50})$ are decomposed into:

$$\begin{aligned} \Xi_{n,50} &= b_{n,50}^f \left(\frac{R_{n,50}}{S_n}\right)^{\beta_1} \left(\frac{R_{n,45}}{S_n}\right)^{\beta_2} \Xi_{n,55}^{\rho(1-\theta_{55})}, \\ \Omega_{i,50} &= a_{i,50}^f \left(\frac{L_{i,50}}{S_i}\right)^{\alpha_1} \left(\frac{L_{i,45}}{S_i}\right)^{\alpha_2} \Omega_{i,55}^{\rho(1-\theta_{55})}, \end{aligned} \tag{E.20}$$

where $(\Xi_{n,55}, \Omega_{i,55})$ are continuation values of the attractiveness and they are computed in the estimation part. This is a decomposition of $\Xi_{n,50}$ into (i) endogenous spillovers $(R_{n,50}/S_n)^{\beta_1}(R_{n,45}/S_n)^{\beta_2}$ from population density in 1950 and 1945, (ii) the option value associated with the location n $(\Xi_{n,55}^{\rho(1-\theta_{55})})$, and (iii) the location-specific amenities $b_{n,50}^f$ in the recovery period. Note that the location-specific amenities $b_{n,50}^f$ can be adjusted flexibly to make this equality to always hold. The analogous argument holds for $\{\Omega_{i,50}\}$. Since we assume that the forward-looking model perfectly matches data, we use the observed population and employment in 1945 and 1950 $(R_{n,50}, R_{n,45}, L_{i,50}, L_{i,45})$, implying that the potential multiplicity of equilibrium is not an issue in these steps of the inversion and decomposition.

Step 3. Suppose that the exogenous advantage in 1950 can be decomposed into

$$\ln b_{n,50}^f = \ln \bar{b}_n + \ln b_{n,50}^{\text{Var},f}, \quad \ln a_{n,50}^f = \ln \bar{a}_n + \ln a_{n,50}^{\text{Var},f}$$

where $(\bar{b}_n, \bar{a}_n)$ reflect the (estimated) fixed amenities and productivity and $(b_{n,50}^{\text{Var},f}, a_{n,50}^{\text{Var},f})$ are the structural errors. For the fixed advantages $(\bar{b}_n, \bar{a}_n)$, we use the average value of fundamentals during 1950 and 1975 and we obtain the structural errors $(b_{n,50}^{\text{Var},f}, a_{n,50}^{\text{Var},f})$ that affects the

advantages during 1945-50.

Step 4. We consider the following regression equations:

$$\begin{aligned} \ln \Xi_{n,50} &= \psi_b^f \ln \widetilde{\Xi}_{n,50}^f + \ln b_{n,50}^{\text{Var},f}, \\ \ln \Omega_{i,50} &= \psi_a^f \ln \widetilde{\Omega}_{i,50}^f + \ln a_{i,50}^{\text{Var},f}, \end{aligned} \tag{E.21}$$

where $\widetilde{\Xi}_{n,50}^f = \bar{b}_n^f \left(\frac{R_{n,50}}{S_n}\right)^{\beta_1} \left(\frac{R_{n,45}}{S_n}\right)^{\beta_2} \Xi_{n,55}^{\rho(1-\theta_{55})}$ and $\widetilde{\Omega}_{i,50} = \bar{a}_i^f \left(\frac{L_{i,50}}{S_i}\right)^{\alpha_1} \left(\frac{L_{i,45}}{S_i}\right)^{\alpha_2} \Omega_{i,55}^{\rho(1-\theta_{55})}$ are the components explained by the forward-looking model. The outcome variable is the overall amenities and productivity in 1950 defined by equation (E.20). The explanatory variable is constructed similarly as (E.20), but the exogenous amenities and productivity $(a_{i,50}^f, b_{n,50}^f)$ are replaced with the fixed location-specific amenities and productivity $(\bar{a}_i^f, \bar{b}_n^f)$. We use the geometric average of $(a_{i,t}^f, b_{n,t}^f)$ for $t = 1955, ..., 1975$ as the sample analogue of this fixed effects. $(\ln b_{n,50}^{\text{Var},f}, \ln a_{i,50}^{\text{Var},f})$, the structural errors, are interpreted as regression residuals. If our forward-looking model can explain the recovery without the structural errors, then we have $\phi_b^f = \psi_a^f = 1$ and $R^2 = 1$ in both regressions. In contrast, if our forward-looking model has no explanatory power and everything is explained by the structural errors, then we have $\phi_b^f = \psi_a^f = 0$ and $R^2 = 0$. The estimation is done by the OLS. We interpret (ψ_b^f, ψ_a^f) as descriptive rather than causal.

Note that this analysis does not depend on the potential multiplicity of equilibrium because we use the observed population and employment, which people with perfect foresight correctly expect in 1945 when making their migration decisions. Put differently, $(\Xi_{n,50}^f, \Omega_{i,50}^f)$ are evaluated using the observed population and employment density in 1950 and onward, not by different values in an unobserved equilibrium.

F The Myopic Model

F.1 Myopic equilibrium

At the end of period $t = 1, 2, \cdots$, an individual ω solves the following problem when they are myopic:

$$v_{int}^{\text{Myopic}}(\omega) = \ln u_{int} + \max\left\{\rho \ln u_{j\ell t} + \sigma\varepsilon_{j\ell t+1} \; ; \; \rho \ln u_{ot} + \sigma\varepsilon_{ot+1}\right\}, \tag{F.1}$$

The idiosyncratic shocks follow Type-I extreme value distribution as in the baseline and we can derive the probabilities of location choice $\{\lambda_{int+1}^{\text{Myopic}}\}$. Specifically, the probabilities are given by:

$$\lambda_{int+1}^{\text{Myopic}} = \frac{u_{int}^{\pi}}{\sum_{d\in\{\mathcal{C}\times\mathcal{C},o\}} u_{dt}^{\pi}} = \frac{(A_{it}B_{nt}/\kappa_{int})^{\pi}}{\sum_{j,\ell}(A_{jt}B_{\ell t}/\kappa_{j\ell t})^{\pi} + u_{ot}^{\pi}}, \quad i, n \in \mathcal{C} \tag{F.2}$$

where probabilities are determined by the current period utility $\{u_{int}\}$ without taking account of the option values associated with the location choice.

In this case, for periods $t = 1, 2, \cdots$, the dynamics of population and employment are given by:

$$\begin{aligned} L_{it+1} &= (1-\theta_{t+1})L_{it} + \theta_{t+1}\mathcal{M}\sum_{n\in\mathcal{C}} \frac{c_{int}(l_{it}^{\alpha_1} l_{it-1}^{\alpha_2} r_{nt}^{\beta_1} r_{nt-1}^{\beta_2})^{\pi}}{\sum_{j,\ell} c_{j\ell t}(l_{jt}^{\alpha_1} l_{jt-1}^{\alpha_2} r_{\ell t}^{\beta_1} r_{\ell t-1}^{\beta_2})^{\pi} + 1}, \\ R_{nt+1} &= (1-\theta_{t+1})R_{nt} + \theta_{t+1}\mathcal{M}\sum_{i\in\mathcal{C}} \frac{c_{int}(l_{it}^{\alpha_1} l_{it-1}^{\alpha_2} r_{nt}^{\beta_1} r_{nt-1}^{\beta_2})^{\pi}}{\sum_{j,\ell} c_{j\ell t}(l_{jt}^{\alpha_1} l_{jt-1}^{\alpha_2} r_{\ell t}^{\beta_1} r_{\ell t-1}^{\beta_2})^{\pi} + 1}. \end{aligned} \tag{F.3}$$

where $c_{int} = \left(\frac{a_{it}b_{nt}}{\kappa_{int}u_{ot}}\right)^{\pi}$.

For population and employment dynamics in the first period after the shock ($t = 1$), we assume that workers expect that productivity and amenities are determined by the current employment and population distribution at period $t = 0$ since the shock is large enough to swipe away the accumulation in productivity and amenities. Therefore, for period $t = 1$, we consider:

$$\begin{aligned} L_{i1} &= (1-\theta_1)L_{i0} + \theta_1\mathcal{M}\sum_{n\in\mathcal{C}} \frac{c_{in0}(l_{i0}^{\alpha_1+\alpha_2} r_{n0}^{\beta_1+\beta_2})^{\pi}}{\sum_{j,\ell} c_{j\ell 0}(l_{j0}^{\alpha_1+\alpha_2} r_{\ell 0}^{\beta_1+\beta_2})^{\pi} + 1}, \\ R_{n1} &= (1-\theta_1)R_{n0} + \theta_1\mathcal{M}\sum_{i\in\mathcal{C}} \frac{c_{in0}(l_{i0}^{\alpha_1+\alpha_2} r_{n0}^{\beta_1+\beta_2})^{\pi}}{\sum_{j,\ell} c_{j\ell 0}(l_{j0}^{\alpha_1+\alpha_2} r_{\ell 0}^{\beta_1+\beta_2})^{\pi} + 1}. \end{aligned} \tag{F.4}$$

The probability that workers live in the outside of the city is given by:

$$\lambda_{ot+1}^{\text{Myopic}} = \frac{u_{ot}^{\pi}}{\sum_{d\in\{\mathcal{C}\times\mathcal{C},o\}} u_{dt}^{\pi}} = 1 - \sum_i \sum_n \lambda_{int+1}^{\text{Myopic}} \tag{F.5}$$

for periods $t = 1, 2, \cdots$ and

$$\lambda_{o1}^{\text{Myopic}} = 1 - \sum_i \sum_n \frac{c_{in0}(l_{i0}^{\alpha_1+\alpha_2} r_{n0}^{\beta_1+\beta_2})^{\pi}}{\sum_{j,\ell} c_{j\ell 0}(l_{j0}^{\alpha_1+\alpha_2} r_{\ell 0}^{\beta_1+\beta_2})^{\pi} + 1} \tag{F.6}$$

The *myopic equilibrium* is characterized by followings. Given the initial employment and population $\{L_{i0}, R_{n0}\}$, exogenous population $\mathcal{M}$, migration opportunities $\{\theta_t\}$, fundamentals $\{a_{it}, b_{nt}\}$, value of living outside of the city $\{u_{ot}\}$ and parameters (α_1, α_2, β_1, β_2, π), (F.3) and (F.4) determine the myopic equilibrium $\{L_{it}, R_{nt}\}$. Given the initial conditions ($t = 0$) and parameters, it is that the equilibrium distribution in period $t = 1$ is uniquely determined by (F.4). Then, myopic equilibrium in the following periods are also uniquely determined by (F.3) since its right-hand sides in period $t + 1$ solely depend on the previous period t and $t - 1$ that are prede-

termined. Manipulating the equilibrium conditions for the myopic agents,

$$\tilde{L}_{it+1} = \sum_{n \in \mathcal{C}} \Lambda^1_{int} \tilde{R}_{nt+1}, \quad \tilde{R}_{nt+1} = \sum_{i \in \mathcal{C}} \Lambda^2_{int} \tilde{L}_{it+1} \quad \Rightarrow \begin{bmatrix} \tilde{\mathbf{L}} \\ \tilde{\mathbf{R}} \end{bmatrix} = \begin{bmatrix} \mathbf{O} & \mathbf{\Lambda}^1 \\ \mathbf{\Lambda}^{2\top} & \mathbf{O} \end{bmatrix} \begin{bmatrix} \tilde{\mathbf{L}} \\ \tilde{\mathbf{R}} \end{bmatrix} \tag{F.7}$$

where we let:

$$\tilde{L}_{it+1} \equiv L_{it+1} - (1-\theta_{t+1}) L_{it}, \quad \tilde{R}_{nt+1} \equiv R_{nt+1} - (1-\theta_{t+1}) R_{nt},$$
$$\Lambda^1_{int} \equiv \frac{c_{int} (l^{\alpha_1}_{it} l^{\alpha_2}_{it-1})^{\pi}}{\sum_j c_{jnt} (l^{\alpha_1}_{jt} l^{\alpha_2}_{jt-1})^{\pi}}, \quad \Lambda^2_{int} \equiv \frac{c_{int} (r^{\beta_1}_{nt} r^{\beta_2}_{nt-1})^{\pi}}{\sum_\ell c_{i\ell t} (r^{\beta_1}_{\ell t} r^{\beta_2}_{\ell t-1})^{\pi}}$$

Given predetermined employment and population $\{L_{it}, L_{it-1}, R_{nt}, R_{nt-1}\}$ and exogenous fundamentals $\{c_{int}\}$, the matrix $\mathbf{\Lambda}^1$ and $\mathbf{\Lambda}^2$ are predetermined and the $2N \times 2N$ matrix in (F.7) is full rank. Therefore, myopic equilibrium $\{L_{it+1}, R_{nt+1}\}$ are uniquely determined. For the initial period $t = 1$, we also obtain unique $\{L_{i1}, R_{n1}\}$ analogously.

F.2 Evaluating how much the myopic model explains 1945-50 recovery

Suppose that the myopic location choices describe the recovery during 1945-50. Then, ($\Xi_{n,50}$, $\Omega_{i,50}$) obtained in the step 2 are decomposed into the following:

$$\Xi_{n,50} = b^m_{n,50} \left(\frac{R_{n,45}}{S_n} \right)^{\beta_1+\beta_2}, \quad \Omega_{i,50} = a^m_{i,50} \left(\frac{L_{i,45}}{S_i} \right)^{\alpha_1+\alpha_2}. \tag{F.8}$$

Compared to the forward-looking location choices, the advantages in 1950 are decomposed into two parts: (i) exogenous factor ($b^m_{n,50}$, $a^m_{i,50}$) and (ii) spillovers from the density in 1945.

Then, we decompose the structural residuals ($b^m_{n,50}$, $a^m_{i,50}$) into:

$$\ln b^m_{n,50} = \ln \bar{b}_n + \ln b^{\text{Var},m}_{n,50}, \quad \ln a^m_{i,50} = \ln \bar{a}_i + \ln a^{\text{Var},m}_{i,50},$$

where ($b^{\text{Var},m}_{n,50}$, $a^{\text{Var},m}_{i,50}$) are structural errors when we posit the myopic location choices.

Analogously to the forward-looking case in equations (E.21), we consider the following regression equations:

$$\begin{aligned} \ln \Xi_{n,50} &= \psi^m_b \ln \widetilde{\Xi}^m_{n,50} + \ln b^{\text{Var},m}_{n,50}, \\ \ln \Omega_{i,50} &= \psi^m_a \ln \widetilde{\Omega}^m_{i,50} + \ln a^{\text{Var},m}_{i,50}, \end{aligned} \tag{F.9}$$

where $\widetilde{\Xi}^m_{n,50} = \bar{b}^f_n \left(\frac{R_{n,45}}{S_n} \right)^{\beta_1+\beta_2}$ and $\widetilde{\Omega}^m_{i,50} = \bar{a}^f_i \left(\frac{L_{i,45}}{S_i} \right)^{\alpha_1+\alpha_2}$. These explanatory variables capture the components explained by the myopic model, where we use the geometric average of $(a^f_{i,t}, b^f_{n,t})$ for $t = 1955, ..., 1975$ as the sample analogue of this fixed effects. $(\ln b^{\text{Var},m}_{n,50}, \ln a^{\text{Var},m}_{i,50})$, the structural errors, are interpreted as regression residuals. If the myopic model can explain the

recovery without the structural errors, then we have $\psi_b^m = \psi_a^m = 1$ and $R^2 = 1$ in both regressions. In contrast, if the myopic model has no explanatory power and everything is explained by the structural errors, then we have $\psi_b^m = \psi_a^m = 0$ and $R^2 = 0$. The estimation is done by the OLS. We interpret (ψ_b^m, ψ_a^m) as descriptive rather than causal.

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