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

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Revised, 17th June 2025

Abstract: We provide new theory and evidence on the resilience of the internal city structure after a large shock by analyzing the atomic bombing of Hiroshima. Exploiting newly digitized data, we document that the city structure recovered within five years after the bombing. Our new dynamic intra-city quantitative model incorporates commuting, forward-looking location choices, durable floor space, migration frictions, agglomeration forces, and heterogeneous location fundamentals. Strong agglomeration forces in our estimated model explain Hiroshima's recovery, and we find an alternative equilibrium without the city center recovery. These results highlight the role of agglomeration forces, multiple equilibria, and expectations in urban dynamics.

Key words: agglomeration, history, expectations, atomic bombing, spatial dynamics
jel classification: C73, N45, O18, R12, R23

*We are grateful to Steve Redding for his continued guidance and support and Leah Boustan and Nobuhiro Kiyotaki for their numerous helpful comments. We also thank the editor (Esteban Rossi-Hansberg), four anonymous referees, Elena Aguilar, Gabriel Ahlfeldt, Treb Allen, Mark Bamba, Eduard Boehm, Jaedo Choi, Levi Crews, Ellora Derenoncourt, Klaus Desmet, Farid Farrokhi, Mayara Felix, Allison Green, Gene Grossman, Richard Hornbeck, Allan Hsiao, Wen-tai Hsu, Hiroyuki Kasahara, Guy Michaels, Yuhei Miyauchi, Eduardo Morales, Tomoya Mori, David Nagy, Kentaro Nakajima, Georgios Nikolakoudis, Ezra Oberfield, Gianmarco Ottaviano, Pablo Ottonello, Luigi Pascali, Sebastian Roelsgaard, Yasuhiro Sato, Daniel Sturm, Katsuya Takii, Kensuke Teshima, Lin Tian, Carolina Villegas-Sanchez, David Weinstein, Chansik Yoon, Xuanli Zhu, and seminar and conference participants for their feedback. We thank the Chugoku Region Development Bureau and the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) for providing access to the person-trip survey data. We acknowledge financial support from Princeton University, Hitotsubashi University, the National University of Singapore, and the Funai Foundation for Information Technology. We would also like to thank Hiroki Chiba, Nuo Lei, and Jia Zhiyuan for their excellent research assistance, and Shinji Nakano and Takahiro Sato for their help with the GIS data. An earlier version of this paper was circulated under the title "History versus Expectations in the Spatial Economy: Lessons from Hiroshima." The accompanying Online Appendix is available on the authors' websites. We take sole responsibility for the errors in this paper. Takeda: Department of Economics, National University of Singapore & Centre for Economic Performance, LSE. AS2, 1 Arts Link, Singapore, 117570 (Email: k.takeda@nus.edu.sg); Yamagishi: Institute of Economic Research, Hitotsubashi University & Center for Real Estate Innovation, the University of Tokyo & Global Japan Lab, Princeton University. 2-1 Naka, Kunitachi, Tokyo, Japan. 186-8603 (Email: a.yamagishi@r.hit-u.ac.jp).

1 Introduction

Cities have faced a host of shocks throughout history. Wars, natural disasters, pandemics, and technological shocks have all impacted city structure – the spatial distribution of economic activities within cities. In particular, the city structure would change substantially once a central location in a city with the highest population and employment is destroyed by a large negative shock such as a bombing. However, there remains substantial debate about whether the city structure is resilient to such large shocks and what mechanisms are behind this resilience (Glaeser 2022). Theoretically, the resilience of the city structure after temporary shocks emerges from exogenous locational fundamentals that uniquely determine the distribution of economic activities, or the presence of strong agglomeration forces by which the city structure is determined via a coordination of expectations around the focal point. However, the empirical importance of these different mechanisms remains an open question (Lin and Rauch 2022).

Understanding the mechanisms that underlie the resilience of the city structure would aid the reconstruction of war-torn cities, improve urban revitalization efforts, and inform planning for future shocks. Nevertheless, there are two important challenges in answering these questions. First, we rarely observe a large shock to the city structure while having access to spatially-granular data on economic activities over a long period of time. Second, we need a quantifiable model of the dynamics of the internal city structure that allows us to disentangle the mechanisms underlying the resilience of the city structure.

In this paper, we provide new theory and evidence on the resilience of the city structure by analyzing the atomic bombing of Hiroshima, one of the most remarkable examples of urban resilience in human history. The atomic bombing completely destroyed the city center while sparing its outskirts. This distinctive and massive shock provides a unique laboratory for studying the dynamics of the city structure. We collect and digitize new granular historical data on the distribution of economic activities within Hiroshima. Using these data, we first document that the city structure of Hiroshima recovered to its pre-war state within five years after the bombing. We then construct and calibrate a new dynamic quantitative model of the internal city structure, which explains this observed recovery. In our estimated model, strong agglomeration forces created by population and employment density yield better local amenities and increase productivity. This provided the key incentive for people to again live and work in the city center. Finally, we show that these agglomeration forces induce multiple equilibria. In particular, there exists an alternative equilibrium in which the city center did not recover, in contrast to the observed recovery equilibrium. We argue that self-fulfilling expectations of recovery might have played an important role in realizing the recovery equilibrium.

We begin by describing the historical context and our newly collected data on the distribution of economic activities within Hiroshima. As of 1945, most of the administrative region of Hiroshima lay within 6 kilometers of the city center. On August 6, 1945, the atomic bomb hit near the city center, inducing a near 100% death rate around the center. It also destroyed almost all structures within 2 kilometers of the city center, but many structures on the outskirts of the city were much less affected. Some areas on the outskirts even experienced an increase in population due to the inflows of survivors. Consequently, the atomic bombing was an extremely large shock to the city structure; the pre-war city center now had the lowest population and employment density in the city. To conduct our quantitative analysis at a spatially granular level, we collect and digitize new historical data on population, employment, wartime destruction, and fundamental characteristics at the city block level within Hiroshima. Importantly, our dataset covers both the pre-bombing and immediate post-bombing periods, allowing us to investigate the recovery of central Hiroshima in detail.

Through descriptive and reduced-form analyses, we reveal that the city structure of Hiroshima was resilient to this unprecedented shock. Our findings are twofold: (i) the destroyed city center again became the main hub of economic activity within five years of the atomic bombing; and (ii) the recovery of central Hiroshima is not explained by various observed fundamental location characteristics, which could directly affect amenities and productivity independently of the local density of economic activities (e.g., altitude, access to natural water and train stations). Given these reduced-form findings, we consider in the rest of the paper the following two mechanisms that can potentially explain the recovery of the destroyed city center. First, the destroyed city center retained some unobserved locational advantages that either survived the bombing (e.g., scenic views) or appeared after the bombing (e.g., preferential infrastructure investment). Second, individuals may have expected the recovery of the destroyed city center when making location choices, and the incentive to live and work in the city center again came from agglomeration forces due to the expected high density similar to the pre-war period. We analyze these two possible explanations through the lens of the structural model.

We develop a new dynamic quantitative model of the internal city structure. Our model is the first quantitative urban model that accommodates commuting, forward-looking location choices, durable floor space, migration frictions, agglomeration forces, and heterogeneous location fundamentals. Commuting patterns within a city are endogenously determined by individual choices of workplace and residence. Individuals correctly anticipate the future path of the economy when making location decisions, and neighborhood amenities and productivity depend on population and employment density. Location-specific fundamental amenities and productivity capture the heterogeneous advantages of locations in a city that are independent of population and employment density. In addition, our model incorporates durable floor space, which is supplied by competitive developers given initial floor space stocks, and migration frictions. Both induce history-dependence in the city structure. These model elements are essential for the capture of alternative potential determinants of the dynamics of the internal city structure.

We calibrate our model and evaluate its ability to explain the recovery of central Hiroshima. We estimate the model using the observed location choices of Hiroshima residents from 1955 to 1975, after the period of rapid recovery, because sufficient data for calibrating our model are only available for this time period. We leverage the structure of the model to estimate the model parameters and compute unobserved location characteristics. Our key parameters describe how the agglomeration forces increase amenities and productivity as the population and employment density rise. We estimate these forces under the identification assumption that exogenous changes in the amenities and productivity of each block over time are uncorrelated with the distance from the city center, while allowing for arbitrary heterogeneity in location-specific amenities and productivity. We find strong agglomeration forces in both amenities and productivity. We then assess how well our calibrated model fits the location choice data for 1950 when people had returned to the destroyed city center, finding that our model can successfully account for the observed recovery of the city center.

We highlight that agglomeration forces play a key role in explaining the recovery of central Hiroshima. To this end, we simulate a counterfactual population and employment distribution in which agglomeration forces in amenities and productivity are absent and fundamental productivity and amenities for 1950 are equal to their estimated averages from the 1955–1975 data. We find that our calibrated model without agglomeration forces cannot predict the recovery of the city center, which is consistent with the idea that agglomeration forces played an important role in the resurgence of the center. Theoretically, in the presence of strong agglomeration forces, there is potential for multiple equilibria because the city center would not be attractive if its recovery were not expected in the near future. To investigate this, we numerically solve the model for an alternative rational expectations equilibrium in which the population and employment densities of the city center do not recover. This suggests that the observed pattern of recovery is one equilibrium selected from multiple and that self-fulfilling expectations of recovery might be crucial in selecting such a recovery equilibrium. We argue that certain factors, such as government recovery plans, the anchoring effect of salient location characteristics in the city center (e.g., tram networks, the destroyed Hiroshima castle), property rights, and popular narratives of rebuilding, may have induced expectations that the destroyed city center would return to its high density as in the pre-war period. Our results suggest the importance of these factors in the rapid recovery of the city structure by fostering the formation of such recovery expectations.

Overall, our analysis of Hiroshima highlights the role of agglomeration forces, multiple equilibria, and expectations in the economic dynamics of the city structure. For cities recovering from a large shock, our findings indicate the importance of agglomeration forces and creating potentially self-fulfilling expectations for recovery. Our results further suggest the possibility that policymakers could substantially change the dynamics of the city structure if they influence expectations about a city's future.

This paper contributes to studies on the determinants of the concentration of economic activity in space, which is at the core of urban economics and economic geography. A theoretical literature has uncovered the importance of fundamental location characteristics and agglomeration forces in shaping the spatial distribution of economic activities, including Fujita and Ogawa (1982), Fujita and Thisse (1996), Fujita, Krugman, and Venables (1999), Lucas and Rossi-Hansberg (2002) and Ahlfeldt, Redding, Sturm, and Wolf (2015). Moreover, when agglomeration forces are important relative to heterogeneity in location characteristics so that there are multiple equilibria, initial conditions ("history") or self-fulfilling expectations may determine the spatial distribution of economic activities by selecting a particular equilibrium. Krugman (1991) and Matsuyama (1991) show that self-fulfilling expectations can induce a transition from one steady state to another when multiple equilibria exist, implying that the initial conditions determined by history can be overcome by expectations.[1] We empirically contribute to this discussion by analyzing the

[1]Among others, see Fukao and Bénabou (1993), Rauch (1993), Holmes (1999), Baldwin (2001), Ottaviano (2001), Oyama (2009),

atomic bombing of Hiroshima as a large exogenous shock to the city structure and showing the importance of agglomeration forces, multiple equilibria, and expectations in the economic dynamics of city structure.[2]

Many empirical studies have investigated the importance of historical shocks as determinants of the spatial distribution of economic activities. Previous studies exploiting war-time destruction across cities and regions have typically found that large shocks have only temporary impacts, including Davis and Weinstein (2002, 2008), Brakman, Garretsen, and Schramm (2004), Bosker, Brakman, Garretsen, and Schramm (2007), Miguel and Roland (2011), Feigenbaum, Lee, and Mezzanotti (2022). Among others, Davis and Weinstein (2002) finds that the population distribution *across* Japanese cities after World War II converged with its pre-war trend, including that of Hiroshima. However, studies that exploit shocks other than war-time destruction often find that large shocks can have persistent or permanent effects on the spatial distribution of economic activities, including Redding, Sturm, and Wolf (2011), Bleakley and Lin (2012), Schumann (2014), Siodla (2015), Hornbeck and Keniston (2017), Michaels and Rauch (2018), Brooks and Lutz (2019), Ambrus, Field, and Gonzalez (2020), Heblich, Trew, and Zylberberg (2021), Allen and Donaldson (2022), Brooks, Rose, and Veuger (2022) and Yamagishi and Sato (2025).[3] Our paper is distinctive from these studies in three important ways. First, we analyze the spatial distribution of economic activities *within* a city using the new spatially granular data. Second, we use the atomic bombing of Hiroshima as an exogenous and unprecedentedly large shock to the internal structure of the city. Third, and most importantly, we develop and apply a novel dynamic quantitative urban model to this historical shock to investigate why we observe such resilience in Hiroshima, highlighting the importance of agglomeration forces and self-fulfilling expectations in overcoming the catastrophe. In particular, their importance can reconcile the aforementioned empirical studies that are split on the persistence of historical shocks: we may often observe history independence after the war because expectations of recovery to the pre-war situation tend to emerge after wartime destruction. History dependence may arise in other contexts where such expectations are absent.

Our structural analysis also relates to recent advancements in quantitative spatial models, as reviewed in Redding and Rossi-Hansberg (2017). To analyze the resilience of the city structure, we develop a new quantitative urban model with commuting, forward-looking location choices, durable floor space, migration frictions, agglomeration forces, and heterogeneous location fundamentals. Studies that consider commuting and agglomeration forces within cities (Ahlfeldt et al. 2015; Monte, Redding, and Rossi-Hansberg 2018; Dingel and Tintelnot 2020; Tsivanidis 2022) do not accommodate forward-looking migration decisions, durable floor space, and migration frictions, while those with forward-looking migration decisions

and Barreda-Tarrazona, Kundu, and Østbye (2021) for developments in self-fulfilling expectations and economic geography. Self-fulfilling expectations also matter in other important economic contexts with multiple equilibria, including structural transformation in economic development (Murphy, Shleifer, and Vishny 1989).

[2]Highlighting these factors as a possible theoretical explanation for the resilience of the spatial distribution of economic activities, Fujita and Thisse (1996) states "[a]nother reason for [a spatial structure's] inertia...is the formation of self-fulfilling prophecies about the development of some areas. Indeed, it seems reasonable to consider existing cities as focal points that help agents coordinate their spatial decisions. In such a context, reshaping the urban landscape would then require major changes in agents' expectations."

[3]Harada, Ito, and Smith (2024) and Redding and Sturm (2023) estimate the long-run impact of bombing on neighborhood quality within Tokyo and London. Compared to them, we do not analyze neighborhood quality as such data are unavailable and instead focus on the dynamics of the re-emergence of the city structure.

(Caliendo, Dvorkin, and Parro 2019; Balboni 2025; Heblich, Trew, and Zylberberg 2021; Warnes 2021; Allen and Donaldson 2022; Almagro and Domínguez-Iino 2022; Kleinman, Liu, and Redding 2023) do not incorporate commuting or agglomeration forces. Among others, Monte, Porcher, and Rossi-Hansberg (2023) presents a model for one-dimensional cities on the real line with forward-looking individuals who choose work arrangements and commuting patterns. In contrast, our model allows for an arbitrary number of discrete locations within cities and location fundamentals, which are tractable when mapping the data to the model.[4] Importantly, we integrate commuting, forward-looking location choices, durable floor space, migration frictions, agglomeration forces, and heterogeneous location fundamentals into a single framework that is otherwise parsimonious. Such a parsimonious nature is particularly useful in data-scarce environments, including but not limited to the case of Hiroshima.

Finally, this paper relates to studies on the recovery of Hiroshima from the atomic bombing (Hiroshima City Government, 1971; 1983a). There is little econometric analysis on the distribution of economic activities within the city and the resurgence of the city center. Our paper formally analyzes the recovery pattern using newly-digitized granular historical data and a novel quantitative economic model. This provides new evidence on the resilience of Hiroshima's city structure and a new approach to understanding the economic mechanisms behind the resilience.

The rest of the paper is structured as follows. Section 2 describes the historical context and data. Section 3 presents the reduced-form analysis and Section 4 introduces the theoretical framework. Section 5 calibrates the model and demonstrates that our model accurately fits the recovery of central Hiroshima. In Section 6 we undertake a counterfactual analysis to show the roles of agglomeration forces and expectations in the recovery. Section 7 explores the potential factors contributing to the formation of expectations. Section 8 concludes.

2 Historical Background and Data

This section briefly describes the history of Hiroshima prior to the atomic bombing and the impact of the bombing on the city (Subsection 2.1) and how we construct new granular spatial data on the population, employment, and other characteristics of Hiroshima (Subsection 2.2).

2.1 *Historical Background*

The development of Hiroshima started in the late 16th century when Terumoto Mōri, a local samurai lord, built Hiroshima castle.[5] Hiroshima has been a major city in the *Chugoku* region of Japan since then. Early in the 20th century, the city grew quickly. In 1935, 310,118 people lived in Hiroshima, making it the seventh-largest city in Japan by population. As Japan gradually transitioned to a war economy through the Second Sino-Japanese War (1937–1945) and the Pacific War (1941–1945), growth slowed and then reversed. Before

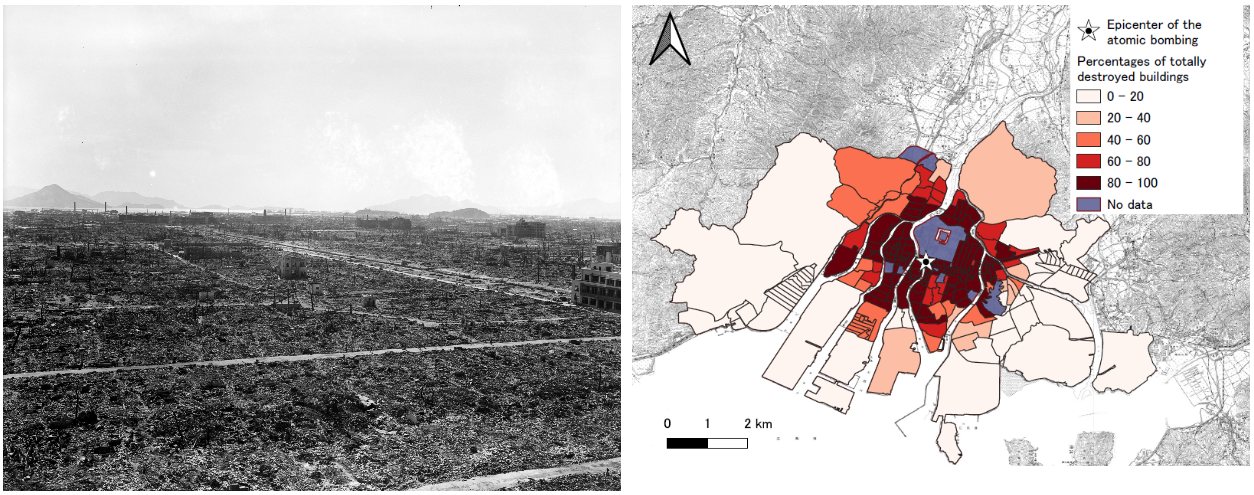
[4] As an early theoretical contribution, Rossi-Hansberg (2004) presents the canonical urban model with shocks to internal city structure.

[5] In this paper, we use the word "Hiroshima" to refer to the administrative Hiroshima City (*Hiroshima-shi*). We sometimes explicitly state Hiroshima City to clearly distinguish it from Hiroshima Prefecture.

the atomic bombing, the city had an estimated population of 350,000. As the U.S. overwhelmed Japan during World War II, most Japanese cities endured extensive non-atomic air raids (Davis and Weinstein 2002). However, the U.S. avoided bombing Hiroshima to preserve the city as the "best laboratory" for demonstrating the effects of the atomic bomb.[6] Consequently, the atomic bombing was essentially the only direct destruction the city experienced during WWII.

Figure 1: Destruction of the atomic bombing in Hiroshima

(a) Total destruction near the epicenter **(b)** Block-level destruction rate of buildings



Note: Panel (a) is a photograph from the United States Strategic Bombing Survey made available by the U.S. National Archives and Records Administration. Panel (b) shows a map of Hiroshima at the time of the bombing, along with block-level data (197 blocks in total) on the fraction of completely destroyed buildings and the epicenter (Hiroshima City Government 1971; Takezaki and Soda 2001). Remote islands (*Nino-shima*, *Kanawa-jima*, *Touge-shima*) are omitted for better visibility. We use as the background image the 1950 topographic map taken from the Time Series Topographic Map Viewer of Japan (Tani 2017, https://ktgis.net/kjmapw/).

On August 6, 1945, the U.S. Air Force dropped the atomic bomb "Little Boy" near the center of Hiroshima. The damage to people and buildings was unprecedentedly catastrophic. The city government of Hiroshima estimates that 140,000 people died by the end of 1945 as a result of the atomic bombing, although it is difficult to determine the exact number.[7] The death rate was near 100 percent for those within 1 kilometer of the epicenter. The bomb also destroyed a large number of buildings: 51,787 out of 76,237 buildings in Hiroshima were completely destroyed and 18,720 were partly destroyed. The vast majority of buildings within 2 kilometers of the city center were completely destroyed. This can be seen in Panel (a) of Figure 1, which was taken near the epicenter of the bombing. The population of Hiroshima dropped to

[6]Based on "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 October 28, 2023), the target of the bombing was determined based on the city's size and its flat terrain to best measure the damage from the bombing. Notably, local economic conditions were not considered when selecting targets.

[7]The real death toll is likely to be even higher because the atomic bombing caused severe injuries and diseases that killed many after 1945. Source: https://www.city.hiroshima.lg.jp/site/english/9803.html (last accessed on October 28, 2023). This damage was much more severe than that in other cities that endured extensive air raids. For example, the population of Tokyo was approximately 7 million in 1940. 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 October 28, 2023). The killing and building destruction rates in Hiroshima are substantially greater than those in Tokyo due to its smaller city size.

136,518 as of November 1945, about one-third of the pre-war population.

In contrast to the total destruction in central Hiroshima, the outskirts of the city were much less damaged. Panel (b) of Figure 1 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, buildings in the light-colored areas away from the epicenter were much less damaged. As a result, the outskirts of Hiroshima experienced a significant increase in the population as survivors flooded in. As of November 1, 1945, Hiroshima beyond 3 kilometers from the epicenter had 142 percent of its pre-bombing population.

The war ended on August 15, 1945. People initially doubted whether Hiroshima could recover. Notably, despite the then-limited scientific knowledge, radioactive contamination was a major concern immediately after the bombing. Indeed, rumors circulated that "nothing will grow here for 75 years."[8] However, available evidence suggests that the radioactive contamination of Hiroshima city decayed quickly and it became relatively quickly safe to live near the epicenter after the bombing. First, according to the Hiroshima City government, radiation at the epicenter was 1/1,000th a day after the bombing and 1/1,000,000th a week later.[9] Second, a large typhoon hit Hiroshima on September 17, 1945, about six weeks after the bombing. According to the U.S. Atomic Bomb Casualty Commission, the typhoon probably washed away quite of the contaminated material, bringing the radioactivity down to a relatively safe level (Takahashi 2008). Third, for compensation purposes, there is a formal definition of the victims of the atomic bombing (*hibakusha*) by the Ministry of Health, Labour and Welfare. While they recognize the possibility that going near the epicenter after the bombing might cause health problems, based on the available scientific evidence, they conclude that going near the epicenter two weeks after the bombing would not cause health problems.[10] Given these considerations, we do not explicitly consider radioactive contamination in this paper as we believe that radioactive contamination played little role in considering the recovery of Hiroshima's city center.[11]

Despite initial pessimism, people gradually became optimistic about Hiroshima's destroyed city center (Hiroshima City Government 1971). Although it is difficult to identify a single factor, several factors may have contributed to such optimism. First, the city government of Hiroshima published a recovery plan. The bombing forced the government to face various challenges, such as the loss of human resources, facilities, and important documents. Combined with the severe budget shortage, it could not implement most of its plan for several years after the bombing. That said, even such a small-scale public policy toward rebuilding might have induced optimism about Hiroshima's future.[12] Second, the presence of salient location char-

[8]Source: https://www.bbc.com/news/world-asia-53660059, last accessed on October 28, 2023.

[9]Source: https://www.city.hiroshima.lg.jp/site/english/9809.html, last accessed on October 28, 2023.

[10]This is also consistent with NHK Hiroshima Station Atomic Bomb Project Team (1988), which found little long-run health impacts on people who engaged in rescue activities near the epicenter shortly after the bombing. For more details about the definition of *hibakusha*, see https://www.mhlw.go.jp/stf/newpage_13405.html (In Japanese, last accessed on December 2 2024).

[11]In particular, we are of the opinion that (1) radioactive contamination was not a problem throughout a city for our calibration, which uses data from 1955 and 1975, and (2) it had a minimal impact on the recovery period from 1945 to 1950. If anything, since radioactive contamination is a disamenity, the consideration of it would further strengthen the recovery tendency of the pre-war city center.

[12]The recovery council was formed in February 1945 and consisted of 26 members, including the former mayor, city councilors,

acteristics in the city center, such as the transportation network and the destroyed Hiroshima castle, may have anchored people's expectations for recovery despite the severe damage. Third, pre-war private property ownership was preserved, although almost all homeowners near the city center lost their homes and many landowners and homeowners close to the city center were killed by the bombing. Finally, rebuilding narratives may have been shared by people and coordinated their expectations. We revisit the discussion about the formation of recovery expectations in Section 7.

Notwithstanding the lack of strong public actions, Hiroshima's total population experienced a strong recovery due to private efforts. In 1955, Hiroshima had a population of 357,287, which was larger than the 1935 population. Hiroshima continued to grow and physically expanded along the way.[13] Today, Hiroshima has a population of approximately 1.2 million, making it the 10th largest Japanese municipality and the largest in the *Chugoku* region of Japan. Moreover, the destroyed pre-war city center of Hiroshima again became the center in the post-war period. Using the new data we introduce in the next section, this paper documents the resilience of the city structure and then examines the underlying mechanism behind the resilience.

2.2 *Data*

We have collected and digitized various sources of information on the economic activity in Hiroshima before and after the war. Here, we provide a brief overview of our data sources. Appendix A provides further details.

Spatial Units The spatial unit of our analysis is a city block (*cho-cho-moku*) in Hiroshima. As our primary definition of city blocks, we use the block boundaries as of the bombing constructed by Takezaki and Soda (2001). In comparing the pre-war and post-war periods, we focus on areas that were part of Hiroshima as of the bombing.[14] Throughout this paper, we use the block definitions of 1945. The pre-war central business district (CBD) is defined as the mid-point of the *Kamiya-cho* block and *Hacchobori* block, which were the two prominent central areas of pre-war Hiroshima. Note that the recovery of the city center documented below implies that the pre-war city center corresponds to the post-recovery city center. We address the revisions of the block boundaries over time by converting all data to the 1945 block definitions based on areal weighting interpolation, and we digitize the block boundaries of 1966 and 1976 to implement this. Throughout the paper, the number of blocks is 174 and the average size of the blocks is 0.32 square

and local business leaders. However, despite the exceptionally catastrophic damage, Hiroshima could not receive special budgetary treatment until the enactment of the Hiroshima Peace Memorial City Construction Law in 1949. In 1947, the budget for the reconstruction of Hiroshima City was 0.56 billion JPY, which was only 2.5 percent of the estimated total budget of 23 billion JPY (Shinoda 2008). The city focused on providing public housing, but it could only provide 3,000 units during 1945–1950, relative to the over 70,000 buildings destroyed. The restoration of the pre-war infrastructure was also prioritized, but this did provide a particular advantage to the city center as the city outskirts also had comparable infrastructure.

[13] As shown in Davis and Weinstein (2002), the aggregate city population recovered its pre-war trend around twenty years after the atomic bombing.

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

kilometers.[15]

Destruction by the Atomic Bombing We primarily use the fraction of completely destroyed buildings as a measure of the severity of destruction. The block-level destruction rate is reported in Hiroshima City Government (1971). We augment the digitization of Takezaki and Soda (2001) by consulting Hiroshima City Government (1971) to correct typos in their data and obtain additional information on missing values. Panel (b) of Figure 1 in the previous section illustrates the share of completely destroyed buildings in each block.

Population We collect and digitize the population data at the block level. We refer to the Statistical Handbook of Hiroshima (*Hiroshima-shi toukei sho*) for 1933–1936 and the Statistical Abstract of Hiroshima (*Hiroshima shisei youran*) for 1945–1953.[16] From 1955, the population data is taken from the Population Census. Panel (a) of Figure 2 provides a visualization of Hiroshima's population over time. The population of Hiroshima increased prior to the atomic bombing, dropped significantly after the bombing, and resumed growth again after WWII. We also observe that the center of Hiroshima declined as a share of the population over time, reflecting the suburbanization of the city that absorbed most post-war population growth. Note that this declining trend was already observed pre-WWII, suggesting that a smaller central population share after WWII does not necessarily mean that recovery was incomplete.

Employment We collect and digitize employment data at the block level from various sources.[17] For 1938, we refer to the Survey of Commerce and Industry in Hiroshima (*Hiroshima-shi shoukou-gyou keiei chousa*) which records the number of establishments at the block level. The number of commercial buildings immediately after the bombing is available in the Statistical Abstract of Hiroshima (*Hiroshima shisei youran*). For 1953, we exploit the Survey on the Daytime Population of Hiroshima (*Hiroshima-shi chukan jinko chosa*), where we assume that the daytime population approximates employment. From 1957 to 1975, we use the Business Establishment Statistical Survey (*Jigyousho toukei chousa*).[18] Based on these data, we approximate block level employment every five years from 1950 to 1975. Panel (b) of Figure 2 shows employment in Hiroshima over time. Total employment dropped significantly in 1945 after the bombing but increased again post-war, and the number of workers employed in the central area recovered to its pre-war level. The share of employment in the city center rose throughout the post-war period, implying an increased

[15]A Japanese city block is generally smaller than a U.S. census tract, which has a population of around 4,000, but larger than a U.S. census block, which has 40 housing units. In our data on Hiroshima, the average area size for blocks is 0.04 (0.13) square kilometers within 1 (3) kilometer of the CBD, and the average block area is 2.19 square kilometers among blocks more than 3 kilometers from the CBD.

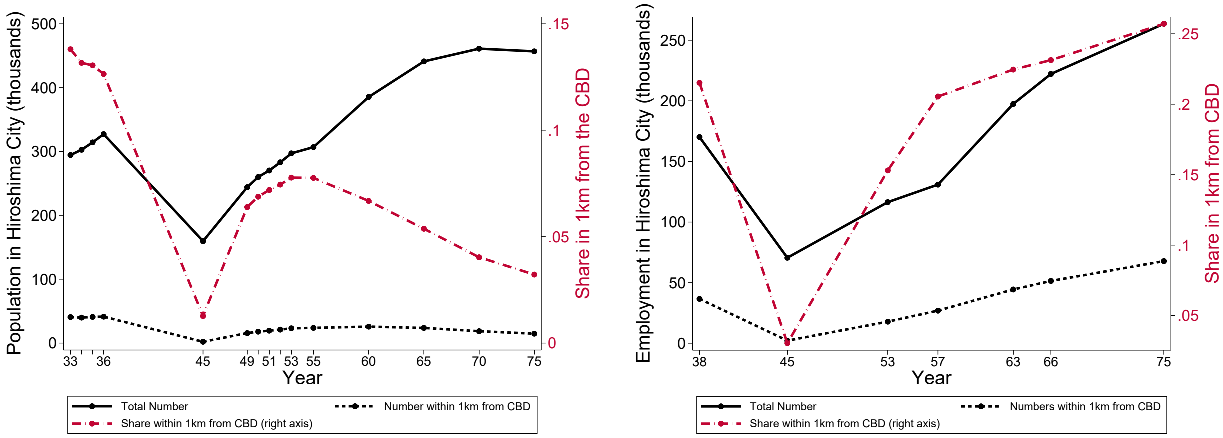
[16]For 1945–1950, the population is reported using a more aggregated block definition. We combine this information with the block-level destruction rate of buildings to predict the block-level population distribution (see Appendix A for details).

[17]While we do not distinguish employment by sector, available evidence suggests that the locations of manufacturing and service sector employment are highly correlated in Hiroshima (see Figure A.8b in the Appendix). We also abstract from agricultural employment. Even in 1950, when agricultural employment was large in the Japanese economy, the Population Census indicates that less than 10 percent of workers in Hiroshima City engaged in agriculture.

[18]For 1953–1963, employment was reported using less geographically granular units than blocks. We address this by combining the best available block-level information to approximate the block-level employment distribution. When employment data are unavailable but establishment data are available, we follow Ahlfeldt et al. (2015) and assume that the number of establishments is proportional to employment. See Appendix A.2 for empirical results consistent with this assumption.

concentration of employment.

Figure 2: Population and employment over time in Hiroshima City



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

Note: The figures show the total population and employment within the entire city and within 1 kilometer of the CBD (left axis), as well as the shares of population and employment within 1 kilometer of the CBD (right axis).

Commuting and Transportation Networks We use trip-level microdata from the 1987 Hiroshima City Person-Trip Survey to analyze commuting patterns. The data captures the workplace, residence, and representative travel mode for each commuting trip. We also collect and digitize road, bus, and train networks in Hiroshima and compute bilateral travel time between blocks for different modes: walk, bike, car, bus, and train. Although Hiroshima's public transportation networks were generally stable since the war, there were some changes, notably the discontinuation of the *Ujina* line in 1966.[19] To address this, we use the public transportation networks of 1950 for years prior to 1966 and those of 1987 for later years.

Floor Space We use the newly-digitized block-level floor space data, taken from *Hiroshima toshi-iki kotsu chosa shiryo*. This data records the amount of floor space by the construction year as of 1967, allowing us to observe the floor space built prior to the atomic bombing (1945), during 1945–1950, 1950–1955, 1955–1960, and 1960–1965. Assuming a constant depreciation rate for the floor space stock, we are able to calculate the amount of floor space stock in 1945, 1950, 1955, 1960, and 1965. By combining this floor space stock data with our floor space supply model, we back out floor space prices from 1945 to 1965 that are consistent with the observed floor space supply. Since we lack comparable floor space data during 1965 and 1975, we use a prediction model of floor space prices in 1970 and 1975. We validate our prediction using the assessed land price data in 1975 (*kouji chika*). We describe the details in Appendix A.2.

Location Characteristics We collect various information on the location characteristics of each block. In particular, we exploit data on altitude, ruggedness, soil condition, geographical coordinates, adjacency to rivers, distance to the pre-war CBD, distance to train stations, distance to Hiroshima port (*Ujina* port),

[19]The *Hijiyama/Minami* line and *Eba* line opened in 1944 for military purposes, and these lines have been maintained after the war. These lines improved transportation access in the outskirts.

distance to bodies of water, distance to cultural assets for each block. Distances are calculated using the centroid of each block shape. In addition, although zoning regulation in Japan in most of our sample period was quite lax in that it allowed for substantial mixed use, we measure the block-level zoning regulation by digitizing the 1940 Hiroshima Urban Planning Area Map (*Hiroshima toshi keikaku chiiki-zu*).[20] Appendix A.3 provides the details.

3 Reduced-form Evidence

In this section we analyze the population density to illustrate the pattern of destruction and recovery of the city structure of Hiroshima. Subsection 3.1 describes how the atomic bombing destroyed central Hiroshima and how the city subsequently recovered to its pre-war city structure. In Subsection 3.2, we formalize this recovery result in a regression analysis. We also find that the recovery tendency is robust to controlling for observable prominent location characteristics, which refer to characteristics of a location that directly affect amenities and productivity independently of the local density of economic activities (e.g., altitude, access to natural water). In Subsection 3.3, we conduct various robustness checks.

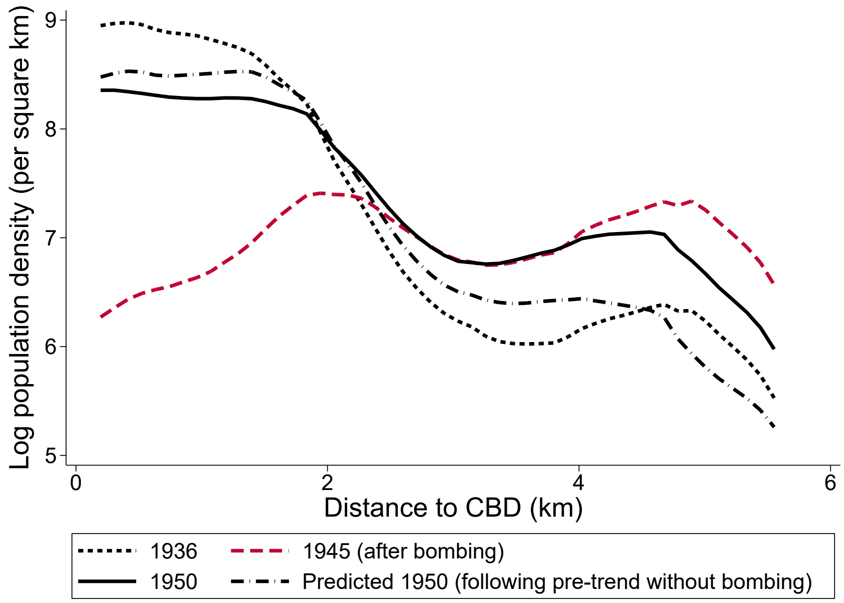
3.1 *Descriptive Evidence on the Destruction and Recovery of the City Structure*

In Figure 3 we non-parametrically plot the population density within Hiroshima by distance to the CBD, where we normalize the total population of the city to 100,000 each year to facilitate comparisons of the inner-city structure over time. The figure shows that the city structure of Hiroshima was completely changed by the atomic bombing but quickly recovered to the pre-WWII city structure. In 1936 the city had a typical monocentric structure: the city center had the highest population density, and the density fell as one moved away from the center. This monocentric pattern was completely reversed by the atomic bomb hitting the densely populated city center. Figure 3 shows that, after the bombing, the city center was wholly destroyed and consequently had the lowest population density in the city. In contrast, areas two kilometers away from the center, which avoided total destruction (see Figure 1b), became the most crowded places in the city. Areas further away from the city center also experienced significant increases in population density as many survivors escaped to the outskirts.

Despite the "reversal" of the monocentric city pattern after the bombing, the monocentric structure had already re-emerged in 1950, just five years after the bombing. The rate of population recovery in the city center was remarkable. While the recovery from total destruction is qualitatively clear, the recovery may not have been perfect, as the concentration of 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 comparing the actual population distribution in 1950 and the predicted 1950 distribution, based on extrapolating the

[20]For instance, although one is prohibited from operating theaters and large factories in "residential" zones, there was no restriction to operate restaurants, shops, and small factories in "residential" zones. Note that although our zoning data are from the pre-bombing period, zoning remained largely unchanged for approximately 20 years after the bombing. The zoning regulation was revised in 1968 with the introduction of the new Urban Planning Law, long after the recovery of city structure was complete, so that the land use pattern of Hiroshima stabilized.

Figure 3: Population density by distance to the city center



Note: The figure shows the local polynomial regression of the log population density on the distance to the CBD for different years. To eliminate the effect of changes in the total population, we normalize the total population each year to 100,000. The predicted population distribution of 1950 is computed based on the 1936 population distribution, assuming that each block experienced an annual population growth rate equal to the pre-war (1933–1936) rate.

pre-war population growth trends from 1936 to 1950. The next section formalizes this recovery result through a regression analysis, which allows us to consider the statistical significance of our findings and incorporate various location characteristics as controls.

3.2 *Regression Analysis of the Recovery of Central Hiroshima*

We now analyze the magnitude of the recovery at the spatially granular level of the blocks. Note that recovery implies that the set of blocks that lost more population due to the atomic bombing grew faster in the post-war period. We operationalize this idea with the following regression model:

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

where i is the block, t is the post-war year, e.g. 1950, X_i is the vector of the location characteristics, and v_i is the error term. We regress the post-war log change in population density on the log change in population density from 1936 to 1945, reflecting the damage from the atomic bombing.[21] The estimated coefficient γ represents the degree of recovery back to the pre-war city structure.[22] If $\gamma = 0$, the population density lost during the war did not recover in the post-war period. This would imply that the shock of the

[21] We use the 1936 population density because it is the closest observation we have before 1945. In our data, the population density in 1945 is measured in November 1945 and is positive for all blocks.

[22] Since we include a constant in X_i, γ is invariant to population level in year t. In other words, the coefficient γ captures the degree of convergence to the pre-war population distribution, where the total city population is normalized to the pre-war one.

atomic bombing has permanent effects on the city population distribution. In contrast, if $\gamma = -1$, the lost population density completely recovered in the post-war period, so the shock had only temporary effects on the population distribution. To check the robustness to the model specification, we also consider an alternative regression specification at the end of this section.

In some specifications, we control for location characteristics X_i such as altitude and distance to train stations, allowing us to investigate how the degree of recovery γ changes after conditioning on location characteristics. We interpret these regressions as capturing the correlation between population density lost during the war and post-war population growth, either unconditional or conditional on location characteristics X_i. It does not necessarily have a causal interpretation.

Panel (a) of Figure 4 illustrates the relationship between the wartime and post-war population density growth rates for each block as of 1950, along with the regression line. The fitted line is somewhat less steep but already close to a slope of −1, implying the strong resilience of the city structure just five years after the bombing. Panel (b) of Figure 4 demonstrates that a similar result is obtained when examining the population distribution in 1960, suggesting that the recovery was essentially complete by 1950. Therefore, for brevity, we confine our regression analysis to the recovery from 1945 to 1950.

Column (1) of Table 1 provides the regression result for the growth of population density in 1950, as depicted in Panel (a) of Figure 4. The coefficient is −0.712, which is statistically distinguishable from zero, and the null hypothesis of complete persistence is rejected.[23] Although we can also statistically reject the null hypothesis of purely temporary shocks ($\gamma = -1$), the results suggest a strong recovery of the city structure within just five years.

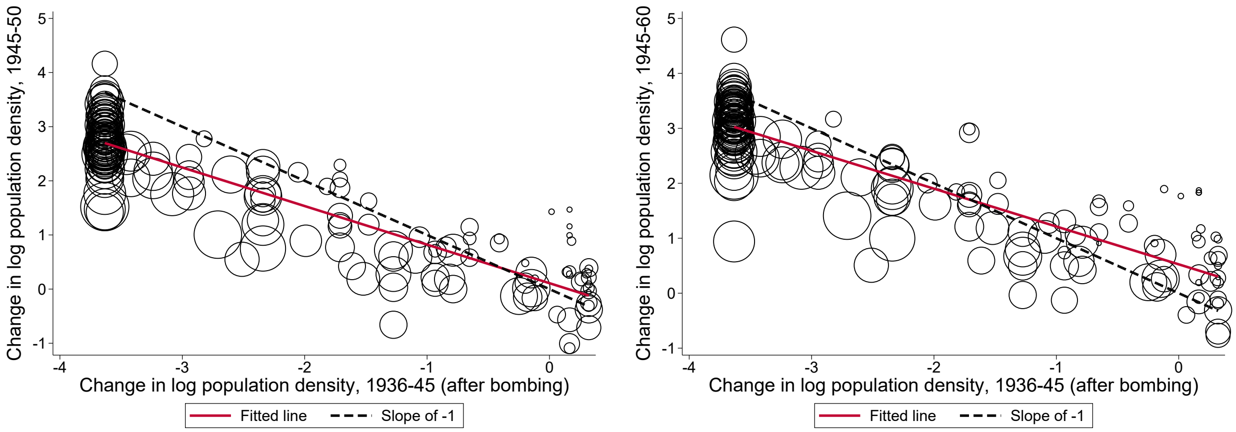
Accounting for Location Characteristics We have documented the quick recovery of Hiroshima's city center. We now examine the extent to which the recovery of the city center can be explained by the observed location characteristics that could directly affect amenities and productivity independently of the local density of economic activities, such as altitude and access to natural water.

Before proceeding with the regression analyses, we discuss heuristically why the locational advantage of central Hiroshima may not account for its resurgence. Following Krugman (1993), we consider two types of location characteristics: natural location characteristics (known as "first nature") and built location characteristics (known as "second nature"). For the first, natural conditions within the city, such as altitude and distance to water, are homogeneous because our geographic scope is limited and most of the city lies within 6 kilometers of the city center.[24] For the second, the built advantages of central Hiroshima were substantially damaged by the bombing. The city center of Hiroshima, areas around *Hacchobori* and

[23]We note that the spatial autocorrelation is unlikely to drive our results. First, using Conley's (1999) standard error to accommodate the spatial autocorrelation within 1 kilometer of each observation does not alter the statistical significance. Second, the residuals do not have a statistically significant correlation with distance from the CBD. Similarly, we also find that the potential spatial autocorrelation of errors would also be inconsequential after controlling for location characteristics. Finally, we aggregate the blocks into 30 groups according to the distance from the CBD. Running the same regression using these less spatially-granular samples yields −0.693, which is very close to −0.712.

[24]In particular, the majority of Hiroshima is located in the delta of the *Ota* river, characterized by a flat terrain with loose soil. The flat terrain was an important reason why the US chose Hiroshima as the bombing target (see footnote 6). Moreover, much of the city is close to water, as the city is cut through by many branches of the *Ota* and faces the sea to the south.

Figure 4: Relationship between population changes from 1945–1950 and population changes due to the atomic bombing by block



(a) Population changes 1945–50 **(b)** Population changes 1945–60

Note: The figures plot changes in the log of population density from 1945 to 1950 or 1960 with those from 1936 to 1945, which were largely driven by the atomic bombing. Each circle represents a block, 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 a line of slope −1 (dashed line), which would be obtained if population changes from the bombing were completely reversed in the post-war period.

Kamiya-cho, is located next to Hiroshima castle, a historical amenity that had been a symbol of the city since the samurai period. The center was also adjacent to the former center, called *Nakajima-cho*, which developed during the samurai period due to its convenient access to the castle and water transportation. These advantages were lost following the bombing. Hiroshima castle was completely destroyed as was *Nakajima-cho*. Although the city center may have retained some transportation advantage, jobs and other economic amenities would have been eliminated as central neighborhoods were completely destroyed and other areas of the city likely enjoyed better conditions after the bombing, as can be seen in other Japanese cities.[25]

We now use our regression model (1) to formally assess the role of locational advantages. Specifically, we control for the observable characteristics of each block. If the recovery was primarily driven by the attractive location characteristics of the destroyed areas, then γ would approach zero as a large part of the post-war population growth would be explained by them. For natural location characteristics, we control for the distance to the nearest water, altitude and ruggedness, dummy variables of bad soil conditions and the adjacency to rivers, and geographic coordinates.[26] As built location characteristics that can be con-

[25] In Japan, some large cities did see their centers shift after the war (e.g., Yokohama, Kobe). In Yokohama, Takano (2023) documents that the city center moved to an area with transportation advantages after the requisition of the former city center by the U.S. Army for nearly ten years. In the context of Hiroshima, the areas around Hiroshima station also provided convenient access to transportation but experienced much less destruction from the bombing, which could have made Hiroshima station the potential new center of Hiroshima.

[26] We make two remarks about natural location characteristics. First, considering potential radioactive contamination would, if anything, reinforce the main finding of our reduced-form analysis that the city center recovered. Since radioactive contamination is a ”bad” that makes the city center less attractive, failing to control for it would underestimate the strength of the recovery. Second, the proximity of water and river adjacency might not only capture their values as natural amenities but also disamenities

Table 1: Change in the population density and war-time damage

	(1)	(2)	(3)	(4)	(5)	(6)
	Change in log population density 1945–1950					
Change in log population density 1936–1945 (γ)	-0.7120[a]	-0.7695[a]	-0.8251[a]	-0.8769[a]	-0.8525[a]	-0.9371[a]
	(0.0271)	(0.0390)	(0.0476)	(0.0581)	(0.0525)	(0.0451)
p-value from testing $\gamma = -1$	0.000	0.000	0.000	0.036	0.006	0.165
Natural location characteristics (first nature)		Yes		Yes	Yes	Yes
Built location characteristics (second nature)			Yes	Yes	Yes	Yes
Pre-war trends in population					Yes	
Within 3 km of the city center						Yes
Number of blocks	174	174	174	174	174	158
R-squared	0.808	0.837	0.831	0.859	0.874	0.874

Note: We report the OLS estimates of equation (1). Natural location characteristics consist of log distance to the nearest water, a dummy for river adjacency, log altitude, ground slope and its square, geographical coordinates (latitude, longitude, and their interaction), and a dummy for bad soil conditions. Built location characteristics consist of log distance to the nearest station, log distance to Hiroshima port (*Ujina* port), log distance to the nearest cultural asset, the initial housing stock condition (the fraction of moderately-destroyed or intact buildings), and the 1940 zoning (dummies for whether the block includes housing area, commercial area, and commercial street area). We also include a dummy for blocks belonging to Hiroshima city prior to its expansion in 1929, which proxies for the initial infrastructure quality, and a dummy for blocks to the east side of *Motoyasu* river because town planning after the bombing was administered by the Hiroshima city government on the east side while the west side was administered by the Hiroshima Prefecture government. In column 5, we also control for the pre-war (1933-1936) population growth rate and its square. In column 6, we confine the sample to blocks within 3 kilometers of the city center. We report the p-value from testing the null $\gamma = -1$, meaning that the population density converged back to the 1936 city structure. Heteroskedasticity-robust standard errors in parentheses. [a] indicates significance at the 1 percent level.

sidered as given right after the bombing, we control for distance to the nearest train station as of 1950, distance to Hiroshima port, distance to the nearest cultural asset, and the quality of housing stock after the bombing.[27] Our built location characteristics also include dummy variables representing the 1940 zoning regulation. We also include a dummy for the original blocks of Hiroshima city, which are defined as belonging to Hiroshima city prior to its expansion in 1929, to account for the possibility that the infrastructure quality might be better in the original city area.[28] In addition, we control for a dummy for blocks to the east side of *Motoyasu* river to capture the fact that some part of the urban planning after the bombing was administered by the Hiroshima City government on the east side while the west side was administered by the Hiroshima Prefecture government.

Columns (2)–(4) of Table 1 present the regression results when controlling for location characteristics. Column (2) controls for natural conditions. We find that natural characteristics do not account for the recovery as the coefficient γ actually moves closer to −1. Column (3) controls for built conditions, again finding that γ gets closer to −1 relative to Column (1). In Column (4) we control for both natural and built location characteristics. We estimate $\gamma \simeq -0.88$, which is even closer to −1. This conclusion remains in

of illegal housing, which was prevalent along the river (Hiroshima Prefecture Government and Hiroshima City Government 2014; Semba 2016).

[27] We measure the quality of housing stock by the fraction of moderately destroyed or intact buildings. As an additional control for housing conditions, we use the number of public housing units constructed between 1945 and 1950 in a robustness check. This has little impact on the regression results (see Appendix B.2 for details).

[28] Evidence suggests that as of 1929, infrastructures such as water, sewage, and electricity were already fully developed in the original blocks. For instance, 96% of households in the original blocks had already used tap water. Source: the 1953 Hiroshima City Water Supply Statistics (*Hiroshima-shi jousuidou toukeihyou*).

Column (5) when controlling for pre-war trends in the population. Note that in Columns (1)–(5), we can also reject the null of perfect path independence ($\gamma = -1$), meaning that the post-war city structure is somewhat different from the pre-war one. Nevertheless, we consistently find γ closer to −1 rather than 0, meaning that the city structure exhibited a strong recovery tendency. Moreover, the observed location advantages of the pre-war city center do not explain its recovery, as the degree of recovery γ becomes stronger after conditioning on observed location characteristics.[29]

Column (6) of Table 1 replicates Column (4) while restricting our sample to blocks within 3 kilometers of the city center. Within such a small area, it is harder to attribute the recovery of the destroyed areas to unobserved fundamentals because the location characteristics are likely more homogeneous.[30] Within this small homogeneous sample, we find that γ gets even closer to −1 relative to Column (4). This result suggests that unobserved location advantages of the destroyed areas may not be the main driver of the recovery. Taken together, our results suggest that the recovery of the city structure was not driven by the advantageous location characteristics of the destroyed areas.

To illustrate the magnitude of the recovery of the *within-city* population distribution of Hiroshima, we compare our estimates to Davis and Weinstein (2002), which examines the recovery of the *across-city* population distribution of Japan after WWII using the analogous regression specification as equation (1). In Table 1, we obtain the coefficient γ between −0.71 (Column 1) and −0.94 (Column 6). Davis and Weinstein (2002, Table 3) finds the coefficient from −0.76 to −1.05, which seems slightly larger in absolute value than our estimates but they substantially overlap. Overall, the strength of the recovery of the city structure (i.e., the *within-city* population distribution) in Hiroshima is comparable to that of the Japanese system of cities (i.e., the *across-city* population distribution).[31]

Testing Recovery via Alternative Specification Besides our main specification (1), we use an alternative regression specification where we regress the logarithm of population density in 1950 on the logarithm of population density in 1936 and 1945 and observed location characteristics:

$$\ln \text{Popdens}_{i,t} = \gamma_1 \ln \text{Popdens}_{i,1945} + \gamma_2 \ln \text{Popdens}_{i,1936} + \eta X_i + v_i \tag{2}$$

The coefficient γ_1 captures how much the initial conditions right after the bombing shapes the post-war city structure. γ_2 captures the degree of resilience: how much the post-war city structure resembles the pre-war city structure. Note that this specification is equivalent to equation (1) if we impose that the sum of two coefficients ($\gamma_1 + \gamma_2$) equals one. This alternative specification allows us to address two concerns. First, the measurement error in the 1945 population may introduce a negative bias into the coefficient γ in equation (1). Specifically, a positive measurement error reduces the outcome variable while increasing

[29]We have also calculated Oster's (2019) bound, which accounts for the presence of unobserved location characteristics. Consistent with the results that the degree of recovery becomes stronger by controlling for observable location characteristics, the Oster's bound indicates a stronger recovery than our estimates in Table 1.

[30]Table A.3 in the Appendix suggests that the standard deviations of the observed location characteristics are smaller for blocks within 3 kilometers of the city center. A similar idea has been invoked in Schumann (2014) in a different context.

[31]Yet, our results do not necessarily reject Davis and Weinstein's (2002) view that exogenous location characteristics primarily determine *across-city* population distribution. This situation is consistent with our findings that, *within the city*, fundamental location characteristics have little impact on population distribution.

the explanatory variable in equation (1), but not in equation (2). Second, by regressing the 1950 population density on location fundamentals (X_i), we can determine the extent to which the city structure can be explained by location fundamentals. If γ_2 becomes near zero once the location fundamentals are controlled for, then resilience of the city structure found in Table 1 would be primarily driven by the fundamentals.

Table B.1 in the Appendix presents the results of estimating equation (2). Columns (1)–(3) of Table B.1 address the first concern of measurement error. We find that the 1936 population density, i.e., the pre-war city structure, is much more strongly associated with the 1950 population density than the 1945 population density, immediately after the bombing. Notably, the 1945 density is no longer significant when the built location characteristics are controlled for. As in Column (6) of Table 1, Column (4) of Table B.1 restricts the sample to areas within 3 kilometers of the CBD to limit the heterogeneity in location fundamentals. Reassuringly, the above conclusion remains valid in Column (4). Overall, the findings in Table 1 are robust to this alternative specification, and the city structure exhibits a strong recovery tendency.

Next, in Columns (5) and (6) of Table B.1, we regress the 1950 population density solely on location fundamentals to determine the extent to which they account for the city structure. While there is some evidence suggesting that some location characteristics, such as distance to water and zoning areas in 1940, are significantly associated with post-war population density, the ability of the specification containing only fundamentals to explain population density is substantially worse than that of our baseline specifications in Columns (3) and (4), which include 1936 and 1945 population density. Indeed, the R-squared of Columns (3) and (4) of Table B.1 is substantially larger than that of Columns (5) and (6). Therefore, the city structure tends to recover to the pre-war city structure, above and beyond the tendency that blocks with advantageous location fundamentals achieve higher population density. This result aligns with our conclusion drawn from Table 1, which suggests that the recovery was not primarily due to the advantageous location fundamentals of the destroyed areas and that other forces likely induced the recovery.

3.3 *Robustness*

We provide further reduced-form evidence on the recovery of the city center by exploiting other information and specifications. In addition, we show that recovery to the pre-war city structure was also observed in Nagasaki, the second city hit by the atomic bombing, and discuss the implications.

Recovery of Employment Distribution In Section B.2 of the Appendix we analyze the impact of the atomic bombing on the distribution of employment. We find that the regression results are very similar to those in Table 1 for the population distribution. As illustrated in Figure A.7 of the Appendix, the pre-war employment distribution also has a monocentric city structure and the central location in employment is the same as the center of population distribution. The recovery of such a monocentric city structure occurred not only for the residential population but also for the employment.

Recovery of Land Price Distribution Unfortunately, we do not have comprehensive land price data in the pre-war period. However, for both pre-war and post-war periods, we are able to measure the location with the highest land price in the city, which could be interpreted as the center of the city. In both 1931 and 1959, the highest land price was observed near *Hacchobori*, the city center both before and after the war.[32] Thus, the resurgence of central Hiroshima is also observed in land prices.[33]

Characteristics of Neighboring Blocks In Section B.2 of the Appendix, we consider the possibility that the post-war population growth rate of a block may depend not only on its own characteristics but also on the characteristics of neighboring blocks. To consider the characteristics of neighbors, we adopt the so-called "SLX model" from the spatial econometrics literature (Halleck Vega and Elhorst 2015) and add spatial lags of the following four neighborhood characteristics to our main regression (1): (i) the log change in population induced by the bombing; (ii) the location characteristics; (iii) the population distribution right after the war that is meant to capture market access after the bombing; and (iv) the geographical area size of blocks.[34] Table B.3 in the Appendix shows that including these spatial lag variables has only a modest impact on our regression results.

The Recovery of Nagasaki In Section B.3 of the Appendix, we examine the city structure of Nagasaki, the second city destroyed by an atomic bomb. As in Hiroshima, the damage in Nagasaki was catastrophic: around 70,000 people were killed and almost all buildings within 2 kilometers of the epicenter were wholly destroyed (Nagasaki City Government 1977). However, in Nagasaki, the atomic bomb hit the outskirts of the city (see Figure B.1a in the Appendix). This is in contrast to Hiroshima, where the atomic bomb hit the city center.[35] Despite this difference, recovery to the pre-war city structure was also observed in Nagasaki. Figure B.1b shows a fitted line from the estimating equation (1) for Nagasaki. Our coefficient of interest is around -0.88 and statistically indistinguishable from -1, suggesting the strong recovery of the city structure in Nagasaki. This similar pattern of recovery in Nagasaki offers two additional implications. First, it bolsters the external validity of our recovery result in Hiroshima. Second, it may limit the importance of potentially lower development costs on large empty plots or creative destruction in our context because the center of economic activities could have shifted toward the completely destroyed periphery of Nagasaki if these factors had been crucial, but we do not find such a shift.[36]

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

[33]This approach can be extended to analyze the recovery of city structure in other bombed cities due to the relatively mild data requirements. Based on the highest land price points reported in Suzuki (2024), we observe that the city center does not move in many other cities in which the city center experienced extensive bombing, such as Tokyo, Maebashi, Takamatsu, and Kagoshima. This suggests that the recovery of the destroyed city center is not specific to the case of the atomic bombing in Hiroshima.

[34]In particular, the market access term addresses the possibility that the city center could recover as the "donut hole of the city": it might still have relatively good market access thanks to its central location despite its destruction. The spatial lag term (iv) also addresses this possibility by controlling for the geographical centrality of each block in Hiroshima, which may affect the city structure (Thisse, Turner, and Ushchev 2024).

[35]Nagasaki was selected by historical coincidence. The US initially intended to bomb Kokura, but changed to the city center of Nagasaki due to the weather conditions. The weather conditions also prevented an attack on the city center of Nagasaki, and consequently the bomb was dropped on the outskirts of Nagasaki. See https://www.peace-nagasaki.go.jp/abombrecords/b020101.html (last accessed on October 28, 2023).

[36]The limited importance of large empty lots or creative destruction in our context may be due to construction technology. While the demolition of old buildings facilitates high-rise buildings by providing a large vacant lot and may enhance productivity when there is an incentive for building taller (Hornbeck and Keniston 2017), Japanese technology for high-rise buildings right after WWII was relatively limited and the shortage of construction materials made high-rise buildings even more unavailable (Hiroshima City Government 1971). Consistent with this, Yamasaki, Nakajima, and Teshima (2023) show that in Tokyo, having a large empty plot increased the value of land only after the advancement of skyscraper technologies in the 1970s.

Summary of Reduced-form Analysis Taken together, our reduced-form analysis reveals that (i) the population distribution in the city recovered back to its pre-war state within five years after the bombing and (ii) the recovery was not explained by the observable location characteristics we control for. To further understand the mechanism behind the resilience of the city structure, we consider the following two mechanisms that can explain the recovery of the city center of Hiroshima. First, there could be some unobserved locational advantages in the destroyed city center that persisted through the bombing (e.g., scenic views) or appeared after the bombing (e.g., durable infrastructure investment). Second, people may have expected the recovery of the destroyed city center when making location choices, and the incentive to again live and work in the city center came from agglomeration forces due to the expected high density as in the pre-war period. To analyze these possibilities, we develop and calibrate a quantitative spatial model that incorporates both agglomeration forces and unobserved location characteristics as potential explanations for the recovery.

4 Theoretical Framework

In this section, we present a dynamic quantitative spatial model to understand the mechanisms of the recovery. To account for the impact of the atomic bombing on the dynamics of the internal city structure during the recovery, the model incorporates forward-looking location choice, durable floor space, migration frictions, commuting, agglomeration forces, and heterogeneous location fundamentals. Individuals make decisions about their residence and workplace subject to migration frictions. They do so taking into account continuation values, defined by the expected future value of living and working in their chosen locations. Developers also provide durable floor space that can be used for residence and production, given the initial floor space stock. A worker's residence and workplace are potentially different, which defines the equilibrium commuting patterns within the city. Locations differ in productivity and amenities that are determined by both agglomeration forces and location fundamentals. Our model is the first tractable dynamic quantitative model of an internal city structure that possesses these elements in a unified framework. Appendix C provides the details of the derivations.

Time is discrete and indexed by t. We consider a single city (Hiroshima City) and a large economy (Hiroshima Prefecture or Japan). The city consists of a discrete set of locations represented by $\mathcal{C}$. We typically use the subscripts n and n' to refer to the place of residence of a worker and the subscripts i and i' to refer to their place of work. The number of locations in the city $N = |\mathcal{C}|$ is fixed over time. The city is located within a larger economy that is modeled as a single location, denoted by o. Locations in the city correspond to blocks and are differentiated by fundamental productivity, amenities, land endowments, initial floor space stock, and geography. Fundamental productivity and amenities capture exogenous locational advantages for production and residence, respectively, and can change over time. The land endowment of each block is constant over time.

Individuals in the economy live for a finite time, T. The mass of the population in the larger economy is denoted by M and is exogenous. While we assume that M is time-invariant, the total population of the city changes over time through migration flows. 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. Individuals outside the city (o) are prohibited from commuting into the city for work. Production occurs in every location in the economy, and firms produce a homogeneous final good that can be freely traded across locations. In each period, an individual may receive an opportunity to change their residence and workplace with some exogenous probability. Given an opportunity to change locations, individuals choose their locations in a forward-looking way, taking into account the expected future values of living and working in particular locations. These forward-looking location choices allow us to characterize the transitions of the population and employment distributions in the city, which depend on agents' expectations about the future.

4.1 *Production*

Firms in the economy are competitive and produce a homogeneous final good. The production technology of a representative firm in location $i \in \mathcal{C}$ is:

$$Y_{it} = A_{it} \left(\frac{L_{it}}{\gamma^L} \right)^{\gamma^L} \left(\frac{H_{it}^m}{\gamma^H} \right)^{\gamma^H} \left(\frac{X_{it}}{1 - \gamma^L - \gamma^H} \right)^{1-\gamma^L-\gamma^H}, \tag{3}$$

where Y_{it} is production in location i, A_{it} is productivity, L_{it} is employment in location i, H_{it}^m is commercial floor spaces used for production, and X_{it} is final goods as the intermediate input at period t. γ^L is the share of labor and γ^H is the share of commercial floor spaces in production, and $\gamma^L + \gamma^H < 1$. Productivity (A_{it}) is determined by the fundamental productivity and employment density in the location:

$$A_{it} = a_{it} \left(\frac{L_{it}}{S_i} \right)^{\alpha}, \tag{4}$$

where a_{it} represents the exogenous component of productivity and S_i is the area size of location i that is time-invariant. The parameter α controls the contemporaneous productivity agglomeration forces with respect to the employment density, and a positive value of α implies that a higher employment density increases productivity. This is in line with numerous empirical findings (Ciccone and Hall 1996; Arzaghi and Henderson 2008) and microfounded by different mechanisms in agglomeration economies (Duranton and Puga 2004).

The homogeneous good is freely traded and chosen as the numeraire.[37] Let w_{it} denote the wage rate and q_{it}^m denote the price of the commercial floor spaces. The first-order conditions for profit maximization and zero profits imply:

$$\frac{1}{A_{it}} (w_{it})^{\gamma^L} (q_{it}^m)^{\gamma^H} = 1. \tag{5}$$

Observe that in (5) the wage rate at location i in period t is determined by exogenous productivity, employment density, and price of floor spaces in that location.

[37] We can incorporate the block-specific costs of transporting the homogeneous good to the outside world. Suppose that the numeraire produced in block i is exported to the outside world subject to the iceberg trade cost: $\tau_i \geq 1$ units of goods must be shipped to sell one unit. This is isomorphic to the case with productivity A_{it}/τ_i in our model.

4.2 *Preferences*

Individuals live for finite periods, consume a homogeneous tradable good and floor spaces for residential use, and inelastically supply one unit of labor. Individuals are hand-to-mouth, always spending their wage w_{it} in period t. Preference takes the Cobb-Douglas form, in which μ is the share of expenditure on residential floor spaces and $1-\mu$ is that on homogeneous tradable good. Therefore, their period utility from living in location n and working in location i at period t is:

$$\ln u_{int} = \ln B_{nt} + \ln w_{it} - \mu \ln q^r_{nt} - \ln \kappa_{int}, \tag{6}$$

where B_{nt} is the common utility benefit from residential amenities at residential place n in period t, w_{it} is labor earnings in workplace i, q^r_{nt} is the price of residential floor spaces, and κ_{int} is the utility cost due to commuting from n to i.

The value of the amenities in a residential place (B_{nt}) depends on the fundamental value of the amenities and the population density:

$$B_{nt} = b_{nt}\left(\frac{R_{nt}}{S_n}\right)^{\beta}, \tag{7}$$

where b_{nt} is an exogenous component in the value of amenities for each location and R_{nt} is the population of location n in period t. In this specification, the elasticity of amenities with respect to population density (β) captures the strength of the net agglomeration effect in a residential place.[38]

Outside the city (o), individuals receive the common utility u_{ot} in period t, which is exogenous in every period. Because u_{ot} governs the attractiveness of living in Hiroshima City relative to the outside economy, it captures aggregate shocks that affect the whole city of Hiroshima.

4.3 *Forward-looking Location Choices*

Workers are forward-looking in making migration decisions subject to the exogenous migration frictions. At the end of period t, share $\theta_t \in (0,1)$ of workers in the economy can change their locations and share $1-\theta_t$ of workers will remain in their current locations in the next period $t+1$. If $\theta_t = 1$, all workers are able to change their location pairs. A low value of θ_t leads to stickiness in workers' location decisions.[39] Intuitively, due to the high fixed cost of moving, migration occurs when an exogenous event arrives, such as job loss or life-cycle shocks. θ_t is interpreted as the probability of experiencing such an event.

When a worker obtains the opportunity to change their locations at the end of period t, they draw idiosyncratic shocks related to location choice in the period $t+1$. For an individual worker, the idiosyncratic shock is independently drawn from a time-invariant independent Type-I extreme distribution $F(\varepsilon) = \exp(-\exp(-(\varepsilon + \Gamma)))$ where Γ is the Euler-Mascheroni constant. At the end of period t, workers

[38] In Appendix C.4 we provide a microfoundation for this specification, where we consider consumption amenities in a residential neighborhood.

[39] This Calvo-style migration friction is also adopted in other recent quantitative spatial models to capture the persistence of migration decisions (Caliendo, Dvorkin, and Parro 2019 Section 5.3; Heblich, Trew, and Zylberberg 2021). This approach is attractive in a setting such as ours in which bilateral migration flows are unobserved.

decide their residence and workplace for the next period considering the option value $\{V_{int+1}\}$ associated with each workplace and residence pair.

Consider a worker ω living in n and working in i at period t. When the worker can move to a different location pair in the next period, they solve the following location choice problem:

$$v_{int}(\omega) = \ln u_{int} + \max\left\{\rho V_{i'n't+1} + \sigma\varepsilon_{i'n't+1}\ ;\ \rho V_{ot+1} + \sigma\varepsilon_{ot+1}\right\} \tag{8}$$

for $t = 1, 2, \cdots, T-1$. $V_{i'n't+1}$ refers to the value function implied by choosing a different residence n' and workplace i' in period $t+1$ and V_{ot+1} is the option value of choosing to live outside the city. $\rho \in (0,1)$ is the discount factor governing the importance of the future values and σ is a positive constant governing the variance of the idiosyncratic shocks. An individual makes a forward-looking migration choice of residence and workplace at $t+1$ given the path of the exogenous and endogenous variables. In particular, an individual correctly anticipates the path of the population distribution (R_{nt}) and employment distribution (L_{it}) that are endogenously determined in equilibrium. We assume away bilateral mobility costs as they are likely sufficiently small within the city.[40]

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

$$V_{int} = \ln u_{int} + (1-\theta_{t+1})\rho V_{int+1} + \theta_{t+1}\sigma \ln\left[\sum_{i'\in\mathcal{C}}\sum_{n'\in\mathcal{C}} \exp(\rho V_{i'n't+1})^{1/\sigma} + \exp(\rho V_{ot+1})^{1/\sigma}\right], \tag{9}$$

for $t = 1, 2, ..., T-1$. The first term is the current utility from residence n and workplace i. The second term is the expected value of staying at the same location pair in the next period when no migration opportunity is realized, with probability $1-\theta_{t+1}$. The third term is the expected value when a worker is able to change their location pair, with probability θ_{t+1}.

For workers residing outside the city, their option value for $t = 1, 2, ..., T-1$ is:

$$V_{ot} = \ln u_{ot} + (1-\theta_{t+1})\rho V_{ot+1} + \theta_{t+1}\sigma \ln\left[\sum_{i'\in\mathcal{C}}\sum_{n'\in\mathcal{C}} \exp(\rho V_{i'n't+1})^{1/\sigma} + \exp(\rho V_{ot+1})^{1/\sigma}\right]. \tag{10}$$

When workers have an opportunity to migrate, they can choose any location pair. Therefore, the last term in the value function is the same as in equation (9). For the last period $t = T$, equations (9) and (10) are written as $V_{inT} = \ln u_{inT}$ and $V_{oT} = \ln u_{oT}$ because future considerations are absent.

Using our assumption that the idiosyncratic shocks are independent and follow a Type-I extreme value distribution $F(\varepsilon)$, we derive the share of workers that live in n and work in i in the next period $t+1$ when they have a migration opportunity:

$$\lambda_{int+1} = \frac{\exp(V_{int+1})^{\rho/\sigma}}{\sum_{i'\in\mathcal{C}}\sum_{n'\in\mathcal{C}} \exp(V_{i'n't+1})^{\rho/\sigma} + \exp(V_{ot+1})^{\rho/\sigma}}, \quad i, n \in \mathcal{C}. \tag{11}$$

[40]Unlike Caliendo, Dvorkin, and Parro (2019) we do not observe bilateral migration flows. This is likely inconsequential as Gechter and Tsivanidis (2023) estimates that in a within-city setting, the fixed cost of moving, which we capture by the Calvo-style shock mobility friction, is substantially larger than the moving cost that increases with moving distance.

This probability λ_{int+1} characterizes the location dynamics of workers in the city for period $t+1$. Workers choose their pair of residence and workplace, correctly anticipating future changes in commuting costs, wages, and residential amenities. Since there is no residence-workplace specific migration cost, equation (11) applies to all workers with a migration opportunity in period t. In addition, the share of workers that live outside the city in period $t+1$ conditional on being able to change their location pair is given by probability $\lambda_{ot+1} = 1 - \sum_{i \in \mathcal{C}} \sum_{n \in \mathcal{C}} \lambda_{int+1}$. Equation (11) shows that the probability of choosing to live in n and work in i is independent of the outside utility V_{ot+1} once conditional on living in the city. This independence arises from the Type-I extreme value distribution (Train 2009), which makes the model calibration tractable for analyzing internal city structures.

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

$$L_{int+1} = (1-\theta_{t+1})L_{int} + \theta_{t+1}\lambda_{int+1}M. \tag{12}$$

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 retained the same workplace and residence from the last period, and the second term is the total number of workers who either moved in from outside the city or changed location pairs within the city. Since the commuting market clears, the mass of workers in workplace i becomes:

$$L_{it+1} = (1-\theta_{t+1})L_{it} + \theta_{t+1}\left[\sum_{n\in\mathcal{C}} \lambda_{int+1}\right] M, \tag{13}$$

where the mass of workers in workplace i is the sum of workers who have no opportunity to change locations and those who join workplace i in period t. Analogously, the mass of workers residing in n becomes:

$$R_{nt+1} = (1-\theta_{t+1})R_{nt} + \theta_{t+1}\left[\sum_{i\in\mathcal{C}} \lambda_{int+1}\right] M. \tag{14}$$

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

Conditional on the wage variation and exogenous location characteristics, the mobility of workers in our model is controlled by the parameter of Calvo-style stickiness θ_t and taste shocks σ. We emphasize that they have different interpretations. Calvo-style migration frictions capture the immobility of workers even if they would like to change their locations. Intuitively, this reflects any 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 degree of sorting in response to utility differences. We discuss how we can identify these two parameters from the data in Subsection 5.1 below.

4.4 *Floor Spaces*

There are competitive developers in the city. They supply floor spaces that can be utilized for residential and commercial use given the current stock of floor spaces. Developers combine homogeneous final goods and land to produce floor spaces, and their production technology exhibits a constant return to scale. Given the floor space price in location n for period $t+1$, Q_{nt+1}, their production of floor spaces in period $t+1$ is given by:

$$J_{nt+1} = \bar{h}_t Q_{nt+1}^{\eta} S_n, \tag{15}$$

where $\bar{h}_t$ is an exogenous term of the construction of the floor spaces and η captures the supply elasticity of floor spaces.[41] Floor spaces are depreciated in every period at a constant rate $\psi \in (0,1)$ in a city. Therefore, the dynamics of floor spaces are:

$$H_{nt+1} = (1-\psi)H_{nt} + J_{nt+1} = (1-\psi)H_{nt} + \bar{h}_t Q_{nt+1}^{\eta} S_n \tag{16}$$

for $t = 0, 1, \cdots, T-1$. The floor spaces increase more in the location where floor space prices (Q_{nt+1}) are high and land size (S_n) is large. In each period, the profit of developers in period $t+1$ is extracted by absentee landlords. Landlords live for finite periods as workers and only consume homogeneous goods. Appendix C.3 contains the details of the problem for landlords.

4.5 *Floor Space Market Clearing*

We let v_{nt} refer to the average labor income of individuals living in location n in a city at period t, which is defined by a weighted average of the wages in all workplaces in a city using the probabilities of commuting from n to i conditional on living in n as weights. Namely, the average labor income is as follows:

$$v_{nt} = \sum_{i \in \mathcal{C}} \frac{L_{int}}{\sum_{i' \in \mathcal{C}} L_{i'nt}} w_{it} \tag{17}$$

Then, the aggregate expenditure on floor spaces for residence in location n in period t is given by $\mu v_{nt} R_{nt}$. We assume that there are no frictions in the allocation of floor space between residential and commercial use. Therefore, a no-arbitrage condition in the floor space market ensures that there is a single price of floor space for both residential and commercial use: $Q_{nt} = q^r_{nt} = q^m_{nt}$ for any period t and any location in a city.[42] In a nutshell, the floor space market clearing condition in period t is:

$$Q_{nt} H_{nt} = \mu \left[\sum_{i \in \mathcal{C}} \frac{L_{int}}{\sum_{i' \in \mathcal{C}} L_{i'nt}} w_{it} \right] R_{nt} + \frac{\gamma^H}{\gamma^L} w_{nt} L_{nt}, \tag{18}$$

where the left-hand side is the value from supplying floor space, and the right-hand side is the total value of demand for floor space by residents and firms.

4.6 *General Equilibrium*

We now define a forward-looking competitive equilibrium in this dynamic economy. The economy starts with the initial distributions of population (R_{n0}), employment (L_{i0}), commuters (L_{in0}) and floor spaces (H_{n0}). The exogenous variables of the model are block-level fundamental productivity (a_{it}) and amenities

[41] Appendix C.3 lays out the problem of competitive developers. The parameter of the floor space supply elasticity η is a one-to-one mapping with the constant share of land in the construction of floor spaces ($\tilde{\eta}$). Specifically, the floor supply elasticity satisfies $\eta = (1-\tilde{\eta})/\tilde{\eta}$ for the relationship.

[42] Our sample shows no blocks fully specialized in residential or commercial use during the post-war period.

(b_{nt}), the sizes of blocks (S_n), the parameter in the production of floor spaces ($\bar{h}_t$), bilateral commuting costs (κ_{int}), the degree of worker location stickiness (θ_t) and utility outside the city (u_{ot}). The economy-wide parameters in the model are the parameters of firms for labor and floor space demand (γ^L, γ^H), the expenditure share on floor spaces by residents (μ), the parameter of floor space depreciation (ψ), the parameter of floor space supply elasticity (η), the agglomeration forces in productivity (α), agglomeration forces in amenities (β), the discount factor of workers (ρ), the variance of idiosyncratic shocks in location choices (σ), and the mass of workers in the economy (M). Then, a dynamic equilibrium is defined as follows:

Definition 1. *Given the exogenous variables of the model and economy-wide parameters, a dynamic equilibrium is characterized by the sequences of wages $\{w_{it}\}$, floor space prices $\{Q_{nt}\}$, population $\{R_{nt}\}$, employment $\{L_{it}\}$, commuters $\{L_{int}\}$, floor spaces $\{H_{nt}\}$, and value functions associated with location choices $\{V_{int}\}$ such that (i) the value functions of workers for their location choices $\{V_{int}, V_{ot}\}$ satisfy (9) and (10) with $V_{inT} = \ln u_{inT}$ and $V_{oT} = \ln u_{oT}$ for the last period T, (ii) the commuters are determined by (12), (iii) the commuting market clears in the city and the masses of workers in workplace and residential locations are given by (13) and (14), (iv) firms' profit maximization and zero profit condition (5), (v) developers maximize their profits and the total floor spaces are given by (16), and (vi) floor space prices are determined by the floor space market clearing (18).*

Since productivity and amenities evolve with employment and population density, we can summarize a dynamic equilibrium by population, employment, floor space prices, and the value function adjusted by the value of living outside the city. Equations (5), (9), (10), (13), and (14) constitute $N^2 + 2N$ equations for each t, which can be solved for $N^2 + 2N$ endogenous variables of population $\{R_{nt}\}$, employment $\{L_{it}\}$ and value function $\{V_{int}\}$ given floor space prices $\{Q_{nt}\}$. Then, equations (16) and (18) together pin down the floor space prices $\{Q_{nt}\}$ in each period. Location choices are based not only on current real income but also on the option values associated with each pair of locations, and they determine the future path of location choices taking into account future shocks. The detailed expositions of the equilibrium are found in Appendix D.

We define a steady-state equilibrium for the economy as one in which the population and employment distributions are constant over time. We summarize theoretical results for the existence of equilibrium in the following proposition:

Proposition 1. (i) *Given the initial state and exogenous variables, a dynamic equilibrium exists such that for all periods $t = 1, 2, \cdots, T$, $R_{nt} \geq (1-\theta_t)R_{nt-1}$ and $L_{it} \geq (1-\theta_t)L_{it-1}$; (ii) A steady-state equilibrium exists when $\alpha/\gamma^L \neq \sigma/\rho$ and $\beta \neq \sigma/\rho$.*

Proof. See Appendix D.1 and D.2. ■

Proposition 1 shows the existence of a dynamic equilibrium and a steady state, but there may be multiple dynamic equilibria and steady states. Regarding the multiplicity of the steady state, in Appendix D.2 we find that under a regularity condition, the steady state in our model is unique when agglomeration forces are absent. However, if the agglomeration parameters are non-zero, there is a potential for multiple steady states. Therefore, relatively strong agglomeration forces may lead to a multiplicity of steady states. Intuitively, with strong agglomeration forces, individuals have the incentive to collocate in any particular place with a high population or employment density, but there are multiple potential places for the center of population or employment.

Regarding the multiplicity of the dynamic equilibrium, while the analytical characterization of the dynamic equilibria in our quantitative model is not tractable, we provide in Appendix E detailed analytical characterizations using a simplified version of the model. The results are consistent with the earlier stylized models of "history versus expectations" in the spatial economy (e.g., Krugman 1991; Matsuyama 1991; Baldwin 2001; Ottaviano 2001). We first find that the dynamic equilibrium is unique in the presence of severe migration frictions or weak agglomeration forces. In our context, however, the unique dynamic equilibrium from the initial state in 1945 is not able to rationalize the strong recovery of the central area of the city unless the fundamental locational advantages of the destroyed city center are substantially better than those in the periphery.

In contrast, when agglomeration forces are strong and migration frictions are moderate, as in Hiroshima right after the war, multiple dynamic equilibria could exist: one equilibrium of strong recovery in the city center and another equilibrium of no recovery. Intuitively, with strong agglomeration forces, people prefer any particular place with a high population or employment density. Therefore, when the mobility friction is sufficiently low, there are multiple dynamic equilibria, as the central location in equilibrium may remain in the pre-war peripheral location or shift to the destroyed pre-war city center. When migration frictions are severe or agglomeration forces are weak, this logic of multiple dynamic equilibria fails and we obtain the unique dynamic equilibrium. The numerical simulation results in Appendix E.3 also confirm that the dynamic equilibria can indeed be multiple under relatively strong agglomeration forces and moderate migration frictions; and the model can explain the recovery of the totally destroyed location as the center of population and employment.

In our calibration, we solve the model backward for the observed changes in population and employment. We do not require that the economy is exactly in the steady state in the last period T, but we assume that it is sufficiently close to the steady state so that the commuting gravity equation approximately holds, which we estimate in our calibration. Our calibration does not require the uniqueness of the steady state nor a unique path to the steady state because it relies only on the values in the observed equilibrium, as in Ahlfeldt et al. (2015). This feature allows us to calibrate the model when there are multiple steady states so that different expectations may lead to different steady states. When we undertake counterfactuals, we explicitly acknowledge the potential for multiple equilibria.

5 Quantitative Analysis

Our goal in this section is to show how the present model can be matched to the observations in Hiroshima. Our quantification proceeds in three steps, which we discuss in turn. Appendix F presents further details on the calibration.

In Subsection 5.1 we first obtain the commuting costs (κ_{int}) by estimating a model of the travel mode choice. Our model accommodates two aspects of migration frictions. We calibrate each using different information. The dispersion of idiosyncratic taste shocks (σ) is calibrated based on the calibrated discount factor (ρ) and the commuting elasticity (ρ/σ) estimated by a gravity equation for commuting. We infer the stickiness (θ_t) from additional data on the share of people who remain in the same residence over time. The outside utility (u_{ot}) is chosen to match the observed total population of the city. In addition, we calibrate the model's production and utility function parameters (γ^L, γ^H, μ), floor space supply elasticity (η), and floor space depreciation rate (ψ) based on studies in the literature and historical sources for our sample period. Table 2 summarizes the parameter values.

Given the parameters, in Subsection 5.2, we leverage the structure of the model to back out the composites of amenities and productivity that rationalize the observed population and employment changes over time. Intuitively, changes in population and employment by block are, by revealed preference, informative of the option values associated with each location. These option values reflect the attractiveness of each location as a residence or workplace, which is a composite of location fundamentals and agglomeration forces.

In Subsection 5.3, we estimate the key parameters that govern the strength of the agglomeration forces in terms of productivity (α) and amenities (β). We first recover the unobserved fundamentals of productivity and amenities, using the estimated option values and changes in population and employment densities over time. For these fundamentals, we then define the moment conditions and estimate the agglomeration force parameters. In Subsection 5.4 we discuss the robustness of our estimated values for the agglomeration forces. In the estimation, we use the post-recovery location choice data from 1955 to 1975.

Using the data in the recovery period (1945–1950), we assess how well our model fits the observed changes in population and employment distributions in the recovery period in Subsection 5.5. To this end, we first use the location choice data for 1950, which is not used for calibration, to back out the locational advantages in the recovery period. We then decompose these advantages into two components: (i) the advantages in productivity and amenities explained by the model and (ii) the structural residuals in productivity and amenities. We demonstrate that our model predicts the central recovery only with the first model-based component.

5.1 *Step #1: Parameter Calibration (ρ, σ, κ_{int}, θ_t, u_{ot}, γ^L, γ^H, μ, η)*

Travel mode choice and commuting costs (κ_{int}) To estimate commuting costs, we extend the model to incorporate the choice of travel modes following Ahlfeldt et al. (2015) and Tsivanidis (2022). There are five modes of transportation: walk, bicycle, car, bus, and train. In each period, a worker chooses the mode of transportation that minimizes the realization of observed and idiosyncratic travel costs, given their workplace and residence. We assume that the idiosyncratic travel cost follows a Gumbel distribution with two nests: (i) public modes: walk, bus and train; and (ii) private-vehicle modes: bicycle and car. We estimate this nested discrete choice model of travel mode by exploiting the 1987 Hiroshima City Person Trip

Survey and compute the expected commuting cost for two types of workers who may or may not use cars.[43] We then estimate the overall expected travel cost for residence n and workplace i before the realization of the idiosyncratic travel costs, using information on the car ownership rate in Japan in different years. We discuss the details in Appendix F.1.

Commuting gravity (ρ/σ) We suppose that the economy approximately reaches a steady state in the last period and estimate the commuting elasticity of workers using the 1987 Hiroshima City Person Trip Survey.[44] Plugging the average commuting time in 1987 from above into the equilibrium commuting pattern in the steady state yields the following gravity equation:

$$\ln L_{in} = -\frac{\rho}{\sigma}\bar{c}_{in} + \phi_i + \eta_n + \chi, \tag{19}$$

where $\bar{c}_{in}$ is the log bilateral commuting cost determined by travel time, ϕ_i and η_n are workplace and residence indicators and χ is a constant. ρ/σ corresponds to the commuting elasticity with respect to the commuting cost in our model, which decreases in σ (the dispersion parameter of the idiosyncratic shock) and increases in ρ (the discount factor). Lower σ and higher ρ imply a higher sensitivity of migration decisions to utility differentials. We estimate (19) using Pseudo-Poisson Maximum Likelihood to allow for heteroskedasticity and zero bilateral commuting flows for some pairs. Our baseline parameter estimate of ρ/σ is 8.019, which is close to the estimates of the elasticity of commuting flows with respect to commuting costs in Dingel and Tintelnot (2020). In the following, we set ρ/σ to be 8 for all t. See Appendix F.1 for the detailed estimation results.

Discount factor (ρ) We assume that the annual discount rate is 8.5 percent. This value is consistent with the discount rate widely used in the context of developing countries (e.g., Garcia-Cicco, Pancrazi, and Uribe 2010), which is consistent with the relatively low GDP per capita of Japan right after the war.[45] Since one period in our calibration corresponds to five years, we set $\rho = (1/1.085)^5 \simeq 0.66$.

Migration frictions (θ_t) Individuals can change their residence and workplace in period t with probability θ_t. We assume that people change their residence when obtaining a migration opportunity and match this migration friction parameter to the probability that people change their residence during five years, the length of one period in the calibration. The 1960 Population Census reports that around 86 percent of people stayed in the same residence from the prior year. Thus, we set the parameter $\theta_t = 1 - (0.86)^5 \simeq 0.53$ for all $t \geq 1955$, that is, our calibration period.[46]

Utility outside the city (u_{ot}) In our model, the value of the outside option u_{ot} only affects the total population of Hiroshima so that our analysis of the internal city structure is independent of u_{ot}, as in Ahlfeldt et al. (2015). This is because of the logit structure in our model: the location choice probability is independent of the outside utility conditional on living in the city (Train 2009). Given this, we take the observed

[43] When a car is unavailable, the nest of private vehicle modes is reduced to a single choice (bicycle).

[44] Alternatively, we can suppose that individuals can always migrate ($\theta_t = 1$) after the last period.

[45] In 1950, Japan's GDP per capita was less than one-fifth of the United States.

[46] Although the context is different, this value is very close to the value used in Heblich, Trew, and Zylberberg (2021).

Table 2: Citywide parameter values and sources

Parameter	Notation	Value	Source
Commuting elasticity	ρ/σ	8	Estimation of commuting gravity equation
Five-year discount factor	ρ	0.66	Garcia-Cicco, Pancrazi, and Uribe (2010)
Migration frictions for 1955-75	θ_t	0.53	The 1960 Population Census
Cost share of labor in production	γ^L	0.7	Fukao, Tatsuji, and Settsu (2019)
Cost share of floor space in production	γ^H	0.1	Valentinyi and Herrendorf (2008)
Expenditure share for residential floor space	μ	0.15	The 1966 Hiroshima household expenditure survey
Floor space supply elasticity	η	4	Yoshida (2016), Kii et al. (2022)
Floor space depreciation rate	ψ	0.05	The 1968 Annual Report of Building Construction

Note: This table summarizes the parameter values in the model. The first column lists each parameter; the second column contains the corresponding notation; the third column gives its calibrated value; and the fourth column summarizes the source for the calibrated value.

total population of Hiroshima city as given and assume that the value of the outside option is adjusted to rationalize this total population, which essentially amounts to assuming a closed city model (Fujita 1989). Formally, the model predicted population of the city is $(1-\lambda_{ot})M = \mathbb{M}_t$, $t = 1, ..., T$, where λ_{ot} is the probability of choosing to live and work outside the city computed in the model and $\mathbb{M}_t$ is the observed total population of Hiroshima city. We can solve this for the sequence of the outside utility $\{u_{ot}\}_{t=1}^{T}$ that rationalizes the observed total population.

Production cost share (γ^L, γ^H) and Expenditure share (μ) We calibrate the model's production and utility function parameters. For the former, we assume a value for the share of labor in the production of $\gamma^L = 0.7$, which is in the middle of the share of labor compensation in the 1950s to 70s for Japan (Fukao, Tatsuji, and Settsu 2019). We assume a share of floor space in production costs of $\gamma^H = 0.1$, which is around the estimated value of the expenditure share on the structure for the nonagricultural sector in Valentinyi and Herrendorf (2008). Finally, we set a value for the share of housing in consumer expenditure (μ) equal to 0.15, following the observed spending share for housing in the Household Expenditure Survey in 1966 (Hiroshima City Government, Citizen's Affairs Department 1966).

Floor space supply elasticity (η) To determine the floor supply elasticity (η), we exploit the equilibrium relationship in our model $\eta = (1-\tilde{\eta})/\tilde{\eta}$, where $\tilde{\eta}$ denotes the input share of land in floor space production. Following Yoshida (2016) and Kii, Tamaki, Kajitani, and Suzuki (2022) that estimate production function of new housing in Japan, we set $\tilde{\eta} = 0.2$. This value also lies in the middle of Epple, Gordon, and Sieg (2010) and Combes, Duranton, and Gobillon (2021). This implies the floor supply elasticity of $\eta = 4$.

Floor space depreciation rate (ψ) The five-year depreciation rate (ψ) for the floor spaces is set to be 0.05 based on the ratio of the eliminated floor space to the total floor space. We use the floor space data described in Section 2.2 to observe the total floor space in Hiroshima city as of 1967. We can observe the amount of floor space eliminated in 1967 in the 1968 issue of the Annual Report of Building Construction (*kenchiku toukei nenpou*). This yields an annual depreciation rate of approximately 1%, and converting this into five years leads to $\psi = 0.05$.

5.2 *Step #2: Inversion of the Option Values*

When individuals are forward-looking, their location choices depend on their current real income and the option value associated with each location. In this step, we back out the option values by leveraging the population and employment dynamics of the model. Specifically, for $t = 1, 2, \cdots, T-1$, the option value of location n as a residential place can be summarized by the continuation value of amenities in the location:

$$\Xi_{nt} = b_{nt} \left(\frac{R_{nt}}{S_n} \right)^{\beta} \prod_{\tau=t+1}^{T} \left[b_{n\tau} \left(\frac{R_{n\tau}}{S_n} \right)^{\beta} \right]^{\prod_{s=t+1}^{\tau} \rho_s (1-\theta_s)} . \tag{20}$$

Analogously, the option value of location i as a workplace can be written as

$$\Omega_{it} = a_{it} \left(\frac{L_{it}}{S_i} \right)^{\alpha} \prod_{\tau=t+1}^{T} \left[a_{i\tau} \left(\frac{L_{i\tau}}{S_i} \right)^{\alpha} \right]^{\prod_{s=t+1}^{\tau} \rho_s (1-\theta_s)} . \tag{21}$$

These option values express the attractiveness of each location as a residence and workplace. They are a composite of amenities and productivity that include both fundamental amenities (b_{nt}) and productivity (a_{it}), and the agglomeration forces from population and employment density.

When $\theta_t = 1$, all workers can change locations every period; therefore, the future values of their choices are independent of their current location choices. In contrast, rarer migration opportunities (small θ_t) lead to more weight placed on the future evolution of amenities and productivity since workers are less likely to change their locations. In sum, these option values reflect the value of amenities and productivity for each location when workers choose locations in a forward-looking way.

Equations (13) and (14) imply that the option values (Ξ_{nt}, Ω_{it}) satisfy the following equations:

$$\begin{aligned} R_{nt} - (1-\theta_t) R_{nt-1} &= \sum_{i \in \mathcal{C}} \frac{K_{int} \left(\Lambda_{nt}^{-\mu} \Xi_{nt} \right)^{\rho/\sigma}}{\sum_{n' \in \mathcal{C}} K_{in't} \left(\Lambda_{n't}^{-\mu} \Xi_{n't} \right)^{\rho/\sigma}} [L_{it} - (1-\theta_t) L_{it-1}], \\ L_{it} - (1-\theta_t) L_{it-1} &= \sum_{n \in \mathcal{C}} \frac{K_{int} \left(\Lambda_{it}^{-\gamma^H/\gamma^L} \Omega_{it}^{1/\gamma^L} \right)^{\rho/\sigma}}{\sum_{i' \in \mathcal{C}} K_{i'nt} \left(\Lambda_{i't}^{-\gamma^H/\gamma^L} \Omega_{i't}^{1/\gamma^L} \right)^{\rho/\sigma}} [R_{nt} - (1-\theta_t) R_{nt-1}], \end{aligned} \tag{22}$$

where Λ_{nt} and K_{int} summarizes current and future floor space prices and commuting costs, respectively (see equations F.8 and F.9 in the Appendix for the definition). Intuitively, equation (22) states that the number of residents that actively choose to live in block n for period t, $R_{nt} - (1-\theta_t)R_{nt-1}$, is written as the sum of the products of the number of workers that actively choose to work in block i for period t, $L_{it} - (1-\theta_t)L_{it-1}$, and their conditional residential choice probabilities for location n given by $\frac{K_{int} \left(\Lambda_{nt}^{-\mu} \Xi_{nt} \right)^{\rho/\sigma}}{\sum_{n' \in \mathcal{C}} K_{in't} \left(\Lambda_{n't}^{-\mu} \Xi_{n't} \right)^{\rho/\sigma}}$.

We solve the system of equations (22) for the option values (Ξ_{nt}, Ω_{it}) conditional on the observed population (R_{nt}), employment (L_{it}), floor space prices (Λ_{nt}), commuting costs (K_{int}), and migration frictions (θ_t).[47] We can recover unique (Ξ_{nt}, Ω_{it}) that rationalize the observed changes in the mass of workers without using any information on the unobserved equilibrium outcomes and without making assumptions about the strength of the agglomeration forces.

[47] In Appendix F.3, we show the existence and the uniqueness of the option values, following the proof of Ahlfeldt et al. (2015; Lemma A.6 and Lemma A.7). Since equations (22) are homogeneous of degree zero because they exploit only information on the

5.3 *Step #3: Estimation of the Agglomeration Parameters (α, β)*

Next, we back out fundamental productivity (a_{it}) and amenities (b_{nt}) by using observed employment and population density, according to the inverted option values (Ξ_{nt}, Ω_{it}). Given the agglomeration forces (α, β), we use (20) and (21) to derive the fundamentals by location for each period $t = 1955, 1960, \cdots, 1975$. Then, we assume that fundamental productivity and amenities consist of location-fixed components ($\{a_i^F\}$, $\{b_n^F\}$), time-trend components ($\{a_t^*\}$, $\{b_t^*\}$), and time-varying errors ($\{a_{it}^{\mathrm{Var}}\}$, $\{b_{nt}^{\mathrm{Var}}\}$):

$$\ln a_{it} = \ln a_i^F + \ln a_t^* + \ln a_{it}^{\mathrm{Var}}, \quad \ln b_{nt} = \ln b_n^F + \ln b_t^* + \ln b_{nt}^{\mathrm{Var}}. \tag{23}$$

Location-specific productivity and amenities capture the fundamental advantages of locations. For example, natural conditions that are constant over time, such as altitudes and slopes, are included here. Manmade conditions that are approximately constant throughout our post-recovery period sample, such as durable infrastructure quality, are also included here. The trends of productivity and amenities reflect the change in their levels over time within the city. The time-varying errors ($\{a_{it}^{\mathrm{Var}}\}$, $\{b_{nt}^{\mathrm{Var}}\}$) are the structural residuals in our model, which are needed to match the observed population and employment distributions perfectly.

Averaging out the trend terms and taking the differences between two consecutive periods, we have:

$$\Delta \ln \left(\frac{a_{it}}{\widetilde{a}_t} \right) = \Delta \ln \left(\frac{a_{it}^{\mathrm{Var}}}{\widetilde{a}_t^{\mathrm{Var}}} \right), \quad \Delta \ln \left(\frac{b_{nt}}{\widetilde{b}_t} \right) = \Delta \ln \left(\frac{b_{nt}^{\mathrm{Var}}}{\widetilde{b}_t^{\mathrm{Var}}} \right), \tag{24}$$

where we denote the geometric mean across locations as $\widetilde{a}_t = \exp\left(\frac{1}{N}\sum_{i\in\mathcal{C}} \ln a_{it}\right)$.

The structural residuals of productivity and amenities in (24) difference out both common trends across all blocks in the city in each year and time-invariant locational advantages. Using (24), we consider the following moment conditions:

$$\begin{aligned} &\mathbb{E}[\Delta \ln(a_{it}/\widetilde{a}_t) \times \mathbb{1}_i(k)] = 0, \\ &\mathbb{E}[\Delta \ln(b_{nt}/\widetilde{b}_t) \times \mathbb{1}_n(k)] = 0, \end{aligned} \tag{25}$$

where $\mathbb{1}_n(k)$ is an indicator such that location n is in grid k, where the grid is defined based on the distance from the CBD. We define five grid cells based on the distance from the CBD and equally allocate blocks into these grid cells in our baseline specification.[48] We use the moment conditions (25) to estimate the parameters for the agglomeration forces.

Our identification assumption for using the moment conditions (25) is that log changes in the idiosyncratic fundamental productivity and amenities terms are not correlated with the distance from the city center. In other words, the systematic change in the gradient of economic activity relative to the distance from the CBD is explained, on average, by the mechanisms of the model rather than by systematic changes

relative migration probabilities across blocks within the city, the uniqueness is up to scale. Since we take the total population of Hiroshima City from the data and assume that the outside utility (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 migration between Hiroshima City and the outside world. We normalize the geometric mean of $\{\Xi_{nt}\}$ and $\{\Omega_{it}\}$ to one.

[48] We carry out a robustness check for the sensitivity of the estimates to the number of grid cells (using ten cells). See Table F.2 in Appendix F.8.

in the pattern of structural residuals (24). This identification assumption seems intuitively plausible in post-recovery Hiroshima because the spatial extent of our study is small and all blocks in the data experienced similar changes in the economic and political environment, implying that changes in fundamental amenities and productivity are unlikely to be correlated with distance from the city center.[49]

Table 3: Generalized method of moment estimates for agglomeration parameters

	(1) Productivity	(2) Amenities	(3) Productivity	(4) Amenities
Elasticity of the employment density (α)	0.103^a		0.111^a	
	(0.0002)		(0.0002)	
Elasticity of the population density (β)		0.213^a		0.223^a
		(0.0003)		(0.0004)
Sample of blocks	All blocks in the city		Blocks within 3 km of CBD	
Sample of periods	Every 5 years from 1955 to 1975		Every 5 years from 1955 to 1975	
Instruments	5 grids for CBD distance		5 grids for CBD distance	

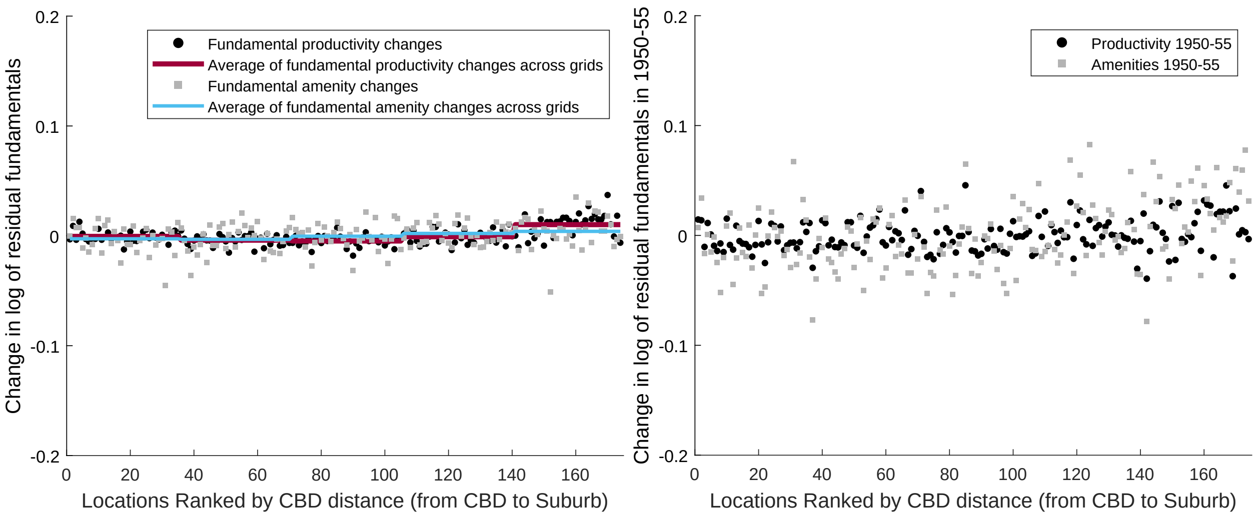
Note: This table reports the two-step generalized method of moments (GMM) estimates exploiting the moment conditions (25). The Eicker-Huber-White heteroskedasticity-robust standard errors are in parentheses. We use data for five periods (1955, 60, 65, 70 and 75). We define five grid cells according to the distance to the CBD for the moment conditions. In Columns (1) and (2) we use all 174 blocks in the city. In Columns (3) and (4), we use 158 blocks that lie within 3 kilometers of the CBD. ^{a} indicates significance at the 1 percent level.

Table 3 reports the estimation results using the two-step generalized method of moments (GMM). Columns (1) and (2) report our baseline estimates of the agglomeration parameters for productivity (α) and amenities (β), respectively. Overall productivity (A_{it}) in the workplace rises by around 10 percent when current employment density doubles. Turning to amenities, doubling the population density is associated with an 21 percent increase in the value of amenities. In Columns (3) and (4) in Table 3 we show similar results when we restrict our sample to blocks within 3 kilometers of the CBD. This result is reassuring because, by focusing on a smaller area, we expect changes in fundamental amenities and productivity to be more homogeneous as they face similar shocks and policies, making our identification assumption even more plausible.

We also assess the validity of our moment conditions in a number of ways. First, to confirm that changes in fundamental amenities and productivity are not correlated with distance from the city center, we plot them against the distance from the city center. Panel (a) of Figure 5 plots the average changes during our estimation sample period (1955–1975) and Panel (b) of Figure 5 plots the changes for the period 1950–1955, which are not used for our estimation. In both figures, the moment conditions appear plausible as the changes are generally independent of the distance from the CBD. Second, since the fundamental amenities and productivity are likely to be more homogeneous within a small geographic area, we also estimate the set of parameters using only blocks within 3 kilometers of the CBD. In particular, this addresses the potential concern of post-recovery suburbanization driven by systematic increases in attractiveness for

[49] Since the radioactivity level very quickly fell to a safe level (see Section 2.1) and our estimation data start in 1955, it was unimportant for changes in amenities and productivity.

Figure 5: Examining the moment conditions for changes in the location fundamentals



(a) Targeted moments: Average from 1955 to 1975 **(b)** Untargeted moments: From 1950 to 1955

Note: These figures display changes in the residuals of the fundamental amenities $\Delta \ln(b_{nt}/\tilde{b}_t)$ and productivity $\Delta \ln(a_{it}/\tilde{a}_t)$. The horizontal axis is expressed by a location index based on the distance from the CBD. In Panel 5a gray squares (black dots) show the average of the changes in the residuals of amenities (productivity) over four periods: 1955–60, 1960–65, 1965– 70, and 1970–75. The blue (red) line is the average value of this difference for amenities (productivity) in each of the five grids used by the moment condition. Panel 5b shows changes in the residuals of the fundamental amenities $\Delta \ln(b_{n,55}/\tilde{b}_{55})$ and productivity $\Delta \ln(a_{i,55}/\tilde{a}_{55})$ for 1950–1955. Each dot is an amenity residual for a block, and the squares are for productivity. See Appendix F.6 for more details.

either production or residence further away from the CBD.[50] Section 5.4 presents further results consistent with our moment conditions.

Because we estimate strong positive agglomeration forces in both amenities and productivity, the model could have multiple equilibria in light of Proposition 1. The strength of the agglomeration forces we estimate is broadly in line with those in the existing literature, although the direct comparison is difficult due to differences in the models and empirical contexts. Our estimated elasticity of productivity with respect to employment density is 0.1, which is comparable to many previous estimates of agglomeration forces in productivity (e.g., Rosenthal and Strange 2004; Ahlfeldt et al. 2015; Heblich, Redding, and Sturm 2020; Tsivanidis 2022) and also well within the range of estimates in the meta-analysis by Melo, Graham, and Noland (2009). Our estimated elasticity of amenities with respect to population density is 0.21. This value is slightly larger but relatively close to the estimates of Ahlfeldt et al. (2015) and Heblich, Redding, and Sturm (2020). Furthermore, the elasticity is consistent with the recent findings of the elasticity of substitution in the consumption of non-tradable goods in a city (Miyauchi, Nakajima, and Redding 2025), which serves as a microfoundation of the agglomeration force in amenities, as illustrated in Appendix C.4.

[50]We also demonstrate that fundamental productivity and amenities were not significantly changed by the atomic bombing, as evidenced by a comparison of the estimated fundamentals in the 1930s and 1955. We assume that the population distribution in 1930 is in a steady state, and fundamental productivity and amenities in the 1930s are estimated to rationalize the population distribution in 1936 and the employment distribution in 1938. This analysis implies that including any policies and public investments implemented in the ten years following the bombing, fundamental amenities and productivity did not change significantly from the pre-war period. See Appendix F.7 for the results.

5.4 *Robustness of the Agglomeration Parameter Estimates*

Instruments based on Pre-war Population Density A potential concern with defining instruments based on the distance to the CBD is that the results could be sensitive to the definition of the city center. To address this, we instead use the population density in 1936 to define the grid cells. We report the estimation results in Table F.2 in Appendix F.8. We find similar results: the agglomeration parameters for productivity and amenities are 0.096 and 0.205, respectively.

Spatial Spillovers in Productivity and Amenities So far, we have assumed that agglomeration forces in productivity and amenities are at work only in the local block. While this is consistent with empirical evidence that agglomeration forces are highly localized (e.g., Arzaghi and Henderson 2008; Ahlfeldt et al. 2015; Gechter and Tsivanidis 2023), productivity in each block may also depend on the employment of surrounding blocks. To consider the spatial spread of spillovers, we estimate the agglomeration forces when productivity and amenities are a function of employment and population density, with weights decreasing exponentially with travel time. Specifically, following Ahlfeldt et al. (2015), productivity in block i is: $A_{it} = a_{it}\left[\sum_{i'\in\mathcal{C}} e^{-\delta\tau_{ii'}}\left(\frac{L_{i't}}{S_{i'}}\right)\right]^{\alpha}$, where δ is a parameter characterizing the spatial decay of productivity and τ_{in} is travel time between blocks. When $\delta \to \infty$, there is no spatial spread of spillovers, as in our baseline specification. We specify amenities in an analogous way. Figure F.5 in Appendix F.8 shows the estimated values of the agglomeration parameters (α, β) given different values of spatial decay (δ). As we can see in the figure, the estimated values of the agglomeration parameters range from 0.10 to 0.12 for productivity and from 0.20 to 0.25 for amenities, which are close to the baseline estimates. In particular, when the spillover decay parameter δ is larger than 0.3, as estimated by Ahlfeldt et al. (2015), Figure F.5 suggests little impact of accommodating the spatial spillovers in our agglomeration parameter estimates.

Lagged Effects of Agglomeration Forces Our main model assumes that the amenities and productivity of each block depend on its current population and employment density. However, they could also depend on its past population or employment densities. First, current productivity could reflect the histories of capital, public goods and innovation as determined by past economic activities; second, current amenities could depend on the stock of housing or local infrastructure that is related to past population.[51] In addition to migration frictions, these effects also may induce history dependence. To take this into account, we specify productivity and amenities in period t as a function of current employment and population densities and the previous employment and population densities in period $t-1$, following Allen and Donaldson (2022). We estimate the parameters characterizing both the current and lagged spillover effects using similar moment conditions. Table F.3 in Appendix F.8 shows the results. The elasticity of productivity with respect to the current employment density is 0.154 and the historical employment density is −0.063. The elasticity of amenities with respect to the current population density is 0.212 and the historical population density is 0.001. Overall, the influence of the lagged population and employment density is small relative to that of the current density, and the strength of the contemporaneous density remains similar to our baseline

[51] Allen and Donaldson (2022) provide microfoundations for these specifications. In a previous version of this paper (Takeda and Yamagishi 2023), we also provided alternative microfoundations in the within-city context.

estimates.[52]

5.5 *Accounting for the Recovery: Location Choice for 1950*

We are now in a position to assess how well our calibrated model fits population and employment changes during the recovery period from 1945 to 1950, data that were not used for calibration. To this end, we evaluate how well the endogenous component of location advantages and the time-invariant unobserved characteristics can fit the workplace and residence choices of 1950, the first location choices made in our model after the atomic bombing. Intuitively, we evaluate how much of the incentive to work or live in a given location during the recovery period can be explained by our model. See Appendix G.1 for more details.

We first use equations (20) and (21) to construct the predicted option values of each location as a residence ($\Xi^F_{n,1950}$) and workplace ($\Omega^F_{i,1950}$), then substitute them into equation (22) to solve for the predicted population and employment in 1950. By construction, the option values in our model are a composite of (i) location-fixed advantages, (ii) the endogenous components of agglomeration forces, (iii) future option values associated with the location, and (iv) idiosyncratic shocks. Among these, factors (i) – (iii) capture the location advantages that our model can explain. In contrast, the idiosyncratic terms (iv), corresponding to ($\{a^{\text{Var}}_{it}\}$, $\{b^{\text{Var}}_{nt}\}$) in equation (24), are structural residuals in amenities and productivity, which fill in the discrepancy between the model prediction and the observed data.

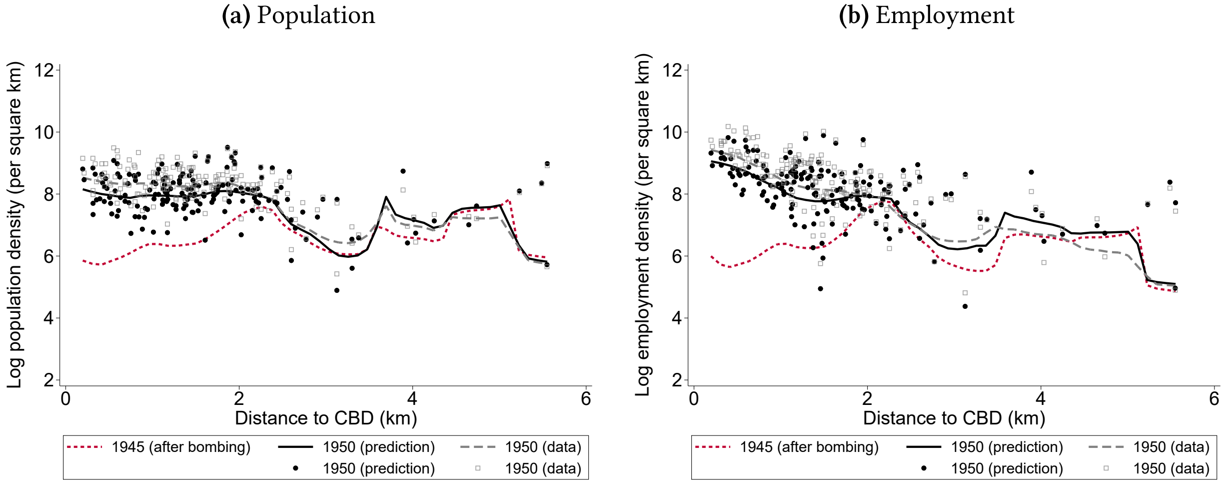
Therefore, to evaluate how well our model can fit the recovery, we exclude the structural errors when constructing the model-predicted option values for residence $\{\Xi^F_{n,1950}\}$ and workplace choices $\{\Omega^F_{i,1950}\}$. In obtaining the predicted location decisions for the recovery period (1945–1950), we use the parameter values from our main calibration, but we assume a higher probability of migration opportunity in this period (i.e., $\theta_{1950} = 0.9$) as available evidence suggests the mobility rate was substantially high during this period, possibly for war-related reasons such as job loss, housing destruction, or the end of temporary reallocation during the war (see Appendix A for more details). Theoretically, such high mobility after the war could be important in inducing the possibility of multiple dynamic equilibria, as discussed in Section 4.6 and Appendix E. Importantly, we assume that the block-fixed amenities and productivity, (a_{i1950}, b_{n1950}), equal the averages estimated for the post-recovery period 1955–1975.[53] In order to focus on the city structure, we follow Ahlfeldt et al. (2015) as in our calibration and suppose that the total population is the same as the data.[54] Appendix G.1 describes the computation procedure in more detail.

[52] Our estimates of agglomeration forces in productivity are broadly similar to those in Allen and Donaldson (2022), which uses long-run county-level data from the U.S. Yet, they find negative contemporaneous agglomeration forces in amenities. This difference may be because our model has the residential floor space market as a separate congestion force and we analyze a more spatially granular setting. The negative agglomeration forces in Allen and Donaldson (2022) may capture congestion in a local housing market, while our estimates of positive agglomeration forces may capture consumption externalities or neighborhood network effects.

[53] Consistent with this assumption about the stability of block-fixed fundamentals, we find in Appendix F.7 that block-fixed amenities and productivity are similar both in the pre-war and post-war periods.

[54] Under the assumption of the same total population as the data, we find that the welfare in the model-predicted city is higher than the data (see Appendix G.4 for the methodology of welfare calculation). This implies that the model predicts a stronger incentive to live in Hiroshima city than the data, rationalizing the recovery of Hiroshima's total population.

Figure 6: Recovery of population and employment: The endogenous part explained by our model



Note: Each figure overlays the observed log population density (Panel a) and employment density (Panel b) with local polynomial regressions using each on the distance from the CBD. We estimate three separate regressions: the 1945 population and employment densities (small dashed line); the observed 1950 population and employment densities (long dashed line); and the 1950 population and employment densities inferred under the counterfactual scenario in which we exclude the structural error components of amenities and productivity (solid line). Each dot represents a block, with different colors for the predicted density and the observed density.

Figure 6 illustrates the population and employment distributions predicted by our model for 1950. The horizontal axis is the distance to the CBD, and the vertical axis shows the population and employment density after the bombing in 1945, as observed in 1950 and as predicted by the model for 1950. For both population and employment, we find that our calibrated model successfully predicts the recovery of the city center, which we indeed observe in the data. The linear regression of the log of the observed population (employment) density in 1950 on the predicted population (employment) density by the model yields a coefficient of 0.80 (1.04) with a high R-squared around 0.75 (0.88).[55] This result shows that our calibrated model successfully explains the fast and strong recovery of the destroyed city center from 1945 to 1950.

6 The Role of Agglomeration Forces

Having demonstrated that our calibrated model can account for the recovery of central Hiroshima, we now analyze the role of agglomeration forces in the recovery. In Subsection 6.1 we undertake a counterfactual experiment in which we exclude agglomeration forces in both productivity and amenities from our calibrated model. In Subsection 6.2 we investigate the existence of multiple equilibria. Consistent with the importance of agglomeration forces, we numerically find an alternative equilibrium in which the city center did not recover. This suggests the possibility that expectations become self-fulfilling by selecting the recovery equilibrium among multiple equilibria.

[55]Note that the prediction of our model is substantially more accurate than just capturing the general tendency that blocks closer to the city center tended to have higher density in 1950. Indeed, regressing the log population (employment) density on the log distance from the city center yields an R-squared of around 0.20 (0.48), which is considerably lower than the R-squared from our model prediction.

6.1 *Agglomeration Forces as the Key Driver of the Recovery*

The city center recovers when individuals regard it as an attractive residence and workplace. Strong agglomeration forces can be a primary source of such attractiveness. These forces operate by increasing the expected population and employment density, which in turn leads to improved amenities and productivity. An alternative possibility is that the city center has attractive location fundamentals so that it attracts population and employment regardless of agglomeration forces. Which forces induced the recovery of central Hiroshima in our calibrated model? To consider these two possibilities, we compute the counterfactual population and employment distributions for 1950 when spillovers in amenities and productivity are absent.

We solve the model for the counterfactual equilibrium 1950 population and employment distributions using the same parameter values as Subsection 5.5 but setting both agglomeration parameters, α and β, to zero.[56] As in the baseline, individuals make forward-looking migration decisions taking into account future fundamental productivity, amenities, floor space prices, and commuting costs. Notably, as in Subsection 5.5, we assume that the fundamental amenities and productivity during the recovery period equal the average amenities and productivity during 1955-1975.[57] If agglomeration forces play the key role in explaining the attractiveness of the city center in our model, then this counterfactual exercise would not be able to predict the recovery.[58] Appendix G.2 describes the computation procedure in more detail.

Figure 7 shows the counterfactual population and employment densities in the absence of agglomeration forces. The model no longer predicts the recovery of the population and employment in central Hiroshima. This is in stark contrast to the main calibrated model in Figure 6. Given that the only deviation from our main calibrated model is the shutdown of agglomeration forces, this result highlights that agglomeration forces play the key model role in explaining the recovery of the city center. Note that, as discussed in the last paragraph of Section 3, the importance of agglomeration forces is in line with our reduced-form results that the observed fundamental location characteristics, which are independent of agglomeration forces, do not explain the recovery.

6.2 *Multiple Equilibria and the Self-fulfilling Expectations of Recovery*

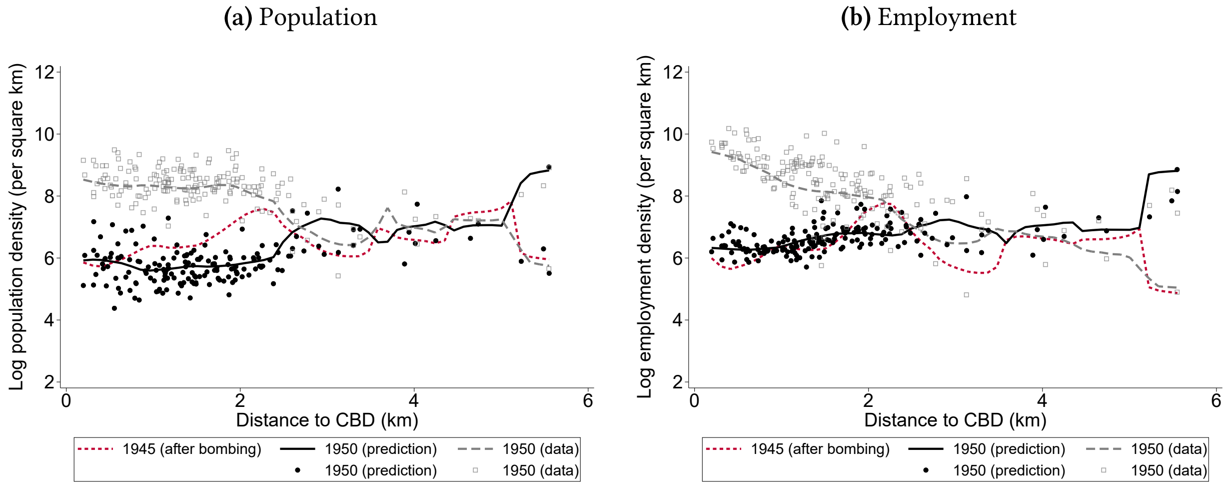
This section examines an alternative equilibrium in which the recovery does not occur. When agglomeration forces are important, as discussed in Section 4, the model may have multiple equilibria because whether the city center remains attractive depends on whether people expect a high-density city center in the near future. There could exist an alternative equilibrium in which central Hiroshima does not recover.

[56] To focus on the population and employment distributions within the city, as in Section 5.5, we assume in this counterfactual that the total population matches the observed data.

[57] This assumption on fundamental amenities and productivity is important because even without agglomeration forces, our model can fit any population and employment distribution in 1950 as long as the structural errors (a_{i1950}, b_{n1950}) can take any value. Therefore, the role of the agglomeration forces highlighted in this subsection presumes that the levels of fundamental amenities and productivity are similar to those in the post-recovery period 1955–1975. Consistent with this assumption, we find that the values of the structural errors (a_{i1950}, b_{n1950}) are similar to the 1955–1975 fundamentals.

[58] The parameters (α, β) capture not only the pure externalities of density but also other channels through which population or employment density affects productivity and amenities. In this counterfactual, we turn off all these density effects simultaneously.

Figure 7: Population and employment distributions with no agglomeration forces



Note: Each figure overlays the log population density (Panel a) and employment density (Panel b) with local polynomial regressions of each on the distance from the CBD. We run three separate regressions: one for the observed 1945 population and employment densities (small dashed line), one for the observed 1950 population and employment densities (long dashed line), and one for the inferred 1950 population and employment densities when we shut down agglomeration forces in both productivity and amenities (solid line). Each dot represents a block, with different colors for the predicted density and the observed density.

If so, the selection of the recovery equilibrium among multiple equilibria might be crucial in explaining the recovery of central Hiroshima.

Specifically, we present an example of an alternative rational-expectations equilibrium in which the city center does not recover. We use the parameter values and fundamentals estimated in Section 5 and assume that the total population matches the observed data. To find an alternative equilibrium, we start with guesses of population and employment. We use the observed 1945 population and employment distributions as our initial guess. Given this initial guess, we then solve for the dynamics of population and employment consistent with the equilibrium conditions. Subsequently, we update our initial guesses and repeat until convergence. Appendix G.3 describes the computation procedure in more detail.

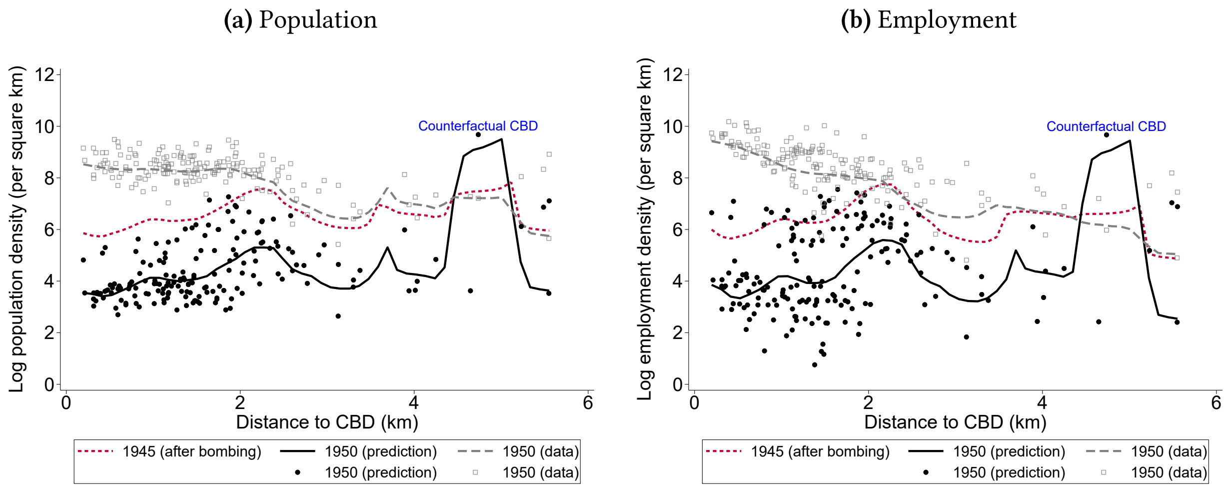
Figure 8 provides a visualization of the population and employment densities in an alternative equilibrium. We compare these with the realizations of population and employment in 1950 and the initial pattern of 1945. We label a block with a high concentration of population and employment in this counterfactual as a counterfactual CBD.[59] In Panel (a), we find that pre-war central Hiroshima does not recover, and its population density is even lower than the initial level in 1945. In Panel (b), we find a similar pattern for employment. In addition to finding that the counterfactual equilibrium illustrated in Figure 8 exhibits a totally different city structure than the observed equilibrium, we also find that workers' welfare is higher in this counterfactual equilibrium than in the observed equilibrium (see Appendix G.4).[60] Overall, these

[59]This block (*Niho machi*) is a plausible candidate for an alternative CBD, as it hosts highly productive firms, such as *Toyo Kogyo* (now known as Mazda Motor, a large automotive manufacturer), and is close to Hiroshima Port. See the map in Figure G.1. Appendix G.5 also presents other potential locations of counterfactual CBD.

[60]This result might be sensible given that the location of the city center of Hiroshima was historically determined by the Hiroshima castle, and the location of the castle did not necessarily reflect advantages in the modern economy (e.g., proximity to train stations and the Hiroshima port). In contrast, as discussed in Appendix G.5, the city center in counterfactual equilibria tends

results suggest that a totally different city structure could have emerged as an alternative equilibrium.

Figure 8: Population and employment distribution in an alternative equilibrium



Note: Each figure plots the log population density (Panel a) and employment density (Panel b) with local polynomial regressions of each on the distance from the CBD. We run three separate regressions: one for the observed 1945 population and employment densities (small dashed line), one for the observed 1950 population and employment densities (long dashed line), and one for the inferred 1950 population and employment densities in an alternative equilibrium (solid line) when people expect that the pre-war CBD will not recover and an alternative block located at the vertical dashed line will grow. Each dot represents a block, with different colors for the predicted density and the observed density. The location with the growing population and employment density is labeled "Counterfactual CBD".

This multiplicity of equilibria highlights the potential importance of self-fulfilling expectations as an equilibrium selection device (Krugman 1991; Matsuyama 1991). In our rational-expectations model, if people expect the recovery, then the recovery equilibrium would be selected because such expectations make the city center an attractive residence and workplace due to agglomeration forces. In contrast, if people do not expect the recovery of the city center, then no recovery equilibrium is realized as the city center remains unattractive. Therefore, our result suggests the possibility that the formation of expectations in recovery might have been crucial in inducing the recovery of central Hiroshima after the bombing.

7 Discussion on the Origin of Expectations in the Recovery

Our analysis has demonstrated that the emergence of expectations that the destroyed pre-war city center would regain high density post-war might have been crucial in explaining the recovery of central Hiroshima. We now discuss the potential factors contributing to the formation of recovery expectations, while we remain agnostic about *why* such expectations emerged.

Government Recovery Plan It is possible that the presence of a government recovery plan facilitated the formation of recovery expectations.[61] However, while the government recovery plan might have helped

to have such advantages. For further discussions on the comparison of welfare levels across different equilibria in the dynamic spatial economy, see. for example, Krugman (1991), Rauch (1993) and Monte, Porcher, and Rossi-Hansberg (2023).

[61]Here, we focus on the role of the government as a potential cause of optimistic expectation formation because our reduced-form analysis in Section 3 has already suggested that controlling for the direct impact of public policies, such as public housing

confirm the existing optimistic expectations, we believe it was unlikely to have played an important role as the initial seed of such optimistic expectations in Hiroshima because the publication of the plan lagged the onset of the recovery.[62] The delay in publishing the recovery plan might be because the atomic bomb severely damaged the functioning of the government itself in many ways. First, the governments faced a substantial shortage of human resources as many workers at the Hiroshima City or Prefecture Government were killed by the bombing, and even if they survived, many suffered from injuries or atomic bomb after-effects.[63] Second, the bomb destroyed public offices located near the city center, which led to the loss of resources and administrative documents necessary for the recovery plan. Finally, the government was substantially underfunded and implementation of the plan faced substantial difficulty.[64] Overall, the strict constraint on governmental activities due to the atomic bombing hindered the government from leading the recovery, especially at the initial stage of the recovery.[65] That said, despite all these severe difficulties faced by the government, our argument is still consistent with the possibility that even a small-scale public action to rebuild the city center induced optimism about the recovery among people.[66]

Land Ownership Land ownership is an additional factor to consider. However, in our context, the recovery is unlikely to be explained by the strong tendency of the original landowners to return to their prior homes. In particular, personal land ownership was quite rare in pre-WWII Japan; the rate of land ownership in pre-WWII urban areas in Japan was likely less than 10 percent and most residents were renters (Kato 1988).[67] Moreover, unlike conventional air raids, the death rate near the epicenter of the atomic bombing was nearly 100 percent, implying that the number of surviving landowners was small.[68] To further analyze the influence of land ownership on the recovery quantitatively, we carry out a counterfactual analysis in which we assume that landowners consisted of 20 percent of the total population in 1936 and those who survived the bombing returned to their pre-bombing block by 1950 due to personal attachment. However, without agglomeration forces, we do not find a strong recovery of central Hiroshima relative to the observations (see details in Appendix G.6). In this sense, considering landowners' location attachment does not

and zoning, does not explain the recovery.

[62]As seen in Figure A.6 in the Appendix, the recovery process had already started one year after the bombing. However, even the first version of the recovery plan was later than the first anniversary of the bombing.

[63]For instance, Hiroshima Prefecture Government and Hiroshima City Government (2014) documents that about two weeks after the bombing, only about 80 out of 1,200 city government workers could actually work because many were killed or heavily injured.

[64]While the government built some public housing even under the severe budget shortage, Appendix B.2 reports that controlling for the number of public housing units supplied during 1945–1950 does not alter our regression results.

[65]Consistent with this, Masaru Ono, a member of the Hiroshima City Government Reconstruction Bureau, recollects that the reconstruction bureau was formed in 1946 because people had already started coming back to the destroyed city center and the mayor realized the need to clarify the reconstruction plan in the center (Hiroshima City Government 1983b).

[66]This is in line with the earlier theoretical argument that even a small-scale policy can greatly affect the spatial distribution of economic activities if the government could successfully affect expectations (e.g., Baldwin, Forslid, Robert-Nicoud, Ottaviano, and Martin 2011).

[67]The fraction of households owning a home was also quite low in pre-WWII urban Japan at around 25 percent (Hinokidani and Sumita 1988).

[68]The land title survived as in the pre-war period: When a landowner died, the land was inherited to their family member. The turnover of business owners was also high. According to Hiroshima City Government (1983a), in 1958, approximately 28 percent of stores on a notable shopping street, *Hondori*, remained in the same location as before the war, while the remaining 72 percent of stores had begun operating only after the bombing.

change our main conclusions that agglomeration forces and the optimistic expectations might have been crucial in rationalizing the recovery of central Hiroshima. That said, our argument is consistent with the possibility that even the small number of surviving landowners that returned to their original locations played an important role in forming expectations in the recovery.[69]

Salient Location Characteristics Another possibility is that the tangible presence of some location characteristics in the city center may have anchored expectations. The first example is the transportation system, especially the tram network. While the direct benefit of access to trains does not appear to be essential to the recovery as we consider transportation access in both the reduced-form and structural analyses, the relatively quick restoration of the pre-war train network may have anchored people's expectations of reconstruction. Another example is the Hiroshima castle. Although the castle itself was completely destroyed by the bombing and was unlikely to provide direct amenity value, its historical salience may have made it difficult for people to expect a situation in which the city center moved away from the castle. Despite our claim in Section 3 that observable location characteristics do not seem crucial in accounting for the recovery of the city center, our argument is consistent with the possibility that some salient location characteristics mattered through fostering recovery expectations.

Narratives Lastly, the narrative of "rebuilding from the atomic bombing" may have sounded like a compelling success story after the tragedy and been shared widely (Shiller 2017).[70] If people were aware that many others shared this narrative, they could expect that the city structure would look like the pre-war Hiroshima in their memory, which might have, in turn, induced the recovery of the pre-war city center.[71]

Summary The above-mentioned factors may influence the attractiveness of each location by either directly improving location-specific fundamental amenities (b_{nt}) and productivity (a_{it}), or via expectation channels. However, as discussed in Subsections 5.5 and 6.1, the ability of our calibrated model to explain the recovery comes primarily from agglomeration forces, not location-specific fundamental amenities and productivity. In the expectations channel, several factors may alter expectations regarding the future population and employment distributions after the bombing, thereby affecting the attractiveness of each location via agglomeration forces. The self-fulfilling nature of expectations found in Subsection 6.2 suggests the possibility that the above-mentioned factors might have played a key role in inducing the recovery by fostering optimistic expectations about the destroyed pre-war city center.

[69]For example, the expectation among people that some landowners will return might foster recovery expectations even among non-landowners. Another possibility is that the landowners might be local community leaders and they might persuade survivors who evacuated from the center to move back. For instance, Ryoichi Nakayama, an owner of an music instrument shop in the city center, tried to convince his neighbors who were evacuating from the center and pessimistic about the center's recovery, to go back to the center (Hiroshima City Government 1983b).

[70]Although it is challenging to empirically assess how powerful and widespread such a narrative was, the 1946 Statistical Abstract of Hiroshima is suggestive in stating '... rumors like "nothing will grow here for 75 years" immediately disappeared among people with their burning desire to rebuild...' (p. 4, translated by the authors).

[71]This relates to the idea of "memory-based expectations," in which people form expectations based on their past experiences (Malmendier and Wachter 2024). To gauge its potential importance, we simulate the model as in Subsection 5.5 assuming that workers expect the population distribution in 1936 and the employment distribution in 1938 to be realized again in 1950. The simulation shows that such purely memory-based expectations, which are optimistic about the recovery of the city center, also induce the recovery of the city center.

8 Conclusion

A major source of public policy debate is the resilience of cities in the face of large shocks. To shed light on this question, we examine the atomic bombing of Hiroshima, which drastically changed the city's structure by completely destroying the city center while sparing the city's outskirts. We collect and digitize new historical data on Hiroshima's population, employment, wartime destruction, and fundamental location characteristics at the city block level. Then, we document the strong resilience of Hiroshima's city structure: the destroyed city center recovered its population density just five years after the atomic bombing. Our reduced-form analysis reveals that controlling for prominent observable location characteristics, such as altitude and access to natural water and train stations, is not crucial in explaining the recovery.

To identify the mechanism behind the recovery, we develop and calibrate a novel dynamic quantitative model of the internal city structure that incorporates commuting, forward-looking migration decisions, durable floor space, migration frictions, agglomeration forces, and heterogeneous fundamentals across locations. Estimating the model with post-recovery data (1955–1975), we find strong agglomeration forces in productivity and amenities. The calibrated model successfully explains the resurgence of population and employment in the city center after the bombing (1945–1950), and agglomeration forces are essential for this success.

In the presence of strong agglomeration forces, multiple equilibria may exist because the city center does not become attractive if it is not expected to achieve high density. We find that our calibrated model has an alternative dynamic equilibrium where the city center fails to recover. This suggests the possibility that the recovery might crucially depend on people's expectations, as they can be self-fulfilling and select the equilibrium of recovery. We argue that certain factors, such as government recovery plans, the anchoring effect of salient location characteristics in the city center, property rights, and popular narratives of rebuilding, might have led people to expect that the destroyed areas would once again achieve high density as in the pre-war period. Taken together, our quantitative findings highlight the potential importance of the agglomeration forces, multiple equilibria, and expectations in shaping the resilience of the city structure.

Beyond the context of Hiroshima's resilience, our results suggest that agglomeration economies and expectations are potentially important determinants of the dynamics of the city structure. This suggests the possibility that policymakers might be able to substantially change the dynamics of the city structure if they could influence expectations about the future city structure. Our theoretical framework developed in this paper could serve as a useful starting point for performing quantitative analyses to understand how the organization of economic activities within cities evolves over time. However, our model does not incorporate an explicit process in which people form expectations. Developing an additional understanding of the ways in which agents can form expectations about a city's future structure is an interesting area for further research.

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Online Appendix for "The Economic Dynamics of City Structure: Evidence from Hiroshima's Recovery" (Not for publication)

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Outline of the Appendix

Appendix A describes the details of the data sources and the construction of the data. Appendix B provides additional reduced form results, including an analysis of the different Japanese city, Nagasaki, which also experienced an atomic bombing in August 1945. Appendix C presents detailed derivations of the model elements, and Appendix D defines the dynamic equilibrium and shows some analytical results for the equilibrium and steady-state. In Appendix E, we present a simplified version of the model to derive analytical characterizations of the dynamic equilibrium. Appendix F provides details for calibration in Section 5 in the main text. Lastly, Appendix G contains details of the counterfactual analysis in Section 6 of the main text, along with auxiliary results.

A Details on the Data

A.1 *Basic Data*

Maps, Spatial Units and Sample Selection The city block (*cho cho moku*) is our spatial unit of analysis. As our main source of geographic and city block data, we use GIS data on block boundaries as of the bombing constructed by Takezaki and Soda (2001). We make several adjustments to block boundaries. Specifically, 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

Table A.1: Summary of the number of blocks and the sample selection procedure

	Counts
Blocks in Hiroshima city as of bombing	197
Blocks that later became Hiroshima Peace Memorial Park	6
Missing building destruction data	8
Missing pre-bombing population data	2
Missing pre-bombing establishment data	2
Blocks exhibiting inconsistency with our calibrated θ_t	3
Blocks that are more than 6km away from city center	2
Dropped blocks in total	23
Blocks in our final sample	174

address this issue by aggregating a handful of blocks in Takezaki and Soda (2001).[1] After these adjustments of the block boundaries, our data have 197 blocks. We take this as the number of blocks as of bombing.

We then drop some blocks due to missing data and other reasons, which we summarize in Table A.1. First, we drop six blocks that later became Hiroshima Peace Memorial Park. Second, we drop eight blocks whose building destruction rate data are missing. Third, we drop two blocks whose pre-war population data are missing because they were parks or military bases. Fourth, we drop two blocks whose data on the number of establishments in 1938 are missing in Hiroshima City Government (1971). Fifth, we drop three blocks that exhibit unusually large changes in population or employment in certain periods, which is likely due to idiosyncratic events outside the model, so that they are inconsistent with our calibrated migration friction parameter θ_t.[2] Finally, to ensure that our geographical scope is small, we drop two blocks whose centroids are more than 6 kilometers from the city center.[3] In our final sample, there are 174 blocks.[4] Table A.1 summarizes the sample selection procedure described above.

Throughout this paper, we use the block boundaries of 1945 as our unit of analysis. Since block boundaries were stable from 1933 to the 1960s, this allows us to conduct our analysis on the recovery without being affected by changes in block boundaries. In particular, our reduced-form analysis is unaffected at all as it does not use data after 1960. Since our calibration of the model uses the data up to 1975, to deal with changes in block boundaries, we also digitize the block boundaries as of 1966 and 1976. For 1966, we use the map found in a 1965 block-level population report on Hiroshima (*Hiroshima-shi machi-betsu jinkou setai shiryou shouwa 40-nen kokusei chosa yori*). For 1976, we use the Hiroshima City map (*Hiroshima shi-*

[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*.

[2] We drop *Hakushima kita-machi*, *Iwamiya-cho*, and *Toriya-cho*. While we are not completely sure of why these blocks exhibit sudden changes 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 $0.0025km^2$) made them prone to idiosyncratic shocks.

[3] We also drop an unpopulated remote island (*Touge-shima*) from our sample. We keep a remote island called *Kanawa-jima*, belonging to the *Niho machi* block in our sample because it is relatively close to the mainland and had a major shipyard.

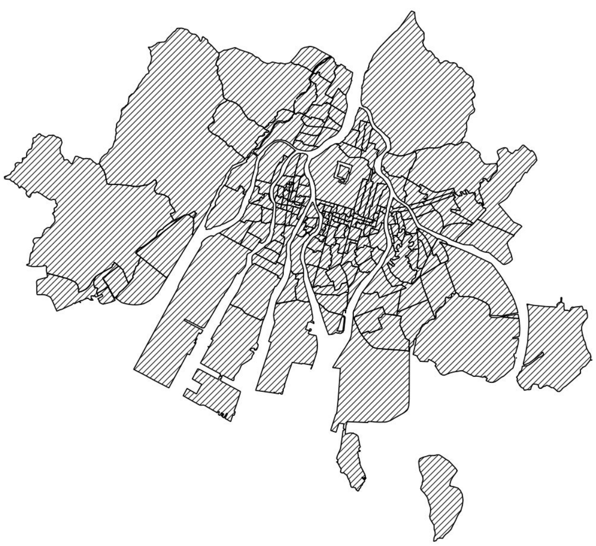
[4] To check that our sample selection procedure does not lead to a significantly biased sample, we re-estimate Column 1 of Table 1 by additionally including seven blocks we drooped for the fourth, fifth, and sixth reasons. Unfortunately, blocks in Heiwa Kinen Kouen, blocks with missing building destruction or pre-bombing population data cannot be used for this regression. We find the coefficient 0.717, which is almost the same as that in Column 1, Table 1, implying that the strength of the recovery tendency hardly changes from our main sample.

gai chizu) issued by a private publisher (*Shobun-sya*) in 1976. Since the block boundary revisions were almost complete at this time, we regard the 1976 map as representing the 1975 block boundaries. Figure A.1 presents the block boundary maps for 1945 and 1975. Due to the re-drawing of boundaries, generally speaking, blocks in peripheral areas were more granular in 1975, while blocks in central locations were granular both in 1945 and 1975. Since the aggregation of peripheral blocks does not introduce a measurement error when measuring population in the definition of 1945 boundaries, we do not believe that such changes in block boundaries induce a significant systematic measurement error in our analysis.

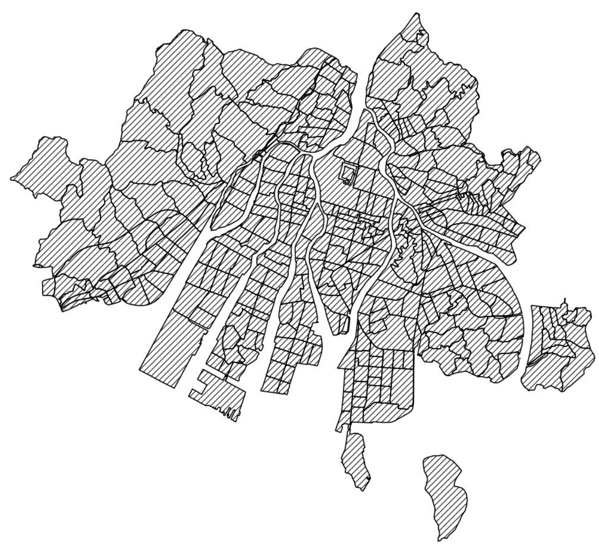
To assign a variable recorded in the revised blocks to the original blocks in 1945, we use a method similar to Eckert, Gvirtz, Liang, and Peters (2020). More specifically, we first calculate the overlaps of the original and the revised block polygons, compute the value for each overlap by assuming that the density of the variable of interest (e.g., population, employment) is constant within each revised block, and aggregate the overlaps to the original blocks. By focusing on the overlapping areas and considering the density of variables of interest, we omit the expanded areas of city boundaries and land-filled areas not present in the 1945 block data. Similarly, focusing on the overlaps allows us to omit the areas that were submerged by the flood control of the *Ota* river.

Figure A.1: Block boundary maps

(a) Block boundaries in 1945



(b) Blocks boundaries in 1975

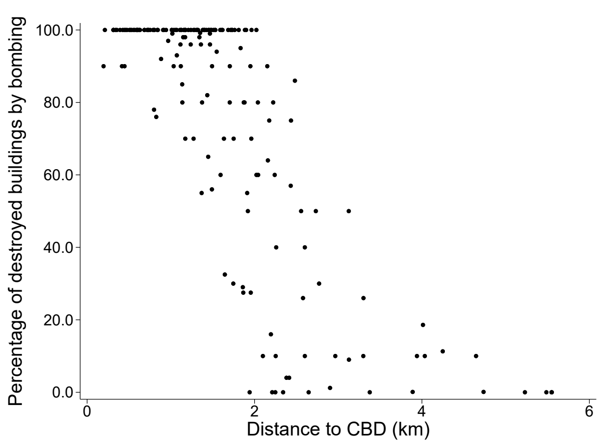


Note: We show our block boundary data for 1945 in Panel (a) and for 1975 in Panel (b). The hashed areas are block areas, and the solid lines represent block boundaries. While the city area of Hiroshima in 1975 is different from that in 1945, we show only the overlapping areas with the 1945 city area to facilitate the comparison of the block boundaries. This implies that Panel (b) disregards the changes in land areas caused by landfills and flood control, as well as the expanded city area resulting from municipal mergers between 1945 and 1975.

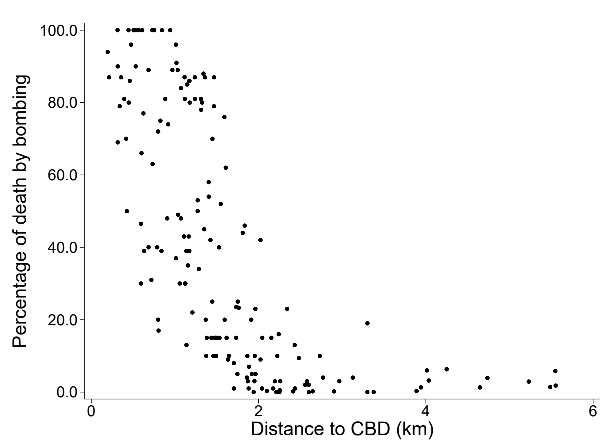
Destruction by the Atomic Bombing The severity of destruction can be measured primarily in two ways: the ratio of buildings destroyed and the ratio of people killed. In this paper, we primarily focus on the building data for two reasons. First, the kill ratio is less reliable because it was extremely difficult to determine who was killed in the destroyed city. Indeed Hiroshima City Government (1971) contains many missing values for the kill ratio due to the absence of reliable data on the kill rate. In contrast, the destruction rate of buildings was easier to record after the bombing and hence has way fewer missing values. Second, Hiroshima City Government (1971) records the "immediate" death rate following the bombing; however, the definition of "immediate" is unclear and seemingly inconsistent across blocks in Hiroshima City Government (1971). This is important in the context of Hiroshima because many people died days, months, or even years after the bombing due to radiation illnesses. Third, previous research on the impact of bombing on the city population (e.g., Davis and Weinstein 2002; Brakman, Garretsen, and Schramm 2004) indicates that 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 texts. We plot the building destruction rate against the distance from the CBD in Figure A.2a. Blocks within 2 kilometers of the CBD were almost entirely destroyed, while those further than 2 kilometers from the CBD tended to experience much less damage. For comparison, we also present a similar plot for the kill rate in Figure A.2b. The high killing rate tends to concentrate in a smaller area (particularly within 1 kilometer of the CBD), and the data has more variation conditional on the same distance from the CBD, partially because the data are noisier.

Figure A.2: Damage to buildings and death rate



(a) Damage to buildings



(b) Death rate of people

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

A.2 *Population, Employment, and Floor Space*

Here we explain the construction of our data on population, employment, and floor space price. The summary statistics can be found in Table A.2.

Table A.2: Summary statistics for population, employment, and floor space prices

	All blocks in the city (174 blocks)		Within 3km from CBD (158 blocks)	
	Mean	Standard deviation	Mean	Standard deviation
Population in 1936	1,880	2,153	1,642	1,103
—— per $1km^2$ in 1936	23,761	14,104	25,752	13,138
Population in 1945	917	2,927	459	916
—— per $1km^2$ in 1945	3,566	5,496	3,374	5,158
Population in 1950	1,495	2,683	1,026	1,091
—— per $1km^2$ in 1950	11,877	6,616	12,583	6,374
Population in 1960	2,215	3,648	1,537	1,689
—— per $1km^2$ in 1960	16,725	8,548	17,737	8,188
Population in 1975	2,625	5,423	1,501	2,694
—— per $1km^2$ in 1975	12,758	5,046	13,065	4,906
Employment in 1938	978	835	949	626
—— per $1km^2$ in 1938	42,517	41,449	46,512	41,422
Employment in 1945	405	1,056	259	420
—— per $1km^2$ in 1945	5,507	8,035	5,602	8,072
Employment in 1953	669	965	505	465
—— per $1km^2$ in 1953	7,358	6,083	7,909	6,099
Employment in 1966	1,277	1,516	1,060	792
—— per $1km^2$ in 1966	18,499	17,408	20,111	17,463
Employment in 1975	1,515	1,880	1,211	993
—— per $1km^2$ in 1975	21,017	21,948	22,821	22,243
Log floor space price in 1950	2.53	0.27	2.58	0.20
Log floor space price in 1955	2.58	0.23	2.63	0.16
Log floor space price in 1960	2.54	0.19	2.57	0.15
Log floor space price in 1965	2.61	0.16	2.64	0.12
Log floor space price in 1970	2.72	0.16	2.74	0.12
Log floor space price in 1975	2.82	0.16	2.85	0.12

Population We collect and digitize block-level population data. For 1933–1936, we use the Statistical Handbook of Hiroshima City (*Hiroshima-shi toukei sho*) that reports population at the block level. We note that military personnel are included in this pre-war population data, whereas they are excluded from the census data. Consequently, our data contains a greater total population than the census data. Nevertheless, our analysis, which focuses on the distribution of the population within a city, is not expected to be affected by this distinction. In fact, the 1935 Population Census data and our population data are highly correlated across blocks in Hiroshima city (correlation coefficient is around 0.975).[5] This suggests that our results would remain quantitatively consistent regardless of whether we work on the population definition of the census. For 1945–1953, we use the Statistical Abstract of Hiroshima City (*Hiroshima shisei youran*). From 1955, we use the population census data.

[5] Furthermore, the null hypothesis that a 1% change in our primary population data is correlated with a 1% change in the population census data cannot be rejected (with p-value around 0.26).

In the post-bombing period prior to 1951, population data is available only at a less spatially granular level than blocks. Therefore, we combine the available data to predict the block-level population distribution. First, population data in 1945 are available only by the distance bins from the epicenter (within 1km, 1-1.5km, 1.5-2km, 2-2.5km, 2.5-3km, more than 3km away). To construct the block-level population data in 1945, we combine the block-level information on the rate of wholly destroyed buildings from Hiroshima City Government (1971) and population changes 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 destroyed buildings by the distance to the epicenter by aggregating the data from Hiroshima City Government (1971). We then regress the population change ratio from the pre-war period to November 1945 on a quadratic function of the fraction of completely destroyed buildings. As seen in Figure A.4a, the regression model fits the data well. We use this regression model to predict block-level population change ratios using the block-level destruction rate of buildings. Finally, we multiply this ratio and the 1936 block-level population to approximate the 1945 block-level population. We also validate our block-level population measure in 1945 using the 1946 edition of *Hiroshima shisei youran*, which provides a map with the population before (August of 1945) and after (August of 1946) the bombing for each school district. While we do not know the exact border of the school districts, we can compute the population change ratios between the two periods, which we expect to be highly correlated with the population changes due to the atomic bombing. We then compare the population change of each school district with that of the census block that appears closest to the relevant school district. Figure A.5 shows the scatter plot and the fitted line. We obtain a very high correlation (around 0.86) between these two measures despite the population being measured at different times and the imperfect correspondence between school districts and blocks.

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.[6] *Shucchojo* divides the city into 18 districts based on the administrative area of each branch of the city government. Each *shucchojo* district is aggregated from blocks, and Figure A.3 illustrates the boundaries of *shucchojo*. Since there are about 180 blocks in our sample, this implies that roughly speaking, each *shucchojjo* consists of 10 blocks.[7] Assuming that within each *shucchojo* the population share of each block is the same as in 1951, we approximate the block-level population in 1949 and 1950 by multiplying this share by the population of the *shucchojo*.

Our main analysis does not use population data from 1946–1948 because the block-level data is hard to construct for this period. However, population data for 1946, 1947, and 1948 are available in the Statistical Abstract of Hiroshima City for distance categories from the epicenter of the bombing. In Figure A.6, we plot the time series of the population share of areas within 1 kilometer of the epicenter using this data.

[6]Similar to the block-level data, we also adjust for shrinkage in *shucchojo* districts by defining the area of each district before and after the *Ota* river flood control. We multiply the original population by the percentage change of the area to obtain estimates for *shucchojo* level population.

[7]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.

Figure A.3: Shucchojo boundaries

Note: The figure illustrates the boundaries of the Shucchojo districts, which is the spatial unit of our population data in 1949 and 1950.

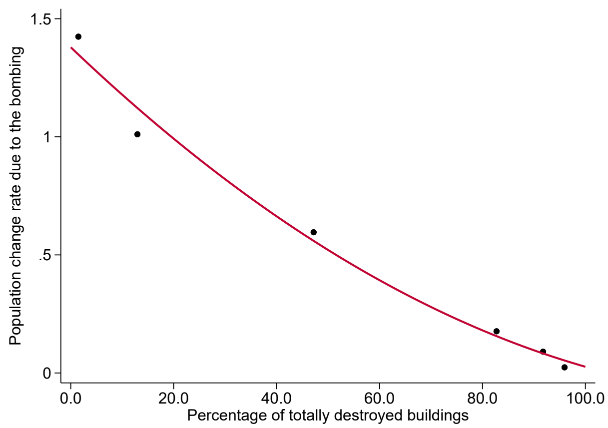
The figure shows that the recovery process had already started strongly in 1946, although the recovery was relatively slow until April 1946. Moreover, the recovery was complete in the sense that the population share of the central area eventually exceeded the predicted share based on the pre-war trend.

Employment We collect and digitize block-level employment data from various historical sources. The Survey of Commerce and Industry in Hiroshima City (*Hiroshima-shi shoukou-gyou keiei chousa*) records the number of establishments (factories and commercial stores) at the block level for 1938. For 1946, the number of buildings used for business is taken from the Statistical Abstract of Hiroshima City (*Hiroshima shisei youran*). For 1953, we rely on the Survey on the Daytime Population of Hiroshima (*Hiroshima-shi chukan jinko chosa*), assuming that the daytime population approximates employment. From 1957 to 1975, we use the Business Establishment Statistical Survey (*jigyousho toukei chousa*).

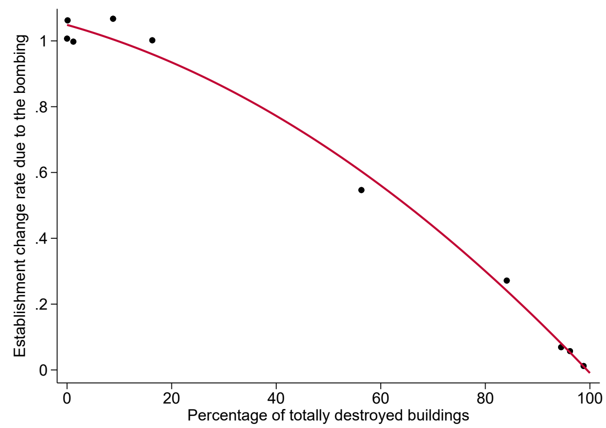
Throughout this paper, we focus on employment in the manufacturing or service sectors and ignore agricultural employment. This is a relatively moderate restriction because we focus on an urban area throughout our sample period.[8]

[8]While most of our data already focus on non-agricultural employment, the 1953 data report total employment, including agricultural employment. To account for this, the number of agricultural workers in 1953 is estimated using the following method. First, we obtain the shucchojo-level share of agricultural households from the 1950 Statistical Abstract of Hiroshima. We estimate that approximately half of the agricultural household members are classified as employed, based on the number of agricultural workers reported in the 1950 Population Census. This information allows us to calculate the fraction of agricultural workers in each shucchojo. We multiply the estimated fraction of agricultural workers by the block-level population in 1953 to approximate agricultural employment at the block level in 1953. We believe that agricultural employment is not central to our results because even in 1950, when agricultural employment was still a significant component of the Japanese economy, less than 10 percent of workers in Hiroshima City were employed in the agricultural sector.

Figure A.4: Population and establishment changes relative to building destruction



(a) Population change



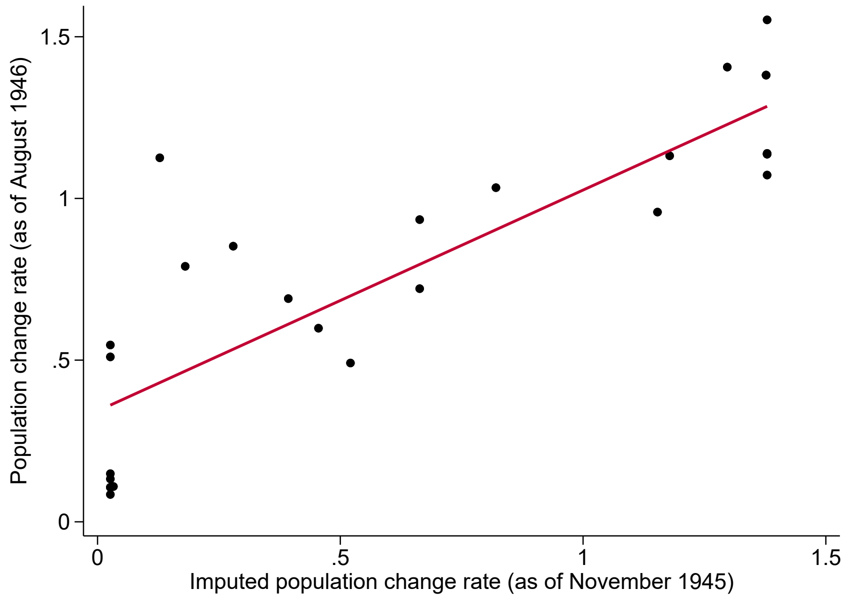
(b) Establishment change

Note: The left panel shows a scatter plot of the percentage of completely destroyed buildings and population change ratios 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 is from the 1946 Statistical Abstract of Hiroshima City, and the destruction rate is a population-weighted average of the block-level destruction rate from Hiroshima City Government (1971). The right panel shows a scatter plot of the percentage of completely destroyed buildings and establishment change ratios due to the bombing for distance categories from the epicenter (0.5km grids up to 5km). Establishment changes are from the 1946 Statistical Abstract of Hiroshima City. In both panels, we fit a quadratic model and plot it.

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

For the first issue, we address it using the analogous strategy as the population data. We calculate the number of establishments as of November 1945, when our first post-war population data is available. We first extract the number of buildings for shops, restaurants, banks, hotels, associations, and entertainment facilities before and after the bombing (August 1946) from the 1946 Statistical Abstract of Hiroshima City. We also approximate the establishment distribution immediately after the bombing (August 1945) by multiplying the number of establishments before the bombing by the proportion of completely destroyed buildings. Specifically, we compute the average fraction of completely destroyed buildings for each bin from the block-level data on the fraction of completely destroyed buildings (Hiroshima City Government 1971), using the 1938 number of establishments as weights. Using linear interpolation, we can approximate the number of establishments for each distance bin in November 1945 based on the data from August 1945 and 1946. Second, we regress the ratio of the number of pre-war establishments to those in November 1945 on the ratio of completely destroyed buildings and its square. Figure A.4b shows that the regression model fits the data well. Finally, we multiply the number of establishments in 1938 by the predicted change ratio using the block-level ratio of destroyed buildings and the estimated regression model shown in Figure

Figure A.5: Validation of our 1945 population data using 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. The horizontal axis shows the predicted population change rate as of November 1945 based on the imputed destruction rate of buildings for each school district. The vertical axis shows the population change as of August 1946, taken from the data. We also plot a linear regression line. The correlation coefficient is 0.8547.

A.4b.[9]

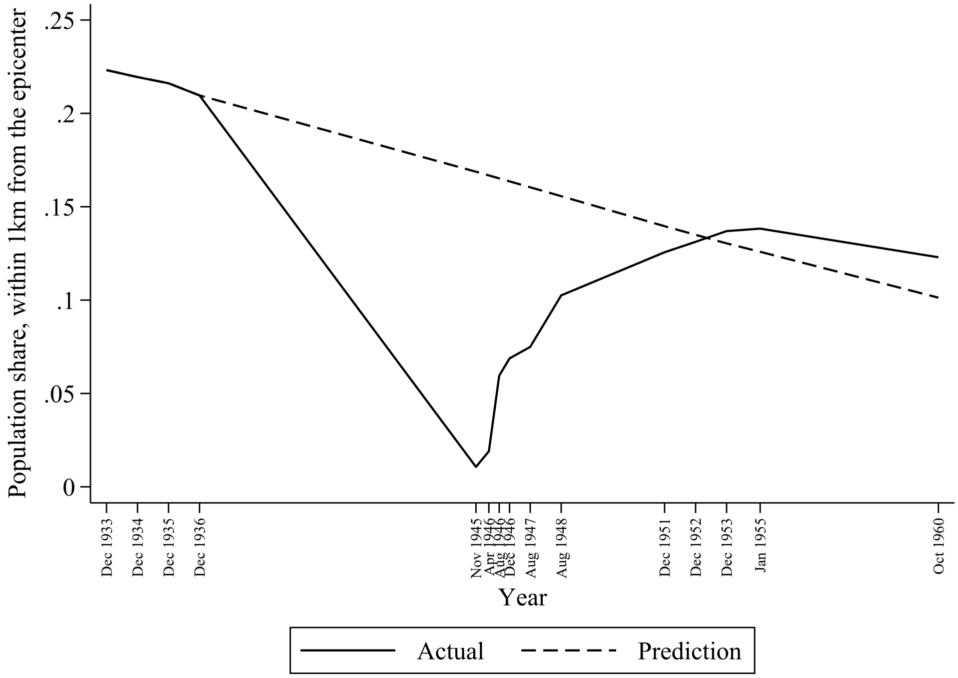
To construct the block-level employment distribution for 1950–1963, we rely on an employment distribution that is recorded at a less spatially granular level (*shucchojo*).[10] Since our 1957 employment data aggregates seven peripheral *shucchojo* districts into one, we define it as the "others" district and use the 12 *shucchojo* areas. The number of workers at the *shucchojo* level is available for 1953, 1957, and 1963. To calculate 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 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 that in 1953 except for the total number of workers, which we scale down by the growth rate of the total population.

For the second issue, we need to construct block-level employment data from the block-level establishment data for 1938 and 1945. For this purpose, we assume that employment is proportional to the number of establishments. To approximate the total employment in 1938 and 1945, we multiply the total population by the labor force participation rate in 1936, which is 44.2 percent according to the 1936 Statistical

[9]The predicted model yields a negative rate of change in the number of establishments for a total destruction rate of 100 percent. To address this, we apply the predicted change rate for blocks with a 100 percent destruction rate to those with a 99 percent destruction rate.

[10]The issues of some blocks belonging to two *shucchojo* districts and changing land areas are addressed in the same way as for the population data (see footnotes 6 and 7 in the appendix).

Figure A.6: Actual and predicted population share within 1 km of the epicenter



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

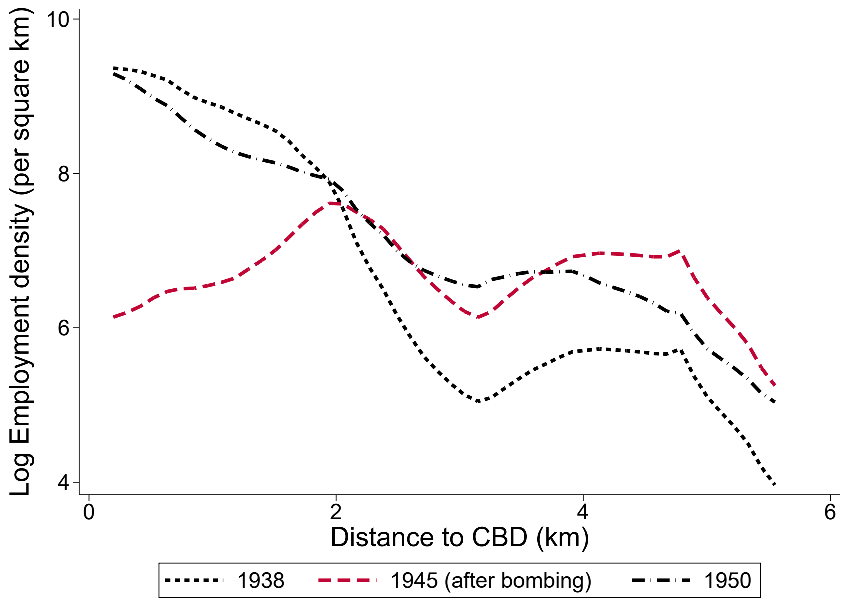
Handbook of Hiroshima City (*Hiroshima-shi toukei sho*). In our structural estimation, however, total employment equals the total population because our model assumes that everyone works. We rescale the total population to the total employment.

Figure A.7 presents the employment density in 1938, 1945, and 1950 in the same way as Figure 3 for population distribution. We see that the distribution of employment also has a monocentric city structure, and the highest employment density occurs at the same point as the location of the highest population density.

While we cannot directly assess how well the establishment data approximate employment for the pre-war period, we can check this using the 1966 data that record both employment and establishment at the block level. Figure A.8a shows that they exhibit a strong positive correlation. Moreover, such an approximation of employment by establishment counts is found to be plausible in other contexts (e.g., Ahlfeldt, Redding, Sturm, and Wolf 2015).

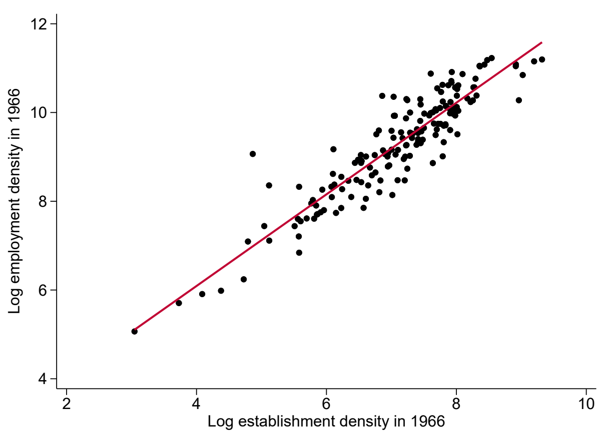
While we focus on the total employment in this paper, the available evidence suggests that the location of employment is highly correlated across sectors. We digitize the 1952 Business Directory of Hiroshima City (*Hiroshima-shi shoko nenkan*). From this, we compute the number of establishments in each city block for both manufacturing and commerce (retail and services). Figure A.8b shows that establishment density is highly correlated across sectors. Therefore, analyzing the spatial distribution of employment likely does not mask substantial sectoral heterogeneity.

Figure A.7: Employment density by distance to the city center

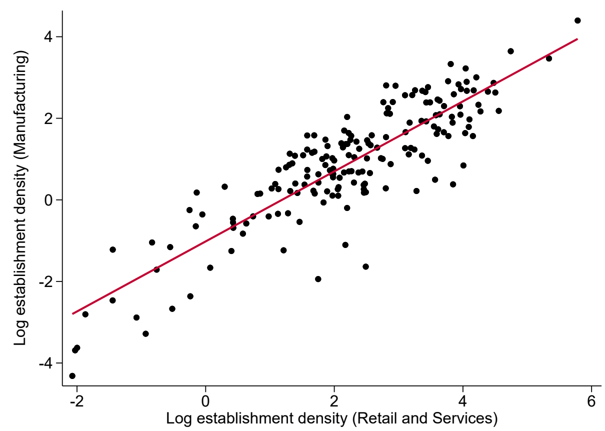


Note: The figure shows the local polynomial regression of the log employment density on the distance to the CBD for different years. To eliminate the effect of changes in the total employment, we normalize the total employment each year to 100,000.

Figure A.8: Validation of employment and establishment data



(a) Correlation of the establishment and employment counts



(b) Correlation of establishment counts by sector

Note: Each dot represents a city block and the red line represents the fitted line. In Panel (A.8a) we plot the logarithm of the employment density against the log establishment density, using the 1966 Business Establishment Statistical Survey. In Panel (A.8b) we plot the logarithm of establishment density in manufacturing sector against log establishment density in non-manufacturing sector (retail and services), using the 1952 Business Directory of Hiroshima City.

Floor Space We use the newly-digitized block-level floor space data, taken from *Hiroshima toshi-iki kotsu chosa shiryo*. This data records the amount of floor space by the construction year as of 1967, allowing us to observe the floor space built prior to 1940, during 1940–1945, 1945–1950, 1950–1955, 1955–1960, and 1960–1965. Note that because our floor space data describe the floor space stock as of 1967, it captures only *surviving* structures. We suppose that for structures built between 1960 and 1965, no structure was lost as of 1967. For structures built between 1955 and 1960, we can observe only a fraction $1 - \psi \in (0, 1)$ of them as some structures were already lost as of 1967 due to depreciation. Here ψ is the five-year depreciation rate, which we set $\psi = 0.05$ based on the Annual Report of Building Construction (see Section 5.1). We similarly suppose that we observe only $(1-\psi)^2$ of the structures built between 1950 and 1955, and $(1-\psi)^3$ for the structures built between 1945 and 1950, and so on. Adjusting for such depreciation allows us to observe the floor space stock H_{nt} for $t = 1945, 1950, 1955, 1960, 1965$.

We back out floor space prices consistent with our floor space supply data using a method analogous to Sturm, Takeda, and Venables (2023). More specifically, our housing supply model implies that the floor space prices in period t can be backed out from the floor space supply $(H_{nt} - (1-\psi)H_{nt-1})$ and area size (S_n):

$$\underbrace{\ln Q_{nt}}_{\substack{\text{Logarithm of} \\ \text{floor space price}}} = \underbrace{\frac{1}{\eta}}_{\substack{\text{Inverse of floor} \\ \text{space supply elasticity}}} \underbrace{\ln \left[\frac{H_{nt} - (1-\psi)H_{nt-1}}{S_n} \right]}_{\substack{\text{Logarithm of the density} \\ \text{of new floor space supply}}} \tag{A.1}$$

Given the sequence of the total floor spaces $\mathbb{H} = \left(\{H_{nt}\}_n\right)_{t=0,1,\cdots,T}$, the vector of area size $\{S_n\}$, the parameter of floor space depreciation ψ and the parameter of floor space supply elasticity η, the floor space prices $\mathbb{Q} = \left(\{Q_{nt}\}_n\right)_{t=1,2,\cdots,T}$ are inferred to be consistent with the developers' problem. Intuitively, the upward housing supply curve implies that more floor space provision is associated with higher floor space prices. The floor space should be higher to explain a given amount of floor space provision when the floor space provision is less elastic.

Note that the floor space supply $(H_{nt} - (1-\psi)H_{nt-1})$ for $t = 1950, 1955, 1960, 1965$ is observed in our floor space data. Based on evidence in the Japanese floor space supply market (Yoshida 2016, Kii, Tamaki, Kajitani, and Suzuki 2022) showing that the input share of land equals 0.2, we set $\eta = 4$ to match this number (see Section 5.1). Combining them, equation (A.1) yields the log floor space prices $\ln Q_{nt}$ for $t = 1950, 1955, 1960, 1965$.[11]

Because we unfortunately do not have comparable floor space data for 1970 and 1975, we construct a prediction model of floor space prices based on the obtained block-level floor space prices in 1950, 1955, 1960 and 1965. Following Nakamura and Saita (2007) and Shimizu, Saita, and Inoue (2019) that estimate a time-series model of Japanese land prices, we first take the difference of floor space prices to have a stationary process, suppose that the first differences in floor space prices in each block follow an AR(2) process, and estimate the model using the OLS.[12] Using this model, we finally predict the 1970 floor space

[11] Since our floor space price data are calculated using the 1966 block boundaries, as we did for population and employment data, we adjust for block boundaries using a method similar to Eckert et al. (2020).

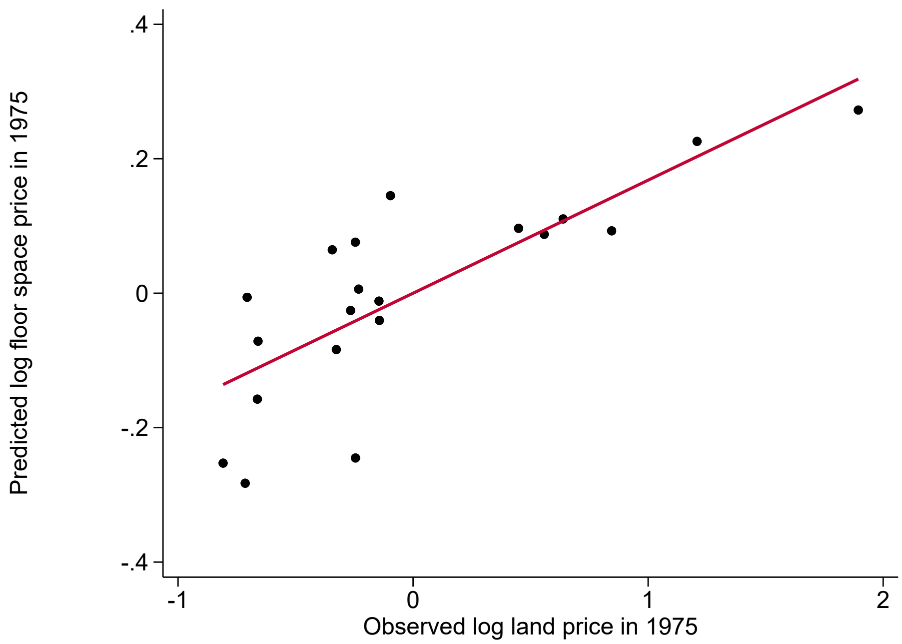
[12] We have also applied AR(1) specification, finding that the predicted floor space prices are strongly correlated with our main predictions with the correlation coefficient higher than 0.99.

prices using the 1965 and 1960 floor space prices, and the 1975 price using the 1970 and 1965 prices.

While we do not have data on floor space prices, we can validate our predicted floor space prices using the land price data in 1975 (*kouji chika*).[13] This is professionally assessed land price data at various points in Hiroshima city by referring to actual transaction prices, and there are 123 sample points in our study area. As the number of blocks is near 200, this implies that each block does not have many sample points and typically has only one or two points. Thus, we aggregate city blocks into 20 grids by the distance from the city center and calculate the average land price for each grid using the sample points of land prices. We similarly calculate the average of our predicted average floor space prices for each grid.

Figure A.9 shows a strong positive correlation between the observed land price index and our floor space price predictions (correlation coefficient is around 0.79). This suggests that our floor space price data for 1975 plausibly capture the true prices in the housing market.[14]

Figure A.9: Validation of our 1975 floor space price data by the land assessment value data in 1975



Note: We plot our predicted floor space prices of each block against the observed land prices taken from *kouji chika*. Both floor space prices and land prices are re-centered so that their mean equals zero. We aggregate blocks into 20 grids by the distance from the city center, and each dot represents the grid. The red line shows the fitted line. Blocks that contain no sample point in the *kouji chika* data are omitted. Although our land price data contains large measurement errors, they exhibit a statistically significant positive correlation (p-value is 0.00, the correlation coefficient is 0.79). The slope of the fitted line is 0.168. The slope should equal the land input share, 0.2 in our calibration, in the steady state. We cannot reject the null that the slope equals 0.2 (p-value is 0.31).

[13] More precisely, we combine the *kouji chika* data and the *todou-fuken chika chosa* data, which are similarly collected as the *kouji chika* data but administered by the prefecture government (while *kouji chika* data are administered by the national government). We purchased these data from the Land Information Center (https://www.lic.or.jp/system/cdrom.html, in Japanese, last accessed on December 1 2024). LaPoint (2021) shows that these assessment land price data are closely related with the market transaction prices.

[14] Moreover, the estimated slope of the fitted line is consistent with our calibrated value of the land input share. Theoretically, in the steady state of our model, we can show that the slope is identical to the land input share, which we calibrate as 0.2 (see Table 5.1). we estimate that the slope of the fitted line is 0.168 and we cannot reject the null that the slope equals 0.2 (p-value is around 0.31).

A.3 *Other Data*

Commuting and Transportation Network We use trip-level microdata from the 1987 Hiroshima City Person-Trip Survey, administered by the Hiroshima City Government. It is broad (about 7 percent of Hiroshima City's population were 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, the origin, destination, and mode(s) of transportation are recorded. The origin and destination are recorded at the level of "zone," which aggregates a few city blocks. There are 66 zones in our sample area. We take the centroid of each zone as a representing point, and we assume that a trip is from the origin centroid to the destination centroid.[15] We restrict our sample to commuting trips whose origin and destination are contained in city blocks in our sample.

We use the following representative modes of transportation: walk, bicycle, car, bus, and train. The representative mode is defined as follows. First, the representative mode is "train" if the trip uses a train or tram. Then, for trips that have not been coded, we code them as "bus" if they use buses. We code trips that have not been coded as "car" as such if they use a motorcycle or automobile. We code trips that have not been coded as "bicycle" if they use a bicycle. Finally, we code a trip as "walk" if it was walked.

To measure the travel time between each workplace-residence pair, we also collect and digitize Hiroshima City's road, bus, and train networks in 1987 and compute the bilateral travel time between the centroids of blocks for each mode: walk, bike, car, bus, and train.[16] Although public transportation networks were generally stable during our sample period, there were a few notable changes, including the discontinuation of the *Ujina* line in 1966. To address this, we also digitize the bus and train networks in 1950. Prior to 1966, we use the public transportation networks of 1950, and after that we use those of 1987. Throughout our sample period, we use the 1987 road network due to its data quality, which is reasonable given that the road network in Hiroshima has not changed significantly from the pre-war period. To formally verify this, we digitize the road networks on published city maps in the pre-war period and in 1950.[17] We compare the travel time from each block centroid to the city center with the 1987 road network. The correlation between the pre-bombing period and 1987 is 0.95, and the correlation between 1950 and 1987 is 0.97, implying that the road network structure was stable throughout our study period.

Location Characteristics (First Nature) The altitude and slope are taken from the Digital National Land Information (*kokudo suuchi joho*) database.[18] For each 250m $\times$ 250m square, the data record the average altitude and the average degree of slope. We assign the value at the centroid of each block. Second, we obtain the location of the water areas for the pre-war and post-war periods. We use the digital map of

[15] While the use of the aggregate spatial unit and the use of the centroid may induce some noise in measuring travel time, we have tried an instrumental variable approach for the gravity equation and obtained similar results (see Appendix F.1).

[16] We use QGIS to compute the travel time. Based on the available evidence, we assume the following travel speeds: 5 km/h for walking, 12 km/h for bicycling, 25 km/h for driving a car, 15 km/h for bus, 12 km/h for tram, and 36 km/h for other trains. When calculating the travel time by bicycle, car, bus, and train, we assume that walking occurs outside its network. We abstract from potential congestion because we have no reliable data about the severity of congestion.

[17] For the pre-bombing map, we digitize a map created by the US Army based on pre-bombing resources (https://maps.lib.utexas.edu/maps/ams/japan_city_plans/). For 1950, we digitize the Geospatial Information Authority of Japan Map.

[18] Source: https://nlftp.mlit.go.jp/ksj/gml/datalist/KsjTmplt-G04-d.html, in Japanese. Last accessed on October 28, 2023.

Takezaki and Soda (2001) for the pre-war period and the Basic Geospatial Information (*kokudo kihon zu*) data for the post-war period. Finally, we take the soil condition from the Land Classification Basic Investigation data.[19] We use the data on the surface strata and assign the soil condition to each block using the centroid location.

Location Characteristics (Second Nature) We collect information on the location of train stations in 1950 from the Digital National Land Information data.[20] The location of the city center is defined as the midpoint of the *Hacchobori* and *Kamiya-cho* blocks. The location of the Hiroshima port (*Ujina* port) is taken from Google Maps. The list of cultural assets (*bunkazai*) in the city is taken from the Hiroshima Metropolitan Area and Hiroshima Prefecture Open Data Portal Site.[21] We compute all distances using the centroid of each block.

Finally we digitize the 1940 Hiroshima Urban Planning Area Map (*Hiroshima toshi keikaku chiiki-zu*) to code zoning regulations relevant to our study period. At this time Japanese zoning regulations had three classifications: housing, commercial, and manufacturing, and some commercial zones along major streets were often separately designated as commercial street area (*rosen-teki shougyou chiiki*). However, it is important to note that the zoning regulation was quite lax and allowed for substantial mixed use, implying that the zone names do not necessarily correspond to the actual land use pattern.[22] For instance, although one could not operate theaters and large factories in "residential" zones, there was no restriction to operate restaurants, shops, and small factories in "residential" zones. Moreover, housing can be located in any zone. This implies a lax zoning regulation, and we indeed observe positive population and employment at all blocks in our sample. With this caveat, we visualize the 1940 zones in Figure A.10, which shows that the manufacturing and commercial areas are located in various areas in the city. We observe that the majority of the blocks contain either commercial or street commercial areas. Note also that although our zoning data are in the pre-bombing period, zoning hardly changed for about 20 years after the bombing. In particular, the introduction of the Building Standard Law of Japan in 1950 hardly affected the zoning regulation in the case of Hiroshima (Hiroshima City Government 1960). The zoning regulation was revised in 1968 by the introduction of the new Urban Planning Law, way after the recovery of city structure was complete so that the land use pattern of Hiroshima stabilized.

For an additional analysis in Appendix B.2, we digitize the location and number of units of each type of public housing from the 1949 and 1950 Statistical Abstract of Hiroshima City (*Hiroshima shisei youran*).[23] The data cover all public housing units constructed by the Hiroshima City or Prefecture Governments from 1946 to 1950.

[19] Source is a 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 October 28, 2023.

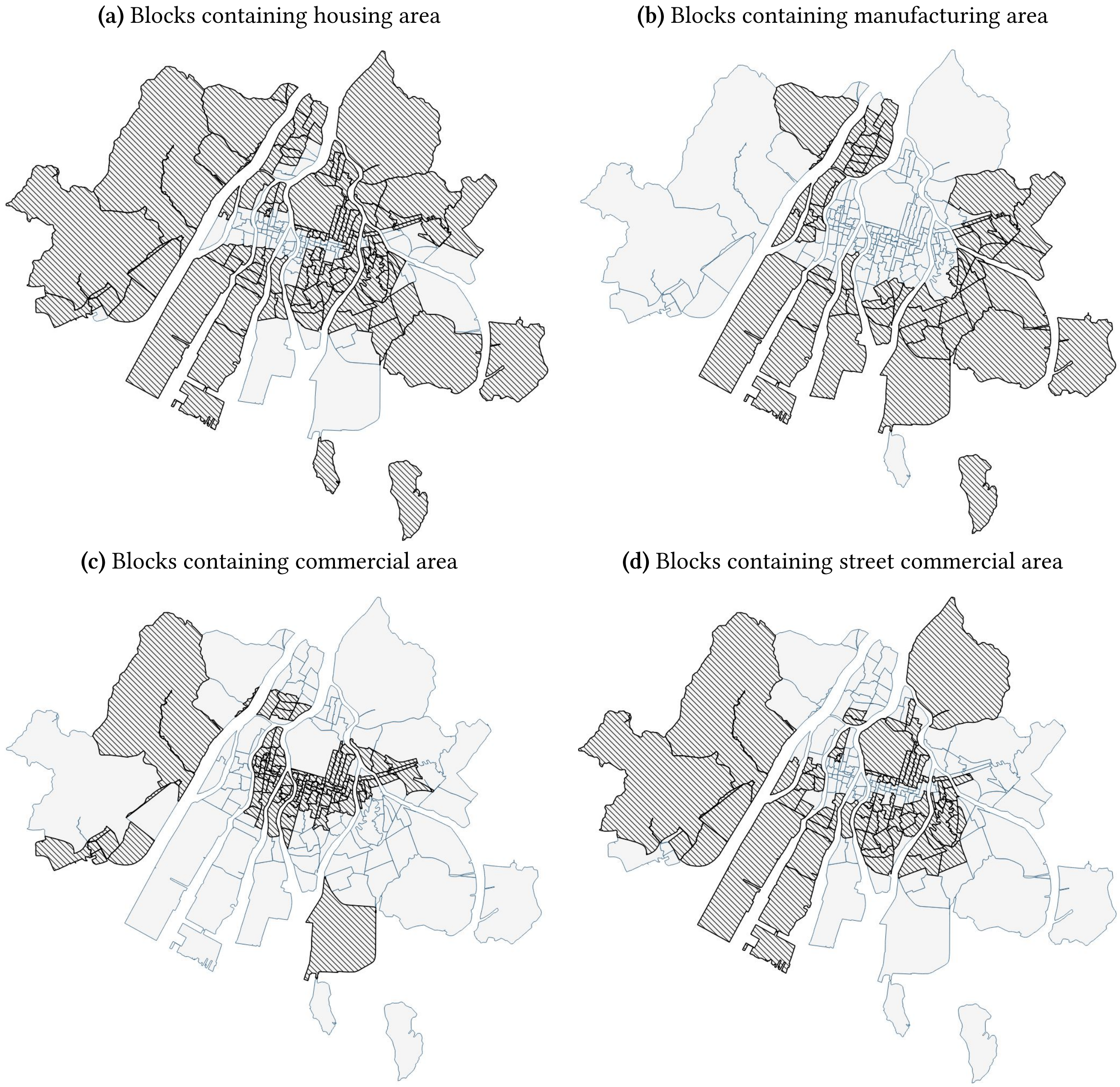
[20] Source: https://nlftp.mlit.go.jp/ksj/gml/datalist/KsjTmplt-N05-v1_3.html, in Japanese. Last accessed on October 28, 2023.

[21] Source: https://hiroshima-opendata.dataeye.jp/resources/9843. Last accessed on October 28, 2023.

[22] Consistent with this, we observe a substantial amount of population in manufacturing or commercial areas and employment in housing areas. For details see the 1938 version of the Urban Building Act (*Shigai-chi kenchikubutsu hou*), for instance, at https://www2.ashitech.ac.jp/arch/osakabe/semi/hourei/buppou/s13.html (in Japanese, last accessed on December 5 2024).

[23] In some cases, the location information in the data does not allow us to uniquely identify the block in which the public housing is located. We still assign a single block based on our best guess of the location of that public housing unit.

Figure A.10: Zoning map of Hiroshima in 1940



Note: We visualize the housing, manufacturing, commercial, and street commercial zones in 1940. The hatched areas correspond to blocks containing housing zones in Panel (A.10a), manufacturing zones in Panel (A.10b), commercial zones in Panel (A.10c), and street commercial zones in Panel (A.10d). Note, however, that the Japanese zoning regulation at this time was quite lax and accommodated substantial mixed land use (see Appendix A.3 for more discussions).

Land Prices We observe the location with the highest unit land price within Hiroshima.[24] The 1931 Statistical Yearbook of Hiroshima City reports this location in 1931. The National Tax Agency reports the location with the highest land price in each prefecture in 1959, and the highest land price in Hiroshima prefecture was in Hiroshima City.[25] Finally, Suzuki (2024) reports the highest land prices in 1934 and 1964

[24]In Japan, to our knowledge, digitized comprehensive land price data in the pre-WWII period is available only for Tokyo and Kyoto (Yamagishi and Sato 2025).

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

Table A.3: Summary statistics for the block characteristics

	All blocks in the city (174 blocks)		Within 3km from CBD (158 blocks)	
	Mean	Standard deviation	Mean	Standard deviation
Block area (km^2)	0.321	0.971	0.132	0.39
Distance to CBD (km)	1.66	1.06	1.4	0.652
Distance to Hiroshima port (km)	4.74	1.08	4.72	0.985
Distance to nearest station (m)	336	319	285	232
Distance to nearest water area (m)	248	229	226	185
Distance to nearest cultural asset (m)	808	637	684	412
Altitude (m)	5.91	14.4	4.25	7.56
Average slope (degree)	0.814	2.4	0.611	2.07
Indicator of river adjacency	0.523	0.501	0.500	0.502
Indicator of bad soil condition	0.96	0.197	0.981	0.137
Latitude	34.4	0.0104	34.4	0.0091
Longitude	132	0.0167	132	0.0123
Annual population growth rate 1933–36	1.03	0.0355	1.03	0.0344
Share of fully destroyed buildings	74.5	35.4	81.1	29.8
Share of half-damaged buildings	18.6	26	15.2	23.6
Share of mildly-damaged buildings	6.65	17.7	3.38	12.1
Share of intact buildings	0.685	3.99	0.316	1.66
Indicator of zoning in 1940: housing area	0.580	0.495	0.570	0.497
Indicator of zoning in 1940: commercial area	0.563	0.497	0.582	0.495
Indicator of zoning in 1940: street commercial area	0.420	0.495	0.418	0.495
Indicator of post-war town planning by Hiroshima City government	0.615	0.488	0.646	0.480
Indicator of Hiroshima city prior to 1929	0.874	0.333	0.918	0.276

for each prefecture of Japan, allowing us to observe the recovery of bombed cities other than Hiroshima.

Migration Rate Our primary data source for migration is the 1960 population census. It asks whether a respondent changed their address, including moves within the same municipality. In the densely populated areas of Hiroshima prefecture, 85.9 percent of prime age residents answered they had not.[26] Converting this into a 5-year interval, we calculate the rate of moving within five years (θ) as 0.53.

However, this migration probability seems too small for the period immediately after the war. Many people were reallocated for wartime reasons, and they would have lower mobility costs (e.g., less attachment to their current residence and a higher probability of job switching). According to the city population registry (*Hiroshima shisei youran*), more than 50,000 people moved out of Hiroshima City in 1949. Since the population of Hiroshima City at the end of 1948 was about 240,000 (1952 *Hiroshima shisei youran*), this implies an annual migration rate of 21 percent 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 was similar to that in 1960.[27] This suggests an annual rate of staying of 0.63, corresponding to a five-year moving rate of 0.9. Therefore, we set $\theta = 0.9$ for the period 1945–1950.

[26]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 October 28, 2023.

[27]This ratio in the densely-populated area of Hiroshima prefecture is around 3:4, implying that the annual migration rate is roughly 0.37.

B Additional Reduced-form Evidence

B.1 *Testing the Recovery in Alternative Specifications of Equation (2) in the Main Text*

Table B.1: Testing the recovery of population density in 1950

	(1)	(2)	(3)	(4)	(5)	(6)
	Log population density in 1950					
	Baseline				**Only fundamentals**	
	All blocks			Blocks in 3km of CBD	All blocks	Blocks in 3km of CBD
Log population density in 1936	0.4940[a]	0.4761[a]	0.5439[a]	0.5842[a]		
	(0.0415)	(0.0527)	(0.0817)	(0.0872)		
Log population density in 1945	0.0900[a]	0.0626[c]	0.0199	-0.0268		
	(0.0317)	(0.0375)	(0.0414)	(0.0403)		
Log distance to water		0.0358	0.0783	0.1549[b]	-0.2484[a]	-0.0743
		(0.0585)	(0.0676)	(0.0754)	(0.0898)	(0.0888)
Log altitude		0.1917	0.1531	0.3818[b]	0.1261	0.3884[b]
		(0.1317)	(0.1670)	(0.1776)	(0.1771)	(0.1918)
Bad soil conditions		0.5134	0.4037	0.1935	0.4374	0.5333
		(0.3878)	(0.4846)	(0.3302)	(0.4794)	(0.4657)
Dummy for river adjacency		-0.0080	0.0402	0.0876	-0.2756[b]	-0.1013
		(0.0784)	(0.1093)	(0.1104)	(0.1260)	(0.1118)
Log distance to nearest station			-0.0207	0.0112	-0.1006	-0.0328
			(0.0563)	(0.0600)	(0.0807)	(0.0702)
Log distance to cultural asset			0.1132	0.1662[b]	0.0686	0.1141
			(0.0751)	(0.0693)	(0.0813)	(0.0791)
Log distance to port			0.7816	0.0951	0.3686	-0.2323
			(0.5243)	(0.9711)	(0.7285)	(1.3213)
Fraction of moderately-destroyed buildings			-0.0022	0.0026	-0.0069	-0.0032
			(0.0041)	(0.0041)	(0.0058)	(0.0055)
Zoning in 1940: housing area			-0.0623	-0.1297	-0.2066[c]	-0.2983[a]
			(0.0944)	(0.0969)	(0.1184)	(0.1102)
Zoning in 1940: commercial area			-0.1024	-0.0790	0.0187	0.0912
			(0.0903)	(0.1048)	(0.1083)	(0.1356)
Zoning in 1940: commercial street area			-0.0624	-0.0649	0.1985[c]	0.1700
			(0.1020)	(0.0998)	(0.1186)	(0.1056)
Hiroshima city prior to 1929			0.0112	0.1688	0.2688	0.5066[b]
			(0.2059)	(0.1899)	(0.2281)	(0.2373)
Post-war town planning by Hiroshima city government			0.1155	0.0740	-0.0340	0.0070
			(0.1734)	(0.1921)	(0.2081)	(0.2096)
Number of blocks	174	174	174	158	174	158
R-squared	0.583	0.631	0.659	0.514	0.446	0.277

Note: We report the OLS estimates of equation (2) in the main text, including the coefficients on the control variables except for latitude, longitude, and slope. ^{a}, ^{b}, and ^{c} indicate significance at the 1, 5, and 10 percent level, respectively.

B.2 *Robustness Checks*

Employment Table B.2 reports the regression results from estimating equation (1) for employment, in the same manner as Table 1 for population. The estimated coefficients are very similar to Table 1, but somewhat closer to −1.[28] In Columns (3)–(6), we cannot reject the null hypothesis of $\gamma = -1$, implying a complete recovery to the pre-war employment distribution.

Table B.2: Changes in employment density and war-time damage

	(1)	(2)	(3)	(4)	(5)	(6)
	Change in log employment density 1945–1950					
Change in log employment density 1938–1945 (γ)	-0.7501^a	-0.8269^a	-0.8463^a	-0.8937^a	-0.9039^a	-0.9285^a
	(0.0363)	(0.0461)	(0.0462)	(0.0577)	(0.0543)	(0.0424)
p-value from testing $\gamma = -1$	0.000	0.000	0.001	0.067	0.079	0.094
Natural location characteristics (first nature)		Yes		Yes	Yes	Yes
Built location characteristics (second nature)			Yes	Yes	Yes	Yes
Pre-war trends in population					Yes	
Within 3 km from the city center						Yes
Number of blocks	174	174	174	174	174	158
R-squared	0.757	0.800	0.793	0.839	0.844	0.883

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

Characteristics of Neighboring Blocks The post-war population growth of block i may depend not only on its own characteristics but also on the characteristics of adjacent blocks $i' \neq i$. To consider the characteristics of neighbors, we adopt the "SLX model" from the spatial econometrics literature (Halleck Vega and Elhorst 2015) and control for the spatial lag of the following four types of dependent variables in our main regression equation (1). The spatial lag of $\ln\left(\frac{\text{Popdens}_{i,1945}}{\text{Popdens}_{i,1936}}\right)$ summarizes the wartime destruction rate of surrounding blocks and the spatial lag of X_i summarizes the location characteristics of the neighboring blocks. We use the exponential spatial weighting matrix by using the geographical distance between the centroids of blocks in kilometers, implying that the characteristics of blocks close to block i are given more weight. In particular, we set the spatial decay parameter at 4.32 following the decay of agglomeration forces in Ahlfeldt et al. (2015). We also construct the spatial lag of the population right after the bombing, which is meant to capture the market access of a given block.[29] In a similar spirit, we further construct the spatial lag of the geographical size of blocks, which is meant to capture the geographic centrality of each block as it can affect the spatial distribution of economic activities (Thisse, Turner, and Ushchev 2024). We additionally control for these spatial lag variables in our main regression analysis. Table B.3 shows that the inclusion of these spatial lag variables does not change our conclusion about the coefficient γ. In particular, we cannot reject the null of complete recovery ($\gamma = -1$) in all specifications at the 5 percent level.

[28] Using the 1966 data exhibits even stronger recovery tendency. For example, repeating Column 1 of Table B.2 yields −0.857.

[29] We set the spatial decay parameter at 0.05 given the commuting cost estimate with respect to the geographical distance in Hiroshima, which was reported in a previous version of this paper (Takeda and Yamagishi 2023).

Table B.3: Controlling for the characteristics of neighboring blocks

	(1)	(2)	(3)	(4)	(5)
	Change in log population density 1945–1950				
Change in log population density 1936–1945 (γ)	-0.9444[a]	-0.9185[a]	-0.8747[a]	-0.8814[a]	-0.8884[a]
	(0.0531)	(0.0635)	(0.0753)	(0.0670)	(0.0615)
p-value from testing $\gamma = -1$	0.297	0.201	0.098	0.079	0.072
Location characteristics (first and second nature)	Yes	Yes	Yes	Yes	Yes
Spatial lag of the changes in log population density 1936-45	Yes				Yes
Spatial lag of the control variables (block characteristics)		Yes			Yes
Spatial lag of the population right after the bombing			Yes		Yes
Spatial lag of the geographical block size				Yes	Yes
Number of blocks	174	174	174	174	174
R-squared	0.863	0.899	0.859	0.859	0.902

Note: We report the OLS estimates of equation (1) when controlling for the spatial lag of the dependent variables based on the geographic distance between the centroids of the blocks. In Column (1), the spatial lags of the change in log population density between 1936-45 and block characteristics are constructed using exponential weights, where the decay parameter is set at 4.32. In Column (2), we construct the spatial lag of each control variable (except for latitudes and longitudes) with decay parameter 4.32 and use them as separate controls. In Column (3), the spatial lag of population right after the bombing is constructed using the decay parameter 0.05. In Column (4), we include the spatial lag of the geographical area size of the blocks. In Column (5), we include all of them. We report p-values from testing the null $\gamma = -1$. Heteroskedasticity-robust standard errors are in parentheses. [a] indicates significance at the 1 percent level.

Public Housing In many cities in Japan, the supply of public housing was a primary policy of the government right after the war. In Table B.4 Column (1) reports the relationship between the number of public housing units and the distance from the CBD. We additionally control for the number of public housing units in our baseline specification to assess how much the provision of public housing after the bombing influenced the recovery of central Hiroshima. Columns (2)–(4) in Table B.4 report the results, which are close to our estimate in Table 1 in the main text. This suggests that the provision of public housing alone did not meaningfully contribute to the recovery of the central city.

Informal Housing A related factor is illegal housing, which is similar to public housing in the sense that some non-market mechanisms might allocate it. Although we do not have a detailed map of the location of the illegal housing, the available evidence suggests that most of them were at various locations along the river (Semba 2016). We therefore expect that the adjacency to rivers, which we control for as natural location characteristics in Table 1, captures the potential impact of illegal housing.

Table B.4: Controlling for the supply of public housing

	(1) Log number of public housing units	(2) Change in log population density 1945–1950	(3)	(4)
Distance to CBD	0.0004^{c}			
	(0.0002)			
Change in log population density 1936–1945 (γ)		-0.7270^{a}	-0.8924^{a}	-0.9397^{a}
		(0.0273)	(0.0511)	(0.0459)
Number of public housing units		0.0023	0.0026^{b}	0.0019
		(0.0014)	(0.0012)	(0.0028)
p-value from testing $\gamma = -1$		0.0000	0.037	0.190
Location characteristics (first and second nature)			Yes	Yes
Number of blocks	22	174	174	158
R-squared	0.234	0.816	0.866	0.874

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

B.3 *Nagasaki*

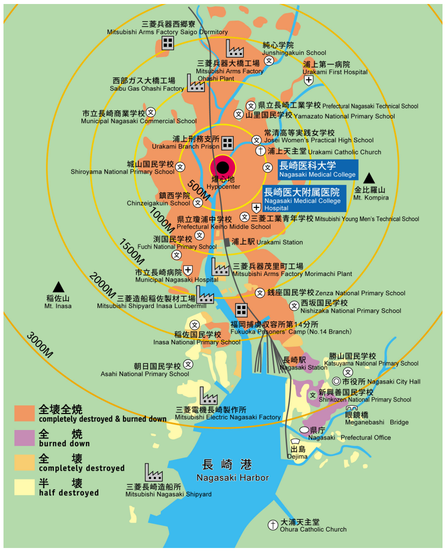
We also analyze the atomic bombing in Nagasaki, the second and last city to experience an atomic bombing as of this writing. We exploit data on the population at the school district level in Nagasaki for May 1945 (pre-bombing), October 1945 (post-bombing) and March 1954. The data are sourced from Nagasaki City Government (1983).

Figure B.1a is the damage map of Nagasaki. The atomic bomb hit the outskirts of the city, and the epicenter is more than 2 kilometers away from the city center, where the Nagasaki City Hall and the Nagasaki Prefectural Office were located. In Figure B.1b we show the relationship between the changes in the log population density from 1945–54 (Vertical axis) and those from May 1945 to October 1945. This is the same as in Figure 4 for Hiroshima. Despite the fact that the atomic bomb hit a different part of the city in the case of Nagasaki, the figure shows a very similar pattern to the case of Hiroshima.

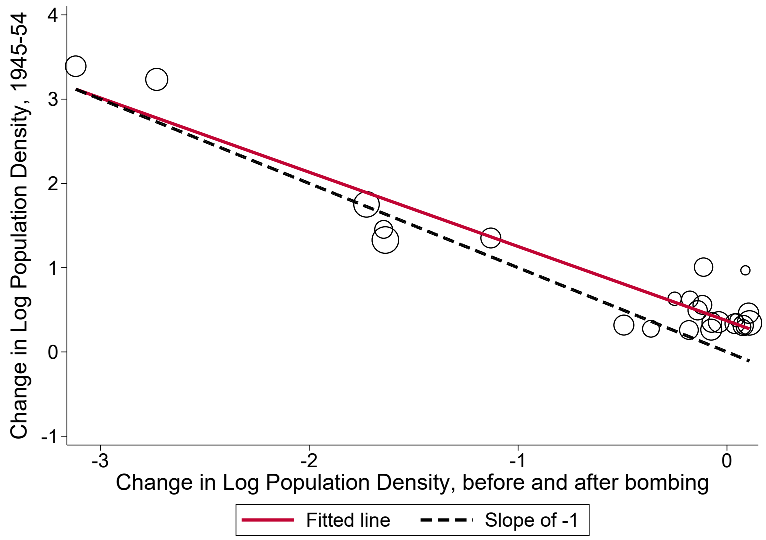
The estimated slope of the fitted line in the figure is −0.882 with a standard error of 0.101. We cannot reject the null hypothesis of $\gamma = -1$ at the conventional level. This is suggestive of the recovery of the pre-bombing city structure in Nagasaki, which reinforces the external validity of our results from Hiroshima. Moreover, in Nagasaki, the center of economic activities did not shift toward the destroyed area. This suggests a relatively limited importance of low development costs or creative destruction in our context (Hornbeck and Keniston 2017) because the destroyed peripheral areas could attract more population and employment than the pre-war period if these factors were dominant.

Figure B.1: Map of Nagasaki and reduced-form results

(a) Map of physical damage caused by the atomic bombing (Nagasaki)



(b) Change in population density (Nagasaki)



Note: The map in Figure B.1a shows the epicenter of the bombing in Nagasaki, as well as major the facilities and the extent of the damage to the structures. This map is provided by the Atomic Bomb Disease Institute at Nagasaki University. Figure B.1b plots the change in the log of population density from 1945 to 1954 compared to changes 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. There are 23 school districts in our sample. We plot the (unweighted) linear fit between these two variables (solid line) as well as a line with slope of -1 (dashed line). Indeed, the destroyed areas may be advantageous in attracting more residents, and their population may be higher than in the pre-war period relative to the intact areas.

C Model Elements

C.1 *Value Function*

When an individual is able to change their locations, she solves the problem of location choice (8) in the main text. The idiosyncratic taste shocks are drawn from a time-invariant and independent mean-zero Type I extreme distribution:

$$F(\varepsilon) = \exp\left[-\exp\left(-(\varepsilon + \Gamma)\right)\right]$$

where Γ is the Euler-Mascheroni constant:

$$\Gamma \equiv -\int_0^\infty \ln x e^{-x} dx$$

For $i, n \in \mathcal{C}$, we have distribution functions:

$$\begin{aligned} G_{int+1}(s) &= \text{Prob}\left[\rho V_{int+1} + \sigma \varepsilon_{int+1} \leq s\right] \\ &= \exp\left[-\exp\left(-\left(\frac{s - \rho V_{int+1}}{\sigma} + \Gamma\right)\right)\right] \end{aligned}$$

Therefore, $\rho V_{int+1} + \sigma\varepsilon_{int+1}$ follows the Gumbel distribution with mean ρV_{int+1} and scale parameter σ. The large value of σ leads to a large variation. Define

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

Then, we have

$$\begin{aligned} H_{t+1}(s) &= \text{Prob}[V^*_{t+1} \leq s] \\ &= \left(\prod_{i\in\mathcal{C}}\prod_{n\in\mathcal{C}} G_{int+1}(s)\right) \times G_{ot+1}(s) \end{aligned}$$

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

$$\begin{aligned} \mu_{t+1} &= \mathbb{E}_{t+1}[s] \\ &= \sigma \ln\left[\sum_{i\in\mathcal{C}}\sum_{n\in\mathcal{C}} \exp\left(V_{int+1}\right)^{\rho/\sigma} + \exp\left(V_{ot+1}\right)^{\rho/\sigma}\right] \end{aligned} \tag{C.1}$$

Therefore, we have value functions (9) and (10) in the main text.

C.2 *Location Choice*

Let $z_{t+1} = \varepsilon + \sigma\Gamma$. When an individual can switch their locations, the probability that she chooses a location pair of workplace i and residential place n in period $t+1$ is

$$\begin{aligned} \lambda_{int+1} &= \int_{-\infty}^{\infty}\left\{\prod_{i'\in\mathcal{C}}\prod_{n'\in\mathcal{C}} \exp\left[-e^{-\frac{1}{\sigma}\left(z_{t+1}+\rho(V_{int+1}-V_{i'n't+1})\right)}\right]\exp\left[-e^{-\frac{1}{\sigma}\left(z_{t+1}+\rho(V_{int+1}-V_{ot+1})\right)}\right]\right\}\frac{e^{-\frac{z_{t+1}}{\sigma}}}{\sigma}dz_{t+1} \\ &= \int_{-\infty}^{\infty}\exp\left[-e^{-z_{t+1}/\sigma}\left(\sum_{i'\in\mathcal{C}}\sum_{n'\in\mathcal{C}} e^{-\frac{\rho}{\sigma}\left(V_{int+1}-V_{i'n't+1}\right)} + e^{-\frac{\rho}{\sigma}\left(V_{int+1}-V_{ot+1}\right)}\right)\right]\frac{e^{-z_{t+1}/\sigma}}{\sigma}dz_{t+1} \end{aligned}$$

Letting $s_{t+1} = e^{-z_{t+1}/\sigma}$, this becomes

$$\begin{aligned} \lambda_{int+1} &= \int_0^{\infty}\exp\left[-s_{t+1}\left(\sum_{i'\in\mathcal{C}}\sum_{n'\in\mathcal{C}}\exp\left(-\frac{\rho}{\sigma}(V_{int+1}-V_{i'n't+1})\right) + \exp\left(-\frac{\rho}{\sigma}(V_{int+1}-V_{ot+1})\right)\right)\right]ds_{t+1} \\ &= \left[\frac{\exp\left(-s_{t+1}\left(\sum_{i'\in\mathcal{C}}\sum_{n'\in\mathcal{C}}\exp\left(-\frac{\rho}{\sigma}(V_{int+1}-V_{i'n't+1})\right) + \exp\left(-\frac{\rho}{\sigma}(V_{int+1}-V_{ot+1})\right)\right)\right)}{-\left(\sum_{i'\in\mathcal{C}}\sum_{n'\in\mathcal{C}}\exp\left(-\frac{\rho}{\sigma}(V_{int+1}-V_{i'n't+1})\right) + \exp\left(-\frac{\rho}{\sigma}(V_{int+1}-V_{ot+1})\right)\right)}\right]_0^{\infty} \\ &= \frac{\exp\left(V_{int+1}\right)^{\rho/\sigma}}{\sum_{i'\in\mathcal{C}}\sum_{n'\in\mathcal{C}}\exp\left(V_{i'n't+1}\right)^{\rho/\sigma} + \exp\left(V_{ot+1}\right)^{\rho/\sigma}} \end{aligned} \tag{C.2}$$

Analogously, the probability that an individual worker lives outside the city is:

$$\lambda_{ot+1} = \frac{\exp\left(V_{ot+1}\right)^{\rho/\sigma}}{\sum_{i'\in\mathcal{C}}\sum_{n'\in\mathcal{C}}\exp\left(V_{i'n't+1}\right)^{\rho/\sigma} + \exp\left(V_{ot+1}\right)^{\rho/\sigma}} \tag{C.3}$$

An individual can change their residential place and workplace with an exogenous probability, $\theta_{t+1} \in (0, 1)$. Using the location choice probabilities, 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:

$$L_{int+1} = (1 - \theta_{t+1})L_{int} + \theta_{t+1}\lambda_{int+1}L_t + \theta_{t+1}\lambda_{int+1}(M - L_t) \tag{C.4}$$

where, on the right-hand side, the first term is the mass of workers who do not have the opportunity for location choices and stay in the same residential place and workplace, the second term is the mass of workers in the city who choose residential place n and workplace i given their opportunity to switch the locations, and the last term is the mass of workers who enter the city from the outside and choose residential place n and workplace i. We can simplify this to

$$L_{int+1} = (1 - \theta_{t+1})L_{int} + \theta_{t+1}\lambda_{int+1}M \tag{C.5}$$

We can use the same idea to derive the dynamics of population (13) and employment (14):

$$\begin{aligned} R_{nt+1} &= \sum_{i\in\mathcal{C}} L_{int+1} \\ &= (1 - \theta_{t+1})R_{nt} + \theta_{t+1}\left[\sum_{i\in\mathcal{C}} \lambda_{int+1}\right] M \end{aligned} \tag{C.6}$$

$$\begin{aligned} L_{it+1} &= \sum_{n\in\mathcal{C}} L_{int+1} \\ &= (1 - \theta_{t+1})L_{it} + \theta_{t+1}\left[\sum_{n\in\mathcal{C}} \lambda_{int+1}\right] M \end{aligned} \tag{C.7}$$

Lastly, the total population of the city is:

$$\begin{aligned} L_{t+1} &= \sum_{i\in\mathcal{C}}\sum_{n\in\mathcal{C}} L_{int+1} \\ &= (1 - \theta_{t+1})L_t + \theta_{t+1}(1 - \lambda_{ot+1})M \end{aligned} \tag{C.8}$$

C.3 *Developers and Landlords*

There are competitive developers in the city. We adopt a similar setup for developers as Sturm, Takeda, and Venables (2023). They supply floor spaces that can be utilized for residential and commercial use. The stock of floor spaces per unit of land in n that exist in period t is given by

$$h_{nt} = (1 - \psi)h_{nt-1} + \widetilde{h}_t z_{nt}^{\zeta}, \quad 0 < \zeta < 1 \tag{C.9}$$

where ψ is the rate of depreciation of the floor spaces; h_{nt-1} is the stock of the floor spaces per unit of land at the end of period $t - 1$; $\widetilde{h}_t$ is a time-variant factor in the floor space production; and z_{nt} is the input of the homogeneous final goods per unit of land. In general, the depreciation rate of floor spaces may include the quality deterioration of housing stock over time, not just the quantity. The parameter ζ captures the return on investment in the construction of floor spaces, which reflects the technology of the developers. In particular, $1 - \zeta$ captures the cost share of land used in the construction of floor spaces.

In addition, we assume that there is an exogenous restriction on the floor spaces per unit of land that captures technological or regulatory constraints:

$$h_{nt} \leq \mathcal{H}_n / S_n < \infty \tag{C.10}$$

for any period t. This captures any constraint for developers, and we consider that $\mathcal{H}_n$ is sufficiently large for all locations in a city. In the following discussion, the constraint is not binding in equilibrium. Technically, we use $\mathcal{H}_n$ to show that the excess demand function for floor spaces is bounded from below.

There are a large number of developers who build housing in the city, and they determine investment z_{nt} to maximize their profit. Letting Q_{nt} refer to the floor space price in the floor space market, the dynamics of floor spaces are:

$$H_{nt} = (1-\psi)H_{nt-1} + \bar{\zeta}\widetilde{h}_t Q_{nt}^{\zeta/(1-\zeta)} S_n, \tag{C.11}$$

where $\bar{\zeta} \equiv \zeta^{\zeta/(1-\zeta)}$ is constant and the second term on the right-hand side is the floor spaces that are newly constructed between period t and $t+1$. Given (C.10), the total floor spaces are given by:

$$H_{nt} = \min\left\{(1-\psi)H_{nt-1} + \bar{h}_t Q_{nt}^{\zeta/(1-\zeta)} S_n,\ \mathcal{H}_n\right\}, \tag{C.12}$$

where we use $\bar{h}_t \equiv \bar{\zeta}\widetilde{h}_t$. In the following, we consider the restriction (C.10) is slack since $\mathcal{H}_n$ is sufficiently large. Therefore, we obtain the dynamics of the floor space supply given in equation (16) in the main text.

In each period, the profit of the developers in period t is extracted by the absentee landlord. Therefore, the value of land in location n in period t equals the aggregate revenue of landlords given by

$$\pi_{nt} S_n = (1-\psi)Q_{nt}H_{nt-1} + (1-\zeta)\bar{h}_t Q_{nt}^{1/(1-\zeta)} S_n, \tag{C.13}$$

where π_{nt} denote land price. If there is no initial stock of housing $H_{nt-1} = 0$, the logarithm of the land price is proportional to the logarithm of the housing price. However, this standard result under the Cobb-Douglas production function of developers no longer holds when there are housing stocks in the previous period, $H_{nt-1} > 0$.

We do not model the details of landlord consumption, which can be justified in the following two scenarios. First, we can suppose that a landlord in each location consumes only final homogenous goods but not floor space, given their income from the land revenue in (C.13). Second, we can consider the absentee landlords. In both cases, landlords supply land to developers in the competitive land market.

C.4 *A Microfoundation of Agglomeration Forces in Amenities*

We show that the specification of preferences and residential amenities (B_{nt}) is consistent with a simple microfoundation. To do so, we present an extended model in which we explicitly consider local consumption amenities.

Conditional on a residential place and workplace, an individual decides their consumption pattern. Individuals consume non-tradable local services and housing in their residences. The indirect utility of an individual who lives in n and works in i in period t is:

$$u_{int} = \frac{w_{it}}{\left(P_{nt}^{\mathrm{G}}\right)^{\mu_G}\left(P_{nt}^{\mathrm{S}}\right)^{\mu_S}\left(q_{nt}^{r}\right)^{\mu}}\frac{\mathcal{B}_{nt}}{\kappa_{int}}, \quad \mu_S + \mu_G = 1-\mu \in (0,1) \tag{C.14}$$

where w_{it} is the wage in i; $P^{\mathrm{G}}_{nt} = 1$ is the price of tradable goods; P^{S}_{nt} is the price index of local services in n; q^r_{nt} is the housing price in n; $\mathcal{B}_{nt}$ is unobserved fundamental amenities; and κ_{int} is commuting costs from n to i. μ is the share of expenditure devoted to housing, and $1-\mu$ is the total share of expenditure devoted to local services (μ_S) and goods (μ_G).

The price index of local services is a CES function of the prices and number of varieties supplied, taking the following form:

$$P^{\mathrm{S}}_{nt} = \left[\sum_{\iota \in \mathcal{I}^{\mathrm{S}}_{nt}} \left(\frac{p_{\iota nt}}{\varphi_{\iota nt}} \right)^{1-\varrho} \right]^{1/(1-\varrho)} , \quad \varrho > 1, \tag{C.15}$$

where ϱ is the constant elasticity of substitution between varieties; we assume that varieties are substitutes ($\varrho > 1$); $\mathcal{I}^{\mathrm{S}}_{nt}$ is the set of varieties available in n; $p_{\iota nt}$ is the price of each variety; and $\varphi_{\iota nt}$ captures the quality of variety as reflected in consumer taste.

The CES demand system implies that expenditures on a single variety in n are

$$e_{\iota nt} = \left(\frac{p_{\iota nt}/\varphi_{\iota nt}}{P^{\mathrm{S}}_{nt}} \right)^{1-\varrho} \mu_G v_{nt} R_{nt} \tag{C.16}$$

In each block, firms in the local service sector produce a variety of goods using homogeneous goods and maximize profit given (C.16). Production incurs a fixed cost of $\bar{f}$ units of homogeneous goods. Then, the price of each variety is given by

$$p_{\iota nt} = \frac{\varrho}{\varrho - 1}$$

and firms make zero profits if they sell the output level:

$$\bar{y} = (\varrho - 1)\bar{f}$$

Then the CES price index (C.15) can be written as

$$P^{\mathrm{S}}_{nt} = \frac{\varrho}{\varrho - 1} \frac{1}{\tilde{\varphi}_{nt}}, \tag{C.17}$$

where

$$\tilde{\varphi}_{nt} = \left[\sum_{\iota \in \mathcal{I}^{\mathrm{S}}_{nt}} (\varphi_{\iota nt})^{\varrho - 1} \right]^{1/(\varrho-1)}$$

The market clearing condition for local services is:

$$\left(\frac{\varrho}{\varrho - 1} \right)^{-\varrho} (\varphi_{\iota nt})^{\varrho-1} (P^{\mathrm{S}}_{nt})^{\varrho-1} \mu_G v_{nt} R_{nt} = (\varrho - 1)\bar{f}, \tag{C.18}$$

where the left-hand side is the demand for variety ι, and the right-hand side is its supply. We substitute the price index into (C.18) and apply the definition of $\tilde{\varphi}_{nt}$ to (C.17) to derive the number of varieties:

$$N^*_{nt} = |\mathcal{I}^{\mathrm{S}}_{nt}| = \frac{\mu_G v_{nt} R_{nt}}{\varrho \bar{f}} \tag{C.19}$$

Next, we suppose that consumer tastes ($\varphi_{\iota nt}$) in n depends on the average income in n (v_{nt}) and idiosyncratic unobserved taste shocks ($\varphi^*_{\iota nt}$):

$$\varphi_{\iota nt} = \varphi^*_{\iota nt}\left(v_{nt}\right)^{\vartheta} \tag{C.20}$$

Then, the taste-adjusted price (p_{snt}/φ_{snt}) is supposed to be decreasing in average income ($\vartheta > 0$), which is consistent with the better quality of consumption amenities in high-income areas (e.g., Diamond 2016). In addition, without loss of generality, we assume that the generalized mean of order-k of unobserved consumer taste shocks is normalized:

$$\left[\frac{1}{N^*_{nt}}\sum_{\iota\in\mathcal{I}^{\mathrm{S}}_{nt}}\left(\varphi^*_{\iota nt}\right)^k\right]^{1/k} = 1$$

When we substitute (C.20) into (C.17) together with (C.19), we obtain:

$$P^{\mathrm{S}}_{nt} = \frac{\varrho}{\varrho-1}\left(N^*_{nt}\right)^{1/(1-\varrho)}\left(v_{nt}\right)^{\vartheta} = \delta_0\left(v_{nt}\right)^{1/(1-\varrho)+\vartheta}\left(R_{nt}\right)^{1/(1-\varrho)}, \tag{C.21}$$

where we let δ_0 refer to a constant parameter. Therefore, the price index of local services is decreasing in the population in the neighborhood with elasticity $1/(1-\varrho)$, which captures the love of variety in the local neighborhood. With respect to the average income (v_{nt}), higher income leads to large varieties of local services with elasticity $1/(1-\varrho)$ while increasing taste-adjusted prices with elasticity ϑ. In a special case with $1/(\varrho-1) = \vartheta$, the price index is independent of the average income.

Finally, we use (C.21) for the price index of local services to obtain indirect utility (C.14), which can be written as similar to the preference (6). In particular, the value of amenities (B_{nt}) in the preference (6) can be a function of the fundamental (unobserved) amenities and the local population.

D Equilibrium

D.1 *Existence of a Dynamic Equilibrium*

Let $\mathbb{V}_{int} \equiv V_{int} - V_{ot}$ and $\mathcal{U}_{int} \equiv u_{int}/u_{ot}$. The Bellman equations imply:

$$\mathbb{V}_{int} = \ln\mathcal{U}_{int} + (1-\theta_{t+1})\rho\mathbb{V}_{int+1}$$

Iterating this, we obtain the value of location choices within a city relative to outside the city:

$$\begin{aligned}\mathbb{V}_{int} &= \ln\mathcal{U}_{int} + \sum_{\tau=t+1}^{T}\left\{\prod_{s=t+1}^{\tau}\rho(1-\theta_s)\right\}\ln\mathcal{U}_{in\tau}\\ &= \ln\left\{\mathcal{U}_{int}\prod_{\tau=t+1}^{T}\left(\mathcal{U}_{in\tau}\right)^{\prod_{s=t+1}^{\tau}\rho(1-\theta_s)}\right\}\\ &= \ln\left\{\frac{w_{it}B_{nt}Q_{nt}^{-\mu}}{\kappa_{int}u_{ot}}\prod_{\tau=t+1}^{T}\left(\frac{w_{i\tau}B_{n\tau}Q_{n\tau}^{-\mu}}{\kappa_{in\tau}u_{o\tau}}\right)^{\prod_{s=t+1}^{\tau}\rho(1-\theta_s)}\right\}\end{aligned} \tag{D.1}$$

The probability that workers choose residential place n and workplace i given their moving opportunity (C.2) in period t can be expressed as:

$$\lambda_{int} = \frac{\exp\left(\mathbb{V}_{int}\right)^{\rho/\sigma}}{\sum_{i'\in\mathcal{C}}\sum_{n'\in\mathcal{C}}\exp\left(\mathbb{V}_{i'n't}\right)^{\rho/\sigma}+1} \tag{D.2}$$

and the probability that workers choose outside the city is:

$$\lambda_{ot} = \frac{1}{\sum_{i'\in\mathcal{C}}\sum_{n'\in\mathcal{C}}\exp\left(\mathbb{V}_{i'n't}\right)^{\rho/\sigma}+1} \tag{D.3}$$

Therefore, we obtain the population in location n:

$$R_{nt} = (1-\theta_t)R_{nt-1} + \theta_t\left[\sum_{i\in\mathcal{C}}\frac{\exp\left(\mathbb{V}_{int}\right)^{\rho/\sigma}}{\sum_{i'\in\mathcal{C}}\sum_{n'\in\mathcal{C}}\exp\left(\mathbb{V}_{i'n't}\right)^{\rho/\sigma}+1}\right]M \tag{D.4}$$

and employment in location i:

$$L_{it} = (1-\theta_t)L_{it-1} + \theta_t\left[\sum_{n\in\mathcal{C}}\frac{\exp\left(\mathbb{V}_{int}\right)^{\rho/\sigma}}{\sum_{i'\in\mathcal{C}}\sum_{n'\in\mathcal{C}}\exp\left(\mathbb{V}_{i'n't}\right)^{\rho/\sigma}+1}\right]M \tag{D.5}$$

Turning to the zero profit condition for the firms, we obtain:

$$w_{it}^{\gamma^L} Q_{it}^{\gamma^H} = A_{it}, \tag{D.6}$$

for any location i and period t.

The total floor space in location n in period t is:

$$H_{nt} = (1-\psi)H_{nt-1} + \bar{h}_t Q_{nt}^{\eta} S_n, \tag{D.7}$$

which is determined by the stock of floor spaces at the end of the previous period (H_{nt-1}) and floor space prices (Q_{nt}) in period t, given the size of the land (S_n) and the model parameters of the depreciation of tge floor spaces (ψ) and the floor space supply elasticity (η).

Lastly, the floor space market clearing condition in period t is:

$$H_{nt}Q_{nt} = \mu v_{nt}R_{nt} + \frac{\gamma^H}{\gamma^L}w_{nt}L_{nt}, \tag{D.8}$$

where the average income of individuals in the residential place n is given by

$$v_{nt} = \sum_{i\in\mathcal{C}}\frac{L_{int}}{\sum_{i'\in\mathcal{C}}L_{i'nt}}w_{it} \tag{D.9}$$

We define the dynamic equilibrium when all location characteristics, including amenities and productivity, are exogenous.

Definition D.1 (Dynamic Equilibrium with Exogenous Fundamentals). *Given the sequence of exogenous productivity* $\{A_{it}\}$, *amenities* $\{B_{nt}\}$, *land area* (S_n), *commuting costs* $\{\kappa_{int}\}$, *utility outside of the city* $\{u_{ot}\}$, *economy-wide parameters and the initial condition* (H_{n0}, L_{in0}), *a dynamic equilibrium is characterized by the sequence of wages* $\{w_{it}\}$, *floor space prices* $\{Q_{nt}\}$, *population* $\{R_{nt}\}$, *employment* $\{L_{it}\}$, *and value functions associated with location choices* $\{\mathbb{V}_{int}\}$ *such that (i) the value functions of workers for their location choices* $\{\mathbb{V}_{int}\}$ *is given by* (D.1) *with* $\mathbb{V}_{inT} = \ln(u_{inT}/u_{oT})$ *for the last period* T*; (ii) the commuting market clears in the city and the masses of workers in workplace and residential locations are given by* (D.4) *and* (D.5) *together with* (D.2)*; (iii) firms maximize their profits and the zero-profit condition leads to a productivity equal to* (D.6)*; and (iv) developers maximize their profits and floor space market clears* (D.8) *with* (D.7) *and* (D.9)*.*

We show that given the exogenous productivity and amenities, a dynamic equilibrium exists. Equation (D.6) implies the wage rate is determined by floor space prices and productivity:

$$w_{it} = \left(A_{it} Q_{it}^{-\gamma^H}\right)^{1/\gamma^L} \tag{D.10}$$

and the relative utility of living in n and working in i to the outside the city becomes:

$$\mathcal{U}_{int} = \frac{\left(A_{it} Q_{it}^{-\gamma^H}\right)^{1/\gamma^L}}{\kappa_{int} u_{ot}} \frac{B_{nt}}{Q_{nt}^{\mu}} \tag{D.11}$$

When we plug this into the value function (D.1), we can express the relative value of living in n and working in i by:

$$\mathbb{V}_{int} = \ln \left\{ \frac{\left(A_{it} Q_{it}^{-\gamma^H}\right)^{1/\gamma^L}}{\kappa_{int} u_{ot}} \frac{B_{nt}}{Q_{nt}^{\mu}} \prod_{\tau=t+1}^{T} \left[\frac{\left(A_{i\tau} Q_{i\tau}^{-\gamma^H}\right)^{1/\gamma^L}}{\kappa_{in\tau} u_{o\tau}} \frac{B_{n\tau}}{Q_{n\tau}^{\mu}} \right]^{\prod_{s=t+1}^{\tau} \rho(1-\theta_s)} \right\}, \tag{D.12}$$

where $\mathbb{Q}_t$ denotes the vectors of $\{Q_{nt}\}$ from period t to the last period T. This implies that the value function in period t is determined by the sequence of floor space prices $\mathbb{Q}_t$ given the exogenous productivity, amenities, commuting costs and outside utility. Conditional on the population distribution $\{R_{nt-1}\}$ and employment distribution $\{L_{it-1}\}$ in the previous period $t-1$, equations (D.4) and (D.5) determine the population and employment distribution in period t. Therefore, we can let $R_n(\mathbb{Q}_t)$ and $L_i(\mathbb{Q}_t)$ denote population and employment as a function of floor space prices.

In addition, we can compute the number of individuals who commute from n to i in period t. Equation (C.5) and the commuting pattern in the previous year L_{int-1} lead to

$$L_{int}(\mathbb{Q}_t) = (1-\theta_t) L_{int-1} + \theta_t \lambda_{int}(\mathbb{Q}_t) M, \tag{D.13}$$

where the second term on the right-hand side is given by (D.2) with (D.12). In turn, we can derive the average labor income of individuals living in location n, $v_{nt}(\mathbb{Q}_t)$ that is given in equation (D.9):

$$v_{nt}(\mathbb{Q}_t) = \sum_{i \in \mathcal{C}} \frac{L_{int}(\mathbb{Q}_t)}{\sum_{i' \in \mathcal{C}} L_{i'nt}(\mathbb{Q}_t)} \left(A_{it} Q_{it}^{-\gamma^H}\right)^{1/\gamma^L} \tag{D.14}$$

Finally, substituting the floor space supply (D.7) into (D.8) yields the excess demand function for floor spaces in location n, which equals zero in equilibrium:

$$
\begin{aligned}
&\mathcal{D}^0_{nt}(\mathbb{Q}_t) \\
&\equiv \frac{1}{Q_{nt}}\left[\mu v_{nt}(\mathbb{Q}_t)R_n(\mathbb{Q}_t) + \frac{\gamma^H}{\gamma^L}\left(\frac{A_{nt}}{Q_{nt}^{\gamma^H}}\right)^{1/\gamma^L} L_n(\mathbb{Q}_t)\right] - \left[(1-\psi)H_{nt-1} + \bar{h}_t Q_{nt}^{\eta} S_n\right] = 0
\end{aligned}
\tag{D.15}
$$

We replicate the excess demand function for T periods to obtain $N \times T$ equations. The excess demand function is continuous and satisfies the boundary condition such that: $\mathcal{D}^0_{nt}(\mathbb{Q}_t) \to \infty$ when $Q_{nt} \to 0$ for any n and t; and $\mathcal{D}^0_{nt}(\mathbb{Q}_t)$ is bounded below by $-(1-\psi)H_{nt-1} + \mathcal{H}_n$ with exogenous large number $\mathcal{H}_n$ in equation (C.10). Therefore, there exist equilibrium floor space prices $\{Q_{nt}\}_{t=1,2,\cdots,T}$ that clear the floor space market clearing condition.

Proposition D.1. *When the productivity and amenities are exogenous (i.e., no agglomeration forces in both productivity and amenities), a dynamic equilibrium exists.*

Agglomeration forces in productivity and amenities When there are agglomeration forces, productivity is a function of the fundamental productivity (a_{it}) and the employment density in the location given in equation (4). Using this, the zero profit condition for firms leads to the wage rate:

$$
\begin{aligned}
w_{it} &= \left(\mathbb{A}_{it} L_{it}^{\alpha} Q_{it}^{-\gamma^H}\right)^{1/\gamma^L}, \\
\mathbb{A}_{it} &\equiv a_{it} S_i^{-\alpha},
\end{aligned}
\tag{D.16}
$$

where $\mathbb{A}_{it}$ captures exogenous productivity adjusted by land size.

The value of amenities is a function of the fundamental amenities (b_{nt}) and the population density in the location as in equation (7). Therefore, the relative utility of living in n and working in i to the outside of the city is expressed by

$$
\mathcal{U}_{int} = \frac{\left(\mathbb{A}_{it} L_{it}^{\alpha} Q_{it}^{-\gamma^H}\right)^{1/\gamma^L}}{\kappa_{int} u_{ot}} \frac{\mathbb{B}_{nt} R_{nt}^{\beta}}{Q_{nt}^{\mu}},
\tag{D.17}
$$

where $\mathbb{B}_{nt} \equiv b_{nt} S_n^{-\beta}$ absorbs all the exogenous characteristics in amenities adjusted by land size. Using them, the value function can be represented by

$$
\begin{aligned}
&\mathbb{V}_{int} = F_V(\mathbb{Q}_t, \mathcal{R}_t, \mathcal{L}_t) \\
&\equiv \ln\left\{ \frac{\left(\mathbb{A}_{it} L_{it}^{\alpha} Q_{it}^{-\gamma^H}\right)^{1/\gamma^L}}{\kappa_{int} u_{ot}} \frac{\mathbb{B}_{nt} R_{nt}^{\beta}}{Q_{nt}^{\mu}} \prod_{\tau=t+1}^{T} \left[\frac{\left(\mathbb{A}_{i\tau} L_{i\tau}^{\alpha} Q_{i\tau}^{-\gamma^H}\right)^{1/\gamma^L}}{\kappa_{in\tau} u_{o\tau}} \frac{\mathbb{B}_{n\tau} R_{n\tau}^{\beta}}{Q_{n\tau}^{\mu}} \right]^{\prod_{s=t+1}^{\tau} \rho(1-\theta_s)} \right\},
\end{aligned}
\tag{D.18}
$$

where the value function depends on the current and future population distribution ($\mathcal{R}_t$) and employment distribution ($\mathcal{L}_t$) compared to equation (D.12). In other words, the future path of the population distribution $\mathcal{R}_t \equiv \left(\{R_{n\tau}\}_{n\in\mathcal{C}}\right)_{\tau=t,\cdots,T}$ and employment distribution $\mathcal{L}_t \equiv \left(\{L_{i\tau}\}_{i\in\mathcal{C}}\right)_{\tau=t,\cdots,T}$ determine the option values associated with the current location choices. Now, we define the dynamic equilibrium when we have agglomeration forces in productivity and amenities:

Definition D.2 (Dynamic Equilibrium with Agglomeration Forces). *Given sequence of exogenous fundamental productivity $\{a_{it}\}$, amenities $\{b_{nt}\}$, land area (S_n), commuting costs $\{\kappa_{int}\}$, utility outside of the city $\{u_{ot}\}$, economy-wide parameters and the initial condition (H_{n0}, L_{in0}), a dynamic equilibrium is characterized by the sequence of wages $\{w_{it}\}$, floor space prices $\{Q_{nt}\}$, population $\{R_{nt}\}$, employment $\{L_{it}\}$, and value functions associated with location choices $\{\mathbb{V}_{int}\}$ such that (i) the value functions of workers for their location choices $\{\mathbb{V}_{int}\}$ is given by* (D.18) *with $\mathbb{V}_{inT} = \ln(u_{inT}/u_{oT})$ for the last period T; (ii) the commuting market clears in the city and the masses of workers in workplace and residential locations are given by* (D.4) *and* (D.5) *together with* (D.2)*; (iii) firms maximize their profits and the zero-profit condition leads to wage rate equal to* (D.16)*; and (iv) developers maximize their profits and floor space market clears* (D.8) *with* (D.7) *and* (D.9).

We show the existence of the population and employment distribution in a dynamic competitive equilibrium. Note that the sequences of population $\mathcal{R}_t$ and employment $\mathcal{L}_t$ satisfy:

$$\begin{aligned} R_{nt} &\geq (1-\theta_t) R_{nt-1}, \\ L_{it} &\geq (1-\theta_t) L_{it-1}, \end{aligned} \tag{D.19}$$

given θ_t for any period and location. For the initial period, we assume that both population (R_{n0}) and employment (L_{i0}) are nonnegative for all locations. To simplify the discussion, we suppose $(1-\theta_{t+\tau})\rho \to 0$ for $\tau \geq 1$. However, our following augment can be applied to the general case since the logic for the proof of the existence of equilibrium is the same when we include the population and employment beyond the next period.

Then, the value function (D.18) for living in n and working in i becomes:

$$\begin{aligned} \mathbb{V}_{int} &= \ln \left[\frac{\left(\mathbb{A}_{it} L_{it}^{\alpha} Q_{it}^{-\gamma^H} \right)^{1/\gamma^L}}{\kappa_{int} u_{ot}} \frac{\mathbb{B}_{nt} R_{nt}^{\beta}}{Q_{nt}^{\mu}} \right] \\ &= \ln \left[\frac{R_{nt}^{\beta} L_{it}^{\alpha/\gamma^L}}{E_{int}} \frac{Q_{it}^{-\gamma^H/\gamma^L}}{Q_{nt}^{\mu}} \right], \end{aligned} \tag{D.20}$$

where E_{int} is a compound of the exogenous factors. Equations (D.4) and (D.5) imply that, given the floor space vector $\mathbb{Q}_t$, equilibrium population and employment in period t solve the system of equations:

$$\begin{aligned} R_{nt} &= (1-\theta_t) R_{nt-1} + \sum_{i \in \mathcal{C}} \frac{(R_{nt})^{\beta\varkappa} \left(E_{int} (Q_{nt})^{\mu} \right)^{-\varkappa}}{\sum_{n' \in \mathcal{C}} (R_{n't})^{\beta\varkappa} \left(E_{in't} (Q_{n't})^{\mu} \right)^{-\varkappa}} \left[L_{it} - (1-\theta_t) L_{it-1} \right], \\ L_{it} &= (1-\theta_t) L_{it-1} + \sum_{n \in \mathcal{C}} \frac{(L_{it})^{\varkappa\alpha/\gamma^L} \left(E_{int} (Q_{it})^{-\gamma^H/\gamma^L} \right)^{-\varkappa}}{\sum_{i' \in \mathcal{C}} (L_{i't})^{\varkappa\alpha/\gamma^L} \left(E_{i'nt} (Q_{i't})^{-\gamma^H/\gamma^L} \right)^{-\varkappa}} \left[R_{nt} - (1-\theta_t) R_{nt-1} \right], \end{aligned} \tag{D.21}$$

where we use $\varkappa \equiv \rho/\sigma$. Letting $\mathbf{z} = (\mathcal{R}, \mathcal{L})$ be a vector of population and employment, we define the operator $\mathcal{O}(\mathbf{z})$ such that the ι-th element $\mathcal{O}_{\iota}(\mathbf{z})$ corresponds to the right-hand side of (D.21).

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 $\mathfrak{R}^{2N}_{++}$ where the operator $\mathcal{O}$ is mapping from the subset to itself. The operator $\mathcal{O}$ is a continuous mapping. Therefore, according to Brouwer's fixed-point theorem, there exists a dynamic equilibrium that satisfies (D.19). Therefore, we define $R_n(\mathbb{Q}_t)$ and $L_i(\mathbb{Q}_t)$ for population and employment, respectively, given the floor space prices.

Finally, we use the floor space market clearing condition. The excess demand function for the floor spaces is given by

$$\begin{aligned}
&\mathcal{D}^1_{nt}(\mathbb{Q}_t) \\
&\equiv \frac{1}{Q_{nt}}\left[\mu v_{nt}(\mathbb{Q}_t)R_n(\mathbb{Q}_t) + \frac{\gamma^H}{\gamma^L}\left(\frac{\mathbb{A}_{nt}\left(L_n(\mathbb{Q}_t)\right)^{\alpha}}{Q_{nt}^{\gamma^H}}\right)^{1/\gamma^L} L_n(\mathbb{Q}_t)\right] - \left[(1-\psi)H_{nt-1} + \bar{h}_t Q^{\eta}_{nt} S_n\right]
\end{aligned} \tag{D.22}$$

In equilibrium, $\mathcal{D}^1_{nt}(\mathbb{Q}_t) = 0$ for any location n in period t. The excess demand function shows: $\mathcal{D}^1_{nt}(\mathbb{Q}_t) \to \infty$ when $Q_{nt} \to 0$ for any n and t; and $\mathcal{D}^1_{nt}(\mathbb{Q}_t)$ is bounded below by $-(1-\psi)H_{nt-1} + \mathcal{H}_n$ with exogenous large number $\mathcal{H}_n$ in equation (C.10). Therefore, there exist equilibrium floor space prices $\{Q_{nt}\}_{t=1,2,\cdots,T}$ that clear the floor space market clearing condition. In summary:

Proposition D.2. *A dynamic equilibrium exists given the initial distribution of economic activities.*

D.2 *Existence and Uniqueness of a Steady-State Equilibrium*

Suppose that the economy reaches a steady state in the long run. If the steady-state equilibrium exists, it is a stationary steady state where all model variables are constant over time. Therefore, we drop the time subscripts of the variables when describing the steady state. In such a stationary steady state, the population in location n can be written using the conditional probabilities that workers commute to i from residential location n:

$$\begin{aligned}
R_n &= \sum_{i \in \mathcal{C}} \lambda^R_{n|i} L_i \\
&= \sum_{i \in \mathcal{C}} \frac{e^{\varkappa \mathbb{V}_{in}}}{\sum_{n' \in \mathcal{C}} e^{\varkappa \mathbb{V}_{in'}}} L_i \\
&= \sum_{i \in \mathcal{C}} \frac{\kappa_{in}^{-\varkappa}\left(\mathbb{B}_n R_n^{\beta}\right)^{\varkappa} Q_n^{-\mu\varkappa}}{\sum_{n' \in \mathcal{C}} \kappa_{in'}^{-\varkappa}\left(\mathbb{B}_{n'} R_{n'}^{\beta}\right)^{\varkappa} Q_{n'}^{-\mu\varkappa}} L_i
\end{aligned} \tag{D.23}$$

Analogously, the employment in workplace i using the conditional probabilities that workers live in n given workplace i becomes:

$$
\begin{aligned}
L_i &= \sum_{n\in\mathcal{C}} \lambda^L_{i|n} R_n \\
&= \sum_{n\in\mathcal{C}} \frac{e^{\varkappa \mathbb{V}_{in}}}{\sum_{i'\in\mathcal{C}} e^{\varkappa \mathbb{V}_{i'n}}} R_n \\
&= \sum_{n\in\mathcal{C}} \frac{\kappa_{in}^{-\varkappa}\left(\mathbb{A}_i L_i^{\alpha} Q_i^{-\gamma^H}\right)^{\varkappa/\gamma^L}}{\sum_{i'\in\mathcal{C}} \kappa_{i'n}^{-\varkappa}\left(\mathbb{A}_{i'} L_{i'}^{\alpha} Q_{i'}^{-\gamma^H}\right)^{\varkappa/\gamma^L}} R_n
\end{aligned} \tag{D.24}
$$

Given the floor space price vector $\mathbb{Q}$, the steady-state equilibrium is characterized by vectors $\{R_n, L_i, \Phi_i, \Psi_n\}$ that solve the system of equations:

$$
\begin{aligned}
R_n^{1-\beta\varkappa} &= \sum_{i\in\mathcal{C}} \kappa_{in}^{-\varkappa}\left(\mathbb{B}_n Q_n^{-\mu}\right)^{\varkappa} Q_n^{-\mu\varkappa} \Phi_i^{-1} L_i, \\
\Phi_i &= \sum_{n\in\mathcal{C}} \kappa_{in}^{-\varkappa}\left(\mathbb{B}_n Q_n^{-\mu}\right)^{\varkappa} R_n^{\beta\varkappa}, \\
L_i^{1-\alpha\varkappa/\gamma^L} &= \sum_{n\in\mathcal{C}} \kappa_{in}^{-\varkappa}\left(\mathbb{A}_i Q_i^{-\gamma^H}\right)^{\varkappa/\gamma^L} \Psi_n^{-1} R_n, \\
\Psi_n &= \sum_{i\in\mathcal{C}} \kappa_{in}^{-\varkappa}\left(\mathbb{A}_i Q_i^{-\gamma^H}\right)^{\varkappa/\gamma^L} L_i^{\alpha\varkappa/\gamma^L}
\end{aligned} \tag{D.25}
$$

To exploit the result of Allen, Arkolakis, and Li (2024), we define the following matrices $\mathbf{C}$ and $\mathbf{D}$ that summarize the parameters from the left and right-hand sides of the system of equations, respectively:

$$
\mathbf{C} = \begin{bmatrix} 1-\beta\varkappa & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1-\alpha\varkappa/\gamma^L & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}, \quad \mathbf{D} = \begin{bmatrix} 0 & -1 & 1 & 0 \\ \beta\varkappa & 0 & 0 & 0 \\ 1 & 0 & 0 & -1 \\ 0 & 0 & \alpha\varkappa/\gamma^L & 0 \end{bmatrix}
$$

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

$$
\begin{aligned}
\alpha &\neq \gamma^L \sigma/\rho, \\
\beta &\neq \sigma/\rho
\end{aligned} \tag{D.26}
$$

and a steady-state population and employment distribution exists conditional on the floor space prices $\mathbb{Q}$.

Next, we define matrix $\mathbf{\Gamma} = |\mathbf{D}\mathbf{C}^{-1}|$. Using the results in Allen, Arkolakis, and Li (2024), the system of equations has a unique up-to-scale solution if all eigenvalues of the matrix $\mathbf{\Gamma}$ are no greater than one. In our case, the sufficient conditions for a unique up-to-scale solution $\{R_n\}$ and $\{L_i\}$ conditional on the floor space prices are:

$$
\begin{aligned}
\frac{|\alpha\varkappa/\gamma^L| + 1}{|1-\alpha\varkappa/\gamma^L|} &\leq 1, \\
\frac{|\beta\varkappa| + 1}{|1-\beta\varkappa|} &\leq 1
\end{aligned} \tag{D.27}
$$

These conditions hold if and only if

$$\begin{aligned} \beta &\leq 0, \\ \alpha &\leq 0 \end{aligned} \tag{D.28}$$

The agglomeration forces in productivity (α) and amenities (β) must be negative so that the congestion force dominates the agglomeration force for both workplaces and residential places to ensure a unique up-to-scale solution.

In the steady state, the number of commuters from n to i is:

$$\begin{aligned} L_{in} &= \lambda_{in} M \\ &= \frac{(\kappa_{in} u_o)^{-\varkappa} \left(\mathbb{A}_i L_i^{\alpha} Q_i^{-\gamma^H}\right)^{\varkappa/\gamma^L} \left(\mathbb{B}_n R_n^{\beta}\right)^{\varkappa} (Q_n)^{-\mu\varkappa}}{\sum_{i' \in \mathcal{C}} \sum_{n' \in \mathcal{C}} (\kappa_{i'n'} u_o)^{-\varkappa} \left(\mathbb{A}_{i'} L_{i'}^{\alpha} Q_{i'}^{-\gamma^H}\right)^{\varkappa/\gamma^L} \left(\mathbb{B}_{n'} R_{n'}^{\beta}\right)^{\varkappa} (Q_{n'})^{-\mu\varkappa} + 1} M \end{aligned} \tag{D.29}$$

The average labor income of workers living in location n is:

$$\begin{aligned} v_n &= \sum_{i \in \mathcal{C}} \lambda_{i|n}^L w_i \\ &= \sum_{i \in \mathcal{C}} \frac{\kappa_{in}^{-\varkappa} \left(\mathbb{A}_i L_i^{\alpha} Q_i^{-\gamma^H}\right)^{\varkappa/\gamma^L}}{\sum_{i' \in \mathcal{C}} \kappa_{i'n}^{-\varkappa} \left(\mathbb{A}_{i'} L_{i'}^{\alpha} Q_{i'}^{-\gamma^H}\right)^{\varkappa/\gamma^L}} \left(\mathbb{A}_i L_i^{\alpha} Q_i^{-\gamma^H}\right)^{1/\gamma^L} \end{aligned} \tag{D.30}$$

Next, we consider the floor space market clearing condition in a steady state. In a steady state, the total floor space in location n is given by

$$H_n = \frac{\bar{h}}{\psi} Q_n^{\eta} S_n \tag{D.31}$$

Combining (D.16), (D.30) and (D.31), the floor space market clearing condition becomes:

$$\begin{aligned} D_n^{SS}(\mathbb{Q}) \equiv{}& \frac{1}{Q_n} \mu \left[\sum_{i \in \mathcal{C}} \frac{\kappa_{in}^{-\varkappa} \left(\mathbb{A}_i L_i(\mathbb{Q})^{\alpha} Q_i^{-\gamma^H}\right)^{\varkappa/\gamma^L}}{\sum_{i' \in \mathcal{C}} \kappa_{i'n}^{-\varkappa} \left(\mathbb{A}_{i'} L_{i'}(\mathbb{Q})^{\alpha} Q_{i'}^{-\gamma^H}\right)^{\varkappa/\gamma^L}} \left(\mathbb{A}_i L_i(\mathbb{Q})^{\alpha} Q_i^{-\gamma^H}\right)^{1/\gamma^L} \right] R_n(\mathbb{Q}) \\ &+ \frac{1}{Q_n} \frac{\gamma^H}{\gamma^L} \left[\frac{\mathbb{A}_n L_n(\mathbb{Q})^{\alpha}}{Q_n^{\gamma^H}} \right]^{1/\gamma^L} L_n(\mathbb{Q}_t) - \frac{\bar{h}}{\psi} Q_n^{\eta} S_n = 0, \end{aligned} \tag{D.32}$$

where we define the excess demand function $D_n^{SS}(\mathbb{Q})$ of floor space prices $\mathbb{Q}$. The first term represents the demand for residential floor space; the second term is the demand for commercial floor space; and the last term is the supply of floor space. A steady-state equilibrium satisfies $D_n^{SS}(\mathbb{Q}) = 0$. Therefore, we inspect the properties of the excess demand function.

Existence First, the excess demand function is continuous in $\mathbb{Q}$ because preference and production technology are characterized by a continuous function. Second, the excess demand function shows $D_n^{SS}(\mathbb{Q}) \to \infty$ when $Q_n \to 0$ for any n; therefore, the function satisfies the boundary condition. Third, the excess demand function is bounded below by an exogenous number. In particular $D_n^{SS} \geq -\mathcal{H}_n$ for any n is given in equation (C.10). Together, we obtain the following proposition:

Proposition D.3. *Under the conditions* (D.26)*, there exists a steady state equilibrium.*

Uniqueness When the excess demand function satisfies the following properties (gross substitution), we can establish the uniqueness of equilibrium

$$\frac{\partial D_n^{SS}(\mathbb{Q})}{\partial Q_n} < 0, \quad \forall\, n \in \mathcal{C} \quad \textit{and} \quad \forall\, \mathbb{Q} \in \mathfrak{R}_+^N \tag{D.33}$$

and

$$\frac{\partial D_n^{SS}(\mathbb{Q})}{\partial Q_\ell} > 0, \quad \forall\, n, \ell, \ell \neq n, \quad \forall\, \mathbb{Q} \in \mathfrak{R}_+^N \tag{D.34}$$

The first inequality (D.33) implies that floor space demand in any particular location is decreasing in its price. Intuitively, higher prices lead to a small population and employment in the location; therefore, the floor space consumption becomes small. When $\alpha = \beta = 0$, this property follows immediately by inspection of (D.32). The second inequality (D.34) implies that demand for floor space in any particular location increases if the price in other location increases. When $\alpha = \beta = 0$ and commuting costs ($\{\kappa_{n\ell}\}$) are sufficiently large, this property is satisfied.[30] Taken together, we obtain the following proposition:

Proposition D.4. *When $\alpha = \beta = 0$ and commuting costs are sufficiently large, the steady-state equilibrium is unique.*

Potential for Multiple Steady State Equilibria When the agglomeration parameters in productivity (α) and amenities (β) are non-zero, there is a potential for multiple steady states. If agglomeration forces are positive, as is standard in urban models, the multiplicity depends on the balance between the strength of the positive agglomeration forces and the dispersion forces from land scarcity and fundamental location characteristics (i.e., commuting costs, idiosyncratic tastes, and exogenous productivity and amenities). In our empirical setting, the multiplicity of the model when agglomeration forces exist is an important feature. Therefore, we further study the property of equilibria in the next section (Appendix E). We also discuss how the estimation procedure is robust to multiple equilibria, as it conditions on the observed equilibrium in the data in Appendix F.

E Detailed Theoretical Characterization of a Simplified Model

To obtain further theoretical characterizations of the equilibrium, we consider a simplified version of the model. We first present a simplified version of the model in Section E.1. In Section E.2 we derive theoretical propositions regarding the uniqueness of dynamic equilibrium and comparative statics. We do so in the context of two locations, following the theoretical literature on history versus expectations in the spatial economy (e.g., Krugman 1991; Matsuyama 1991; Baldwin 2001; Ottaviano 2001).

Our model also predicts that the dynamic equilibrium is unique when there are no agglomeration forces or severe migration frictions, which is consistent with the key findings of this literature. However, in this case, the model does not predict the recovery of the destroyed city center in the sense that it has the

[30] An increase in the floor space in location ℓ (Q_ℓ) increases the population and employment in location n, leading to higher floor space demand in n. However, as long as residents in n commute to ℓ, the increase in Q_ℓ may reduce the wage income of residents in n by reducing the wage rate in ℓ, leading to less floor space demand in n. The sufficiently high commuting cost guarantees that the latter effect is sufficiently small.

highest population and employment density in the city. In contrast, a recovery equilibrium may occur in which the destroyed city center reestablishes as the center of population and employment if agglomeration forces are strong and mobility frictions are moderate. In Section E.3, we provide a numerical illustration of the dynamic equilibrium, which confirms the existence of a recovery equilibrium, using parameter values similar to those used for Hiroshima in the main text. Overall, our analysis suggests that the relatively strong agglomeration forces and the relatively high mobility, which are empirically consistent with the situation in Hiroshima immediately after the war, are essential conditions for the recovery of the destroyed city center of Hiroshima.

E.1 *Simplified Model*

Setup The environment is the same as the model in Section 4 in the main text, except that we simplify the model setup in several ways for analytical tractability. First, the fundamental productivity and amenities are uniform in the city, which aligns with our empirical findings in Hiroshima, where location fundamentals were found to be similar in both the pre-war city center and peripheral areas. Second, we assume that the mass of individuals living in the city always equals one. Third, the area size of each location is the same and normalized to one, implying that the population and employment in each location match their density. Fourth, the economy lasts for two periods ($T = 1, 2$). In the following, we use $\overline{x}_i$ for the variable x_i in the first period, which are taken as given as an initial condition, and focus on the equilibrium variables x_i for the second period.

Productivity and Amenities There are only homogenous products produced by a representative firm in each location. Productivity (A_i) in each location exhibits economies of scale with the parameter α, which controls the degree of increasing return to scale:

$$A_i = L_i^{\alpha}$$

When individuals live in location n, they have the benefit of amenities there. We let B_n refer to the utility benefit from the amenities. The benefit of amenities is determined by how many people live in the location. We let the parameter β control the importance of the size of residents in the value of amenities. In summary, we have:

$$B_n = R_n^{\beta}$$

Technology Consumption goods are produced according to a Cobb-Douglas technology using labor, intermediate inputs, and commercial floor space. We allow for Hicks-neutral productivity differences across locations (A_i). Cost minimization and zero profits imply that payments for labor and commercial floor space satisfy:

$$\begin{aligned}
&\frac{1}{A_i}\left(w_i\right)^{\gamma^L}\left(Q_i\right)^{\gamma^H} = 1 \\
\Longrightarrow\ & w_i = \left(A_i\right)^{1/\gamma^L}\left(Q_i\right)^{-\gamma^H/\gamma^L} \\
\Longrightarrow\ & w_i = \left(L_i\right)^{\alpha/\gamma^L}\left(Q_i\right)^{-\gamma^H/\gamma^L}
\end{aligned}$$

where we substitute productivity in the last expression.

Location Choice The indirect utility of workers living in n and working in i is given by

$$u_{in} = \frac{B_n w_i}{Q_n^{\mu} \kappa_{in}} \tag{E.1}$$

Workers draw an idiosyncratic shock across locations from the Type-I extreme distribution. In the two-period model, the value function for workers who live n and work in i evaluated in the first period is:

$$\overline{v}_{in} = \ln \overline{u}_{in} + (1-\theta)\rho u_{in} + \theta\sigma \ln \left[\sum_{i'} \sum_{n'} \exp(\rho u_{i'n'})^{1/\sigma} \right]$$

where, on the right-hand side, the first term is the indirect utility in the first period; the second term is the value function for workers who have no opportunity to switch locations; and the last term is the expected value for workers who can switch locations. Solving this, the fraction of individuals who choose a location pair (i, n) in the second period when they can change their locations is:

$$\begin{aligned} \lambda_{in} &= \frac{(u_{in})^{\varkappa}}{\sum_{i'} \sum_{n'} (u_{i'n'})^{\varkappa}} \\ \Longrightarrow \lambda_{in} &= \frac{\kappa_{in}^{-\varkappa} \left(R_n^{\beta} Q_n^{-\mu}\right)^{\varkappa} (w_i)^{\varkappa}}{\sum_{i'} \sum_{n'} \kappa_{i'n'}^{-\varkappa} \left(R_{n'}^{\beta} Q_{n'}^{-\mu}\right)^{\varkappa} (w_{i'})^{\varkappa}} \end{aligned} \tag{E.2}$$

where $\varkappa \equiv \rho/\sigma$ is determined by the discount factor (ρ) and the dispersion parameter of the idiosyncratic shock related to location choices (σ), and u_{in} is equation (E.1) for the second period. Using them, the dynamics of population and employment are given by:

$$\begin{aligned} R_n &= (1-\theta)\overline{R}_n + \theta \sum_{i \in \mathcal{C}} \lambda_{in}, \\ L_i &= (1-\theta)\overline{L}_i + \theta \sum_{n \in \mathcal{C}} \lambda_{in} \end{aligned} \tag{E.3}$$

Floor Space Supply The floor space in the initial period ($\overline{H}_n$) is given. The competitive developers in floor space supply lead to the total floor space in the second period:

$$H_n = (1-\psi)\overline{H}_n + Q_n{}^{\eta}, \tag{E.4}$$

where the second term is the floor supply function with constant elasticity η.

Commuters and Conditional Commuting Probabilities The number of commuters in the first period is given by $\overline{L}_{in}$. Using equation (E.2), that of the second period is:

$$L_{in} = (1-\theta)\overline{L}_{in} + \theta\lambda_{in} \tag{E.5}$$

In addition, using equation (E.2), we can define the conditional probability that workers who can switch locations decide to commute to location i given residential place n by:

$$\begin{aligned}
\lambda^{\mathbb{W}}_{in|n} &= \frac{\lambda_{in}}{\sum_{i'} \lambda_{in}} \\
&= \frac{\kappa_{in}^{-\varkappa}\left(w_i\right)^{\varkappa}}{\sum_{i'} \kappa_{i'n}^{-\varkappa}\left(w_{i'}\right)^{\varkappa}} \\
\implies \lambda^{\mathbb{W}}_{in|n} &= \frac{\kappa_{in}^{-\varkappa}\left(w_i\right)^{\varkappa}}{\Psi_n},
\end{aligned} \tag{E.6}$$

where we define

$$\Psi_n = \sum_{i'} \kappa_{i'n}^{-\varkappa}\left(w_{i'}\right)^{\varkappa} \tag{E.7}$$

This measures the accessibility of the residential place n for work. Analogously, the conditional probability that workers who can switch locations decide to live in location n given workplace i is:

$$\begin{aligned}
\lambda^{\mathbb{R}}_{ni|i} &= \frac{\lambda_{in}}{\sum_{n'} \lambda_{in'}} \\
&= \frac{\kappa_{in}^{-\varkappa}\left(R_n^{\beta} Q_n^{-\mu}\right)^{\varkappa}}{\sum_{n'} \kappa_{in'}^{-\varkappa}\left(R_{n'}^{\beta} Q_{n'}^{-\mu}\right)^{\varkappa}} \\
\implies \lambda^{\mathbb{R}}_{ni|i} &= \frac{\kappa_{in}^{-\varkappa}\left(R_n^{\beta} Q_n^{-\mu}\right)^{\varkappa}}{\Phi_i},
\end{aligned} \tag{E.8}$$

where we define

$$\Phi_i = \sum_{n'} \kappa_{in'}^{-\varkappa}\left(R_{n'}^{\beta} Q_{n'}^{-\mu}\right)^{\varkappa} \tag{E.9}$$

for the access of workplace i to residential places. Using them, equations (E.3) imply that population dynamics satisfy:

$$\begin{aligned}
R_n - (1-\theta)\overline{R}_n &= \sum_i \lambda^{\mathbb{R}}_{ni|i}[L_i - (1-\theta)\overline{L}_i] \\
\implies R_n - (1-\theta)\overline{R}_n &= R_n^{\beta\varkappa} Q_n^{-\mu\varkappa} \sum_i \kappa_{in}^{-\varkappa}\left(\Phi_i\right)^{-1}[L_i - (1-\theta)\overline{L}_i]
\end{aligned} \tag{E.10}$$

Similarly, employment dynamics are:

$$L_i - (1-\theta)\overline{L}_i = w_i^{\varkappa} \sum_n \kappa_{in}^{-\varkappa}\left(\Psi_n\right)^{-1}[R_n - (1-\theta)\overline{R}_n] \tag{E.11}$$

Income at Residential Place Using (E.5), we can define the aggregate labor income of workers at residential place n by:

$$\begin{aligned}
I_n &= \sum_i L_{in} w_i \\
\implies I_n &= (1-\theta)\sum_i \overline{L}_{in} w_i + \theta \sum_i \lambda_{in} w_i \\
\implies I_n &= (1-\theta)\sum_i \overline{L}_{in} w_i + \left(\Psi_n\right)^{-1}[R_n - (1-\theta)\overline{R}_n] \sum_i \kappa_{in}^{-\varkappa}\left(w_i\right)^{\varkappa+1}
\end{aligned} \tag{E.12}$$

System of Dynamic Equilibrium Given the initial population $\overline{R}_n$, employment $\overline{L}_i$, commuters $\overline{L}_{in}$, floor space $\overline{H}_n$, and parameters, the equilibrium for the second period is given by the set of endogenous variables (R_n, L_i, Q_n, w_i, H_n, Ψ_n, Φ_i) that solve:

$$R_n = (1-\theta)\overline{R}_n + \left(R_n\right)^{\beta\varkappa}\left(Q_n\right)^{-\mu\varkappa}\sum_i k_{in}\left(\Phi_i\right)^{-1}[L_i - (1-\theta)\overline{L}_i], \tag{E.13}$$

$$L_i = (1-\theta)\overline{L}_i + \left(w_i\right)^{\varkappa}\sum_n k_{in}\left(\Psi_n\right)^{-1}[R_n - (1-\theta)\overline{R}_n], \tag{E.14}$$

$$H_n = (1-\psi)\overline{H}_n + \left(Q_n\right)^{\eta}, \tag{E.15}$$

$$Q_n H_n = \mu\left[(1-\theta)\sum_i \overline{L}_{in} w_i + \left(\Psi_n\right)^{-1}[R_n - (1-\theta)\overline{R}_n]\sum_i \mathcal{K}_{in}\left(w_i\right)^{\varkappa+1}\right] + \frac{\gamma^H}{\gamma^L} w_n L_n, \tag{E.16}$$

$$\Psi_n = \sum_{i'} k_{i'n}\left(w_{i'}\right)^{\varkappa}, \tag{E.17}$$

$$\Phi_i = \sum_{n'} k_{in'}\left(R_{n'}\right)^{\beta\varkappa}\left(Q_{n'}\right)^{-\mu\varkappa}, \tag{E.18}$$

$$w_i = \left(L_i\right)^{\alpha/\gamma^L}\left(Q_i\right)^{-\gamma^H/\gamma^L}, \tag{E.19}$$

where we let $k_{in} \equiv \kappa_{in}^{-\varkappa} \in (0,1]$ summarize the commuting costs.

In the model, a dynamic equilibrium always exists for any initial condition (see Proposition 1 and Appendix D for the existence of a dynamic equilibrium in the general case). Intuitively, the population and employment distribution in the second period is well-defined given those in the initial period and floor space prices, as the right-hand-side of equations (E.13) and (E.14) are continuous mappings from the compact set to itself. Therefore, we can express population and employment in the second period as a function of those in the initial period and floor space prices. Finally, we can repeat this argument to characterize the floor space prices in the second period, which is a fixed point of equation (E.16).

E.2 *Characterization of Equilibria for the Two-Location Case*

Using the model introduced in Section E.1, we provide an analytical characterization of the dynamic equilibria for the city. For analytical tractability, we assume that there are only two locations indexed by $i = 1, 2$, which can be considered as the central business district (CBD) and non-CBD. The symmetric two-locations assumption is motivated by the earlier theoretical literature on history versus expectations in the spatial economy (e.g., Krugman 1991; Matsuyama 1991; Baldwin 2001; Ottaviano 2001).

For the two-location case, it is convenient to focus on the relative value of population, employment, and floor space prices in equilibrium:

$$r \equiv \frac{R_1}{R_2}, \quad \ell \equiv \frac{L_1}{L_2}, \quad \overline{r} \equiv \frac{\overline{R}_1}{\overline{R}_2}, \quad \overline{\ell} \equiv \frac{\overline{L}_1}{\overline{L}_2}, \quad q \equiv \frac{Q_1}{Q_2} \tag{E.20}$$

Since the total population is set to one, we can express the *level* of population and employment by:

$$R_1 = \frac{r}{1+r}, \quad R_2 = \frac{1}{1+r}, \quad L_1 = \frac{\ell}{1+\ell}, \quad L_2 = \frac{1}{1+\ell} \tag{E.21}$$

Letting $k = k_{12} = k_{21} \in (0,1)$ refer to the symmetric commuting costs between two locations, equations (E.13) and (E.18) imply that population distribution in the two-location case is:

$$\Delta R_1 = \frac{(R_1)^{\beta\varkappa}(Q_1)^{-\mu\varkappa}}{(R_1)^{\beta\varkappa}(Q_1)^{-\mu\varkappa} + k(R_2)^{\beta\varkappa}(Q_2)^{-\mu\varkappa}}\Delta L_1 + \frac{k(R_1)^{\beta\varkappa}(Q_1)^{-\mu\varkappa}}{k(R_1)^{\beta\varkappa}(Q_1)^{-\mu\varkappa} + (R_2)^{\beta\varkappa}(Q_2)^{-\mu\varkappa}}\Delta L_2 \tag{E.22}$$

for location 1 and

$$\Delta R_2 = \frac{k(R_2)^{\beta\varkappa}(Q_2)^{-\mu\varkappa}}{(R_1)^{\beta\varkappa}(Q_1)^{-\mu\varkappa} + k(R_2)^{\beta\varkappa}(Q_2)^{-\mu\varkappa}}\Delta L_1 + \frac{(R_2)^{\beta\varkappa}(Q_2)^{-\mu\varkappa}}{k(R_1)^{\beta\varkappa}(Q_1)^{-\mu\varkappa} + (R_2)^{\beta\varkappa}(Q_2)^{-\mu\varkappa}}\Delta L_2 \tag{E.23}$$

for location 2. In this expression we define:

$$\begin{aligned} \Delta R_i &= R_i - (1-\theta)\overline{R}_i, \\ \Delta L_i &= L_i - (1-\theta)\overline{L}_i \end{aligned} \tag{E.24}$$

for $i = 1, 2$. Using the notions (E.20), equations (E.22) and (E.23) and the similar set of equations for employment can be expressed as follows:

$$\begin{gathered} \Delta R_1 = \underbrace{\frac{r^{\beta\varkappa}q^{-\mu\varkappa}}{r^{\beta\varkappa}q^{-\mu\varkappa} + k}}_{=\lambda_1^r(r,q)}\Delta L_1 + \underbrace{\frac{kr^{\beta\varkappa}q^{-\mu\varkappa}}{kr^{\beta\varkappa}q^{-\mu\varkappa} + 1}}_{=1-\lambda_2^r(r,q)}\Delta L_2, \quad \Delta R_2 = \underbrace{\frac{k}{r^{\beta\varkappa}q^{-\mu\varkappa} + k}}_{=1-\lambda_1^r(r,q)}\Delta L_1 + \underbrace{\frac{1}{kr^{\beta\varkappa}q^{-\mu\varkappa} + 1}}_{=\lambda_2^r(r,q)}\Delta L_2, \\ \Delta L_1 = \underbrace{\frac{\ell^{\frac{\alpha\varkappa}{\gamma^L}}q^{-\frac{\varkappa\gamma^H}{\gamma^L}}}{\ell^{\frac{\alpha\varkappa}{\gamma^L}}q^{-\frac{\varkappa\gamma^H}{\gamma^L}} + k}}_{=\lambda_1^\ell(\ell,q)}\Delta R_1 + \underbrace{\frac{k\ell^{\frac{\alpha\varkappa}{\gamma^L}}q^{-\frac{\varkappa\gamma^H}{\gamma^L}}}{k\ell^{\frac{\alpha\varkappa}{\gamma^L}}q^{-\frac{\varkappa\gamma^H}{\gamma^L}} + 1}}_{=1-\lambda_2^\ell(\ell,q)}\Delta R_2, \quad \Delta L_2 = \underbrace{\frac{k}{\ell^{\frac{\alpha\varkappa}{\gamma^L}}q^{-\frac{\varkappa\gamma^H}{\gamma^L}} + k}}_{=1-\lambda_1^\ell(\ell,q)}\Delta R_1 + \underbrace{\frac{1}{k\ell^{\frac{\alpha\varkappa}{\gamma^L}}q^{-\frac{\varkappa\gamma^H}{\gamma^L}} + 1}}_{=\lambda_2^\ell(\ell,q)}\Delta R_2, \end{gathered} \tag{E.25}$$

where we define probabilities $\lambda_1^r(r,q)$, $\lambda_2^r(r,q)$, $\lambda_1^\ell(\ell,q)$ and $\lambda_2^\ell(\ell,q)$ such that

$$\begin{aligned} \lambda_1^r(r,q) &= \frac{r^{\beta\varkappa}q^{-\mu\varkappa}}{r^{\beta\varkappa}q^{-\mu\varkappa} + k}, \quad \lambda_2^r(r,q) = \frac{1}{kr^{\beta\varkappa}q^{-\mu\varkappa} + 1} \\ \lambda_1^\ell(\ell,q) &= \frac{\ell^{\frac{\alpha\varkappa}{\gamma^L}}q^{-\frac{\varkappa\gamma^H}{\gamma^L}}}{\ell^{\frac{\alpha\varkappa}{\gamma^L}}q^{-\frac{\varkappa\gamma^H}{\gamma^L}} + k}, \quad \lambda_2^\ell(\ell,q) = \frac{1}{k\ell^{\frac{\alpha\varkappa}{\gamma^L}}q^{-\frac{\varkappa\gamma^H}{\gamma^L}} + 1} \end{aligned} \tag{E.26}$$

where $\lambda_1^r(r,q)$ is the probability of living in location 1 conditional on working in location 1; $\lambda_2^r(r,q)$ is the probability of living in location 2 conditional on working in location 2; $\lambda_1^\ell(\ell,q)$ is the probability of working in location 1 conditional on living in location 1; and $\lambda_2^\ell(\ell,q)$ is the probability of working in location 2 conditional on living in location 2.

When we combine the set of equations (E.25), we obtain:

$$\frac{\Delta R_1}{\Delta R_2} = \frac{\lambda_1^r(1-\lambda_2^\ell) + (1-\lambda_2^r)\lambda_2^\ell}{1 - \lambda_1^r\lambda_1^\ell - (1-\lambda_2^r)(1-\lambda_1^\ell)} \tag{E.27}$$

if $0 < \theta \leq 1$. Note that if $\theta = 0$, we have $r = \bar{r}$. Using (E.21), the left-hand side of (E.27) becomes:

$$\frac{\Delta R_1}{\Delta R_2} = r + \frac{(1-\theta)(1+r)}{(1+\bar{r}) - (1-\theta)(1+r)}(r - \bar{r}) \equiv G(r;\theta,\bar{r}),$$

where $G(r;\theta,\bar{r})$ is continuous function of r given θ and $\bar{r}$.

By manipulating the right-hand side of (E.27), we obtain the equilibrium condition for the population ratio as follows:

$$G(r;\theta,\bar{r}) = \frac{\lambda_1^r + (1-\lambda_1^r)\left[1 - \frac{1}{k^2\lambda_1^r + (1-\lambda_1^r)}\right]\frac{1-\lambda_1^\ell}{k^2\lambda_1^\ell + (1-\lambda_1^\ell)}}{(1-\lambda_1^r\lambda_1^\ell) - \frac{k^2\lambda_1^r}{k^2\lambda_1^r + (1-\lambda_1^r)}(1-\lambda_1^\ell)} \tag{E.28}$$

Analogously, the employment distribution satisfies:

$$G(\ell;\theta,\bar{\ell}) = \frac{\lambda_1^\ell + (1-\lambda_1^\ell)\left[1 - \frac{1}{k^2\lambda_1^\ell + (1-\lambda_1^\ell)}\right]\frac{1-\lambda_1^r}{k^2\lambda_1^r + (1-\lambda_1^r)}}{(1-\lambda_1^\ell\lambda_1^r) - \frac{k^2\lambda_1^\ell}{k^2\lambda_1^\ell + (1-\lambda_1^\ell)}(1-\lambda_1^r)} \tag{E.29}$$

Now, we establish the following proposition about the equilibrium population ratio (r) and employment ratio (ℓ) conditional on the floor space price ratio (q):

Proposition E.1. ***(i)*** *When $\alpha \leq 0$ and $\beta \leq 0$, there is a unique solution for the population distribution (r) and employment distribution (ℓ) given price ratio (q) and previous population and employment distribution $(\bar{r}, \bar{\ell})$ when the following condition is satisfied:*

$$\frac{1}{\lambda_1^\ell - 1}\frac{\partial\lambda_1^\ell}{\partial\ell} + \frac{1}{\lambda_1^r - \frac{1}{1-k^2}}\frac{\partial\lambda_1^r}{\partial r}\frac{dr}{d\ell} \geq 0. \tag{E.30}$$

A sufficient condition for the above inequality to hold is $\alpha = \beta = 0$ (i.e., no agglomeration).
(ii) *When $\alpha = 0$ and $\beta \leq 0$, the population distribution shows $r > r'$ if $q < q'$; When $\alpha \leq 0$ and $\beta = 0$, employment distribution shows $\ell > \ell'$ if $q < q'$.*

Proof. **(i)** We first show that the solution r to equation (E.28) is unique given (ℓ, q, $\bar{r}$, $\bar{\ell}$). We let $J_R(r,\ell,q)$ refer to the right-hand side of equation (E.28), so that we can solve the equation

$$J_R(r,\ell,q) - G(r;\theta,\bar{r}) = 0$$

for r. Note that the second term, $G(r;\theta,\bar{r})$ is strictly increasing in r and independent to ℓ:

$$\frac{\partial G(r;\theta,\bar{r})}{\partial r} > 0$$

We also obtain:

$$\frac{\partial J_R(r,\ell,q)}{\partial r} = \frac{\partial\lambda_1^r}{\partial r}\underbrace{\frac{k^2}{(\lambda_1^r - 1)^2\left[(k^2-1)\lambda_1^\ell + 1\right]}}_{(+)}$$

When $\beta\varkappa \leq 0$, we have

$$\frac{\partial\lambda_1^r}{\partial r} \leq 0.$$

Since $k \in (0,1)$, we have $k^2 - 1 \in (-1, 0)$, Therefore, by definition, we have $\lambda_1^\ell (k^2-1) \in (-1,0)$, which implies: $\left(k^2-1\right)\lambda_1^\ell + 1 \in (0,1)$. This leads to

$$\frac{\partial J_R(r,\ell,q)}{\partial r} \leq 0$$

Together, when $\beta\varkappa \leq 0$, we show:

$$\frac{\partial J_R(r,\ell,q)}{\partial r} - \frac{\partial G(r;\theta,\bar{r})}{\partial r} \leq 0 \tag{E.31}$$

and

$$\lim_{r\to\infty} J_R(r,\ell,q) = 0, \quad \lim_{r\to 0} J_R(r,\ell,q) = +\infty$$

This implies that there is a unique solution r to equation (E.28) given (ℓ, q, $\bar{r}$, $\bar{\ell}$). In addition, we have:

$$\frac{dr}{d\ell} = -\left[\frac{\partial J_R(r,\ell,q)}{\partial r} - \frac{\partial G(r;\theta,\bar{r})}{\partial r}\right]^{-1} \frac{\partial J_R(r,\ell,q)}{\partial \ell}$$

where

$$\frac{\partial J_R(r,\ell,q)}{\partial \ell} = \frac{\partial \lambda_1^\ell}{\partial \ell} \underbrace{\frac{k^2\left(k^2-1\right)\lambda_1^r}{\left(\lambda_1^r - 1\right)\left[\left(k^2-1\right)\lambda_1^\ell + 1\right]^2}}_{(+)}$$

When $\alpha\varkappa \leq 0$ we have:

$$\frac{\partial \lambda_1^\ell}{\partial \ell} \leq 0 \implies \frac{\partial J_R(r,\ell,q)}{\partial \ell} \leq 0.$$

Therefore, we have:

$$\frac{dr}{d\ell} \leq 0.$$

Note that $dr/d\ell = 0$ when $\alpha = 0$.

Next, we consider equation (E.29). We let $J_L(\ell,r,q)$ refer to the right-hand side of equation (E.29). Then, we obtain:

$$\begin{aligned}
\frac{dJ_L(\ell,r,q)}{d\ell} &= \frac{\partial \lambda_1^\ell}{\partial \ell} \frac{k^2}{\left(\lambda_1^\ell - 1\right)^2\left[\left(k^2-1\right)\lambda_1^r + 1\right]} + \frac{\partial \lambda_1^r}{\partial r} \frac{k^2\left(k^2-1\right)\lambda_1^\ell}{\left(\lambda_1^\ell - 1\right)\left[\left(k^2-1\right)\lambda_1^r + 1\right]^2} \frac{dr}{d\ell} \\
&= \underbrace{\frac{k^2}{\left(\lambda_1^\ell - 1\right)\left[\left(k^2-1\right)\lambda_1^r + 1\right]}}_{(-)} \left[\frac{1}{\lambda_1^\ell - 1}\frac{\partial \lambda_1^\ell}{\partial \ell} + \frac{\left(k^2-1\right)}{\left(k^2-1\right)\lambda_1^r + 1}\frac{\partial \lambda_1^r}{\partial r}\frac{dr}{d\ell}\right]
\end{aligned}$$

Therefore when

$$\frac{1}{\lambda_1^\ell - 1}\frac{\partial \lambda_1^\ell}{\partial \ell} + \frac{1}{\lambda_1^r - \frac{1}{1-k^2}}\frac{\partial \lambda_1^r}{\partial r}\frac{dr}{d\ell} \geq 0$$

we obtain $dJ_L(\ell,r,q)/d\ell \leq 0$. This condition is satisfied when $\alpha = \beta = 0$ since

$$\frac{\partial \lambda_1^\ell}{\partial \ell} = 0, \quad \frac{dr}{d\ell} = 0$$

Given that $G(\ell;\theta,\overline{\ell})$ in equation (E.29) is increasing in ℓ, there is a unique solution ℓ.

(ii) We have shown that the solutions r and ℓ may be unique given q. We now turn to the comparative static for q. When $\alpha = 0$, $J_R(r,\ell,q)$ is a function of r and q since λ_1^ℓ depends on q but not on ℓ. Then, we investigate how the function shifts in response to the change in q. We have:

$$\frac{\partial J_R(r,q)}{\partial q} = \underbrace{\frac{\partial J_R(r,q)}{\partial \lambda_1^r}}_{(+)} \frac{\partial \lambda_1^r}{\partial q} + \underbrace{\frac{\partial J_R(r,q)}{\partial \lambda_1^\ell}}_{(+)} \frac{\partial \lambda_1^\ell}{\partial q} < 0$$

where we use

$$\frac{\partial \lambda_1^r}{\partial q} < 0, \quad \frac{\partial \lambda_1^\ell}{\partial q} < 0$$

Let us consider the equilibrium r and r', which correspond to different values of q and q' such that $q' > q$. Suppose that $r' \geq r$. Then,

$$\begin{aligned} J_R(r',q') - G(r';\theta,\bar{r}) &\leq J_R(r,q') - G(r;\theta,\bar{r}) \\ &< J_R(r,q) - G(r;\theta,\bar{r}) = 0, \end{aligned}$$

which leads to a contradiction. Note that the first inequality in the above holds when $\beta \leq 0$. Hence, in equilibrium, $r' < r$. We use a similar argument for employment since:

$$\frac{\partial J_L(\ell,q)}{\partial q} < 0$$

if $\beta = 0$. This completes the proof. ■

Proposition E.1 takes the floor space prices q as given, implying that the floor space clearing conditions have not yet been taken into account. Proposition E.1 (i) states that the equilibrium must be unique when the agglomeration force parameters (α, β) are non-positive. Importantly, the unique equilibrium case includes the case of no agglomeration ($\alpha = \beta = 0$), which is consistent with findings in the earlier theoretical literature.

Intuitively, when agglomeration forces are strong enough, individuals have an incentive to reside and work together in the same location as other individuals. However, the existence of two locations may result in an equilibrium in which a greater number of individuals reside and work in location 1 and another equilibrium in which a greater number of individuals reside and work in location 2. When the agglomeration forces are not strong, we obtain the unique equilibrium as in Proposition E.1 because this mechanism becomes inactive. In the subsequent proposition, we demonstrate that the equilibrium uniqueness is guaranteed in the absence of agglomeration, even when the floor space clearing conditions are taken into account, by imposing some additional regularity conditions.

Proposition E.1 (ii) shows that when agglomeration forces are not positive, both population and employment must be decreasing in the floor space price because it reduces the incentive to live or work due to the higher floor space cost. We use this result to prove a following proposition.

We now consider the floor space market. The floor space market clearing condition (E.16) for location 1 is:

$$
\begin{aligned}
Q_1 H_1 = {} & \mu(1-\theta)\left[\overline{\lambda}_1^{\ell}\overline{R}_1 (L_1)^{\frac{\alpha}{\gamma^L}} (Q_1)^{-\frac{\gamma^H}{\gamma^L}} + (1-\overline{\lambda}_1^{\ell})\overline{R}_1 (L_2)^{\frac{\alpha}{\gamma^L}} (Q_2)^{-\frac{\gamma^H}{\gamma^L}}\right] \\
& + \mu \Delta R_1 \left[\lambda_1^{\ell} (L_1)^{\frac{\alpha}{\gamma^L}} (Q_1)^{-\frac{\gamma^H}{\gamma^L}} + (1-\lambda_1^{\ell})(L_2)^{\frac{\alpha}{\gamma^L}} (Q_2)^{-\frac{\gamma^H}{\gamma^L}}\right] + \frac{\gamma^H}{\gamma^L}(L_1)^{\frac{\alpha}{\gamma^L}+1}(Q_1)^{-\frac{\gamma^H}{\gamma^L}}
\end{aligned}
\tag{E.32}
$$

Rearranging the right-hand side of this and using equation (E.15), we obtain:

$$
\begin{aligned}
Q_1\left[(1-\psi)\overline{H}_1 + q^{\eta} Q_2^{\eta}\right] = {} & \frac{L_2^{\alpha/\gamma^L}}{Q_2^{\gamma^H/\gamma^L}} \\
& \times \left[\mu(1-\theta)\mathcal{I}_1(\ell, q, \overline{\lambda}_1^{\ell})\overline{R}_1 + \mu \mathcal{I}_1(\ell, q, \lambda_1^{\ell})\Delta R_1 + \frac{\gamma^H}{\gamma^L}\frac{\ell}{1+\ell}\ell^{\frac{\alpha}{\gamma^L}} q^{-\frac{\gamma^H}{\gamma^L}}\right]
\end{aligned}
\tag{E.33}
$$

where we define:

$$
\mathcal{I}_1(\ell, q, \lambda_1^{\ell}) \equiv \lambda_1^{\ell}\ell^{\frac{\alpha}{\gamma^L}} q^{-\frac{\gamma^H}{\gamma^L}} + (1-\lambda_1^{\ell})
$$

For location 2, we similarly obtain:

$$
Q_2\left[(1-\psi)\overline{H}_2 + Q_2^{\eta}\right] = \frac{L_2^{\alpha/\gamma^L}}{Q_2^{\gamma^H/\gamma^L}}\left[\mu(1-\theta)\mathcal{I}_2(\ell, q, \overline{\lambda}_2^{\ell})\overline{R}_2 + \mu \mathcal{I}_2(\ell, q, \lambda_2^{\ell})\Delta R_2 + \frac{\gamma^H}{\gamma^L}\frac{1}{1+\ell}\right], \tag{E.34}
$$

where

$$
\mathcal{I}_2(\ell, q, \lambda_2^{\ell}) = (1-\lambda_2^{\ell})\ell^{\frac{\alpha}{\gamma^L}} q^{-\frac{\gamma^H}{\gamma^L}} + \lambda_2^{\ell}
$$

Taking the ratio of these two conditions, we have:

$$
\begin{aligned}
q\frac{(1-\psi)\overline{H}_1 + q^{\eta}Q_2^{\eta}}{(1-\psi)\overline{H}_2 + Q_2^{\eta}} &= \frac{\mu(1-\theta)\mathcal{I}_1(\ell, q, \overline{\lambda}_1^{\ell})\overline{R}_1 + \mu\mathcal{I}_1(\ell, q, \lambda_1^{\ell})\Delta R_1 + \frac{\gamma^H}{\gamma^L}\frac{\ell}{1+\ell}\ell^{\frac{\alpha}{\gamma^L}} q^{-\frac{\gamma^H}{\gamma^L}}}{\mu(1-\theta)\mathcal{I}_2(\ell, q, \overline{\lambda}_2^{\ell})\overline{R}_2 + \mu\mathcal{I}_2(\ell, q, \lambda_2^{\ell})\Delta R_2 + \frac{\gamma^H}{\gamma^L}\frac{1}{1+\ell}} \\
&= \frac{\mu(1-\theta)\mathcal{I}_1(\ell, q, \overline{\lambda}_1^{\ell})\overline{r} + \mu\mathcal{I}_1(\ell, q, \lambda_1^{\ell})\left(\frac{r}{\overline{r}}\frac{1+\overline{r}}{1+r} - (1-\theta)\right)\overline{r} + \frac{\gamma^H}{\gamma^L}\frac{\ell}{1+\ell}\ell^{\frac{\alpha}{\gamma^L}} q^{-\frac{\gamma^H}{\gamma^L}}}{\mu(1-\theta)\mathcal{I}_2(\ell, q, \overline{\lambda}_2^{\ell}) + \mu\mathcal{I}_2(\ell, q, \lambda_2^{\ell})\left(\frac{1+\overline{r}}{1+r} - (1-\theta)\right) + \frac{\gamma^H}{\gamma^L}\frac{1}{1+\ell}}
\end{aligned}
\tag{E.35}
$$

In summary, we define the dynamic equilibrium for the case of two locations:

Definition E.1. *Given the initial distribution $(\overline{r}, \overline{\ell}, \overline{H}_1, \overline{H}_2)$, the dynamic equilibrium is characterized by the population ratio r solving equation (E.28); employment ratio ℓ solving equation (E.29); floor price ratio q solving equation (E.35); and the level of the floor space price Q_2 is pinned down by equation (E.34).*

In general, even if Proposition E.1 (i) holds so that the equilibrium is unique given the floor space prices, we might still have a multiplicity of equilibria because equation (E.35) might have multiple solutions. To derive the analytical result for the uniqueness of the equilibrium, we require some sufficient conditions for (E.35) to have a unique solution. We summarize the conditions for the uniqueness of equilibrium in the following proposition:

Proposition E.2. ***(i)*** *Suppose the equilibrium is unique given the floor space prices (e.g., the condition for Proposition E.1 is satisfied). In addition, suppose that we have:*

$$\frac{d\log r}{d\log q} < 0, \quad \textit{and} \quad \frac{d\log \ell}{d\log q} < 0, \tag{E.36}$$

$$q^{\eta} \geq H_1/H_2 \tag{E.37}$$

and

$$1 < \ell^{\frac{\alpha}{\gamma^L}} q^{-\frac{\gamma^H}{\gamma^L}} < \mathcal{Z}^* \tag{E.38}$$

where $\mathcal{Z}^*$ *is a solution to*

$$\varkappa \frac{k(\mathcal{Z}^*)^{\varkappa}}{k(\mathcal{Z}^*)^{\varkappa}+1} = \frac{\mathcal{Z}^*}{\mathcal{Z}^*-1}$$

Then, there exists a unique equilibrium defined in Definition E.1.

(ii) *We also have sufficient conditions for the above sufficient conditions (E.36)–(E.38):* ***(ii-a)*** *When* $\alpha = \beta = 0$*, condition (E.36) is satisfied in any equilibrium;* ***(ii-b)*** *When either the economy reaches around the steady state or the initial stock of floor spaces in one location is close to zero (e.g., total destruction due to the atomic bombing), then the condition (E.37) is satisfied for any equilibrium; and* ***(ii-c)*** *If commuting costs are sufficiently high* $(k \to 0)$ *and* $\frac{d\log\ell}{d\log q} < 0$ *as in the second condition (E.36), there exists a unique equilibrium when the condition (E.37) is satisfied.*

Proof. Since we suppose that the equilibrium r and l are unique given the floor space prices, what we want to show is that equation (E.35) uniquely determines q. As a sufficient condition for this, we prove that the right-hand side of the equation (E.35) is decreasing in q and the left-hand side is increasing in q.

(i) We let $\mathcal{O}(q)$ refer to the right-hand side of equation (E.35). We first show that the function $\mathcal{O}(q)$ is decreasing in q. To simplify the notation, we let $\mathcal{Z} = \ell^{\alpha/\gamma^L} q^{-\gamma^H/\gamma^L}$. We observe that

$$\frac{d\mathcal{Z}}{dq} = \mathcal{Z}\left[\frac{\alpha}{\gamma^L}\frac{1}{\ell}\frac{d\ell}{dq} - \frac{\gamma^H}{\gamma^L}\frac{1}{q}\right]$$

and

$$\frac{d\mathcal{Z}}{dq} \gtreqless 0 \iff \frac{d\log\ell}{d\log q} \gtreqless \gamma^H/\alpha$$

Note that $d\mathcal{Z}/dq < 0$ if $\alpha = 0$ as $\mathcal{Z}$ is independent to ℓ. Using this, we can express:

$$\lambda_1^{\ell} = \frac{\mathcal{Z}^{\varkappa}}{\mathcal{Z}^{\varkappa}+k} \implies \frac{d\lambda_1^{\ell}}{d\mathcal{Z}} = \lambda_1^{\ell}\frac{\varkappa k}{\mathcal{Z}^{\varkappa}+k}\frac{1}{\mathcal{Z}}$$

and

$$\lambda_2^{\ell} = \frac{1}{k\mathcal{Z}^{\varkappa}+1} \implies \frac{d\lambda_2^{\ell}}{d\mathcal{Z}} = -\lambda_2^{\ell}\frac{k\mathcal{Z}^{\varkappa}}{k\mathcal{Z}^{\varkappa}+1}\frac{\varkappa}{\mathcal{Z}}$$

Now, we have:

$$\mathcal{I}_1(\ell,q,\lambda_1^{\ell}) = \lambda_1^{\ell}\mathcal{Z} + (1-\lambda_1^{\ell}) \implies \frac{d\mathcal{I}_1(\ell,q,\lambda_1^{\ell})}{dq} = (\mathcal{Z}-1)\frac{d\lambda_1^{\ell}}{dq} + \lambda_1^{\ell}\frac{d\mathcal{Z}}{dq}$$

$$\implies \frac{d\mathcal{I}_1(\ell,q,\lambda_1^{\ell})}{dq} = \lambda_1^{\ell}\frac{d\mathcal{Z}}{dq}\left[\varkappa\frac{k}{\mathcal{Z}^{\varkappa}+k}\frac{\mathcal{Z}-1}{\mathcal{Z}} + 1\right]$$

Analogously, we have:

$$\mathcal{I}_2(\ell,q,\lambda_2^\ell) = (1-\lambda_2^\ell)\mathcal{Z} + \lambda_2^\ell \implies \frac{d\mathcal{I}_2(\ell,q,\lambda_1^\ell)}{dq} = \left[(1-\mathcal{Z})\frac{d\lambda_2^\ell}{d\mathcal{Z}} - \lambda_2^\ell\right]\frac{d\mathcal{Z}}{dq}$$
$$\implies \frac{d\mathcal{I}_2(\ell,q,\lambda_1^\ell)}{dq} = -\lambda_2^\ell \frac{d\mathcal{Z}}{dq}\left[\varkappa\frac{k\mathcal{Z}^\varkappa}{k\mathcal{Z}^\varkappa+1}\frac{1-\mathcal{Z}}{\mathcal{Z}} + 1\right]$$

Then, we can show that

$$\mathcal{Z} > 1 \quad and \quad \frac{d\log\ell}{d\log q} < 0 \implies \frac{d\mathcal{I}_1(\ell,q,\lambda_1^\ell)}{dq} < 0$$

We let $\mathcal{Z}^*$ refer to a solution to

$$\varkappa\frac{k(\mathcal{Z}^*)^\varkappa}{k(\mathcal{Z}^*)^\varkappa+1} = \frac{\mathcal{Z}^*}{\mathcal{Z}^*-1}$$

and $\mathcal{Z}^* > 1$. Then, we obtain:

$$\mathcal{Z} < \mathcal{Z}^* \quad and \quad \frac{d\log\ell}{d\log q} < 0 \implies \frac{d\mathcal{I}_2(\ell,q,\lambda_1^\ell)}{dq} > 0$$

Overall, we have:

$$\frac{d\mathcal{O}(q)}{dq} < 0, \quad \lim_{q\to 0}\mathcal{O}(q) \to +\infty, \quad \lim_{q\to\infty}\mathcal{O}(q) \to 0$$

i.e., the function $\mathcal{O}(q)$ is decreasing in q if

$$1 < \mathcal{Z} < \mathcal{Z}^* \quad and \quad \frac{d\log r}{d\log q} < 0 \quad and \quad \frac{d\log\ell}{d\log q} < 0 \tag{E.39}$$

where the first inequality can be expressed as

$$1 < \ell^{\alpha/\gamma^L} q^{-\gamma^H/\gamma^L} < \mathcal{Z}^*$$

Next, we consider the *level* of floor space price, Q_2, which solves equation (E.34). This equation can be restated as

$$\left[(1-\psi)\overline{H}_2 + Q_2^\eta\right](Q_2)^{1+\frac{\gamma^H}{\gamma^L}} = \mu(1-\theta)\mathcal{I}_2(\ell,q,\overline{\lambda}_2^\ell)\overline{R}_2 + \mu\mathcal{I}_2(\ell,q,\lambda_2^\ell)\left[\frac{1}{1+r} - \frac{1-\theta}{1+\overline{r}}\right] + \frac{\gamma^H}{\gamma^L}\frac{1}{1+\ell}$$

Under the condition (E.39), the right-hand side is increasing in q, implying that the level of floor space prices Q_2 is increasing in q:

$$\frac{dQ_2}{dq} > 0$$

Then, we consider the left-hand side of equation (E.35). We let $\mathcal{T}(q)$ refer to the left-hand side of equation (E.35). Then, we have:

$$\frac{d\log\mathcal{T}(q)}{d\log q} = 1 + \eta\frac{Q_1^\eta}{(1-\psi)\overline{H}_1 + Q_1^\eta} + q\eta Q_2^{\eta-1}\left[\frac{q^\eta}{(1-\psi)\overline{H}_1 + q^\eta Q_2^\eta} - \frac{1}{(1-\psi)\overline{H}_2 + Q_2^\eta}\right]\frac{dQ_2}{dq}$$

Therefore, we show that

$$q^{\eta} \geq \frac{(1-\psi)\overline{H}_1 + Q_1^{\eta}}{(1-\psi)\overline{H}_2 + Q_2^{\eta}} \equiv \frac{H_1}{H_2} \implies \frac{d\log \mathcal{T}(q)}{d\log q} > 0 \tag{E.40}$$

This implies that the left-hand side of equation (E.35) is increasing in q, and the right-hand side of (E.35) is decreasing in q, which pins down a unique solution q.

(ii) We provide sufficient conditions for the above conditions to hold.

(ii-a) Suppose that $\alpha = \beta = 0$. Then, Proposition E.1 implies that

$$\frac{d\log r}{d\log q} < 0, \quad \frac{d\log \ell}{d\log q} < 0$$

Therefore the condition (E.36) is satisfied.

(ii-b) Suppose that the economy reaches around a steady state in the second period. Then, we can express the floor space ratio as:

$$\frac{H_1}{H_2} \approx \left(\frac{Q_1}{Q_2}\right)^{\eta} = q^{\eta}$$

and the condition (E.40) is satisfied for any q. Let us consider another special case, in which $\overline{H}_1 \approx 0$, i.e., the initial stock of the floor space in one location is close to zero. Then, in equation (E.35) implies:

$$\frac{q^{\eta}}{(1-\psi)\overline{H}_1 + q^{\eta}Q_2^{\eta}} - \frac{1}{(1-\psi)\overline{H}_2 + Q_2^{\eta}} = \frac{1}{Q_2^{\eta}} - \frac{1}{(1-\psi)\overline{H}_2 + Q_2^{\eta}} > 0$$

Therefore, we have:

$$\frac{d\log \mathcal{T}(q)}{d\log q} > 0$$

The condition (E.40) is satisfied.

(ii-c) Consider $k \to 0$. In this case, we have $\lambda_1^{\ell} \to 1$ and $\lambda_2^{\ell} \to 1$, which leads to

$$\mathcal{I}_1(\ell, q, \lambda_1^{\ell}) \to \ell^{\alpha/\gamma^L} q^{-\gamma^H/\gamma^L}, \quad \mathcal{I}_2(\ell, q, \lambda_2^{\ell}) \to 1$$

and

$$\frac{d\mathcal{I}_1(\ell, q, \lambda_1^{\ell})}{dq} < 0, \quad \frac{d\mathcal{I}_2(\ell, q, \lambda_1^{\ell})}{dq} = 0$$

when $\frac{d\log \ell}{d\log q} < 0$. Therefore, we have a unique equilibrium when the condition (E.40) is satisfied. This concludes the proof. ■

Proposition E.2 provides sufficient conditions for the uniqueness of the dynamic equilibrium. Importantly, when there are no agglomeration forces ($\alpha = \beta = 0$) and one location has no housing stock (i.e., the complete destruction of the city center), the equilibrium is globally unique as long as commuting costs are sufficiently high. Additionally, the equilibrium is likely to be unique under most parameter values, although it is difficult to analytically exclude this possibility because the high commuting cost is just a sufficient condition for the floor space clearing condition (E.35) to uniquely determine q.

We have seen in Proposition E.1 that the population distribution (r) and the employment distribution (l) are uniquely determined given the floor space prices (q) if the agglomeration forces are weak. Proposition E.2 states that even when the floor space market is taken into account, the dynamic equilibrium is unique if the agglomeration forces are weak. However, the numerical analysis in the next section illustrates that there may be multiple equilibria in the presence of relatively strong agglomeration forces.

The next proposition characterizes the unique dynamic equilibrium in the important case of no agglomeration force. In particular, it provides the relationship between the initial population and employment pattern and that of the second period in equilibrium:

Proposition E.3. *Suppose that $\alpha = \beta = 0$ and the conditions for Proposition E.2 hold. Then, the equilibrium r increases in the initial condition $\bar{r}$, and the equilibrium l increases in the initial condition $\bar{l}$.*

Proof. Given q, we first show that r increases in $\bar{r}$ and ℓ is increasing in $\bar{\ell}$. To this end, we rearrange the migration conditions as follows. Using equations (E.25), $\Delta R_2 = \theta\bar{R} - \Delta R_1$ where $\bar{R}$ denotes the total population of the economy (note that we set $\bar{R} = 1$). If $\alpha = \beta = 0$, we have

$$\begin{aligned}
\Delta R_1 &= \frac{q^{-\tilde{\mu}}}{q^{-\tilde{\mu}}+k}\left[\frac{q^{-\tilde{\gamma}}}{q^{-\tilde{\gamma}}+k}\Delta R_1 + \frac{kq^{-\tilde{\gamma}}}{kq^{-\tilde{\gamma}}+1}(\theta\bar{R}-\Delta R_1)\right] + \frac{kq^{-\tilde{\mu}}}{kq^{-\tilde{\mu}}+1}\left[\frac{k}{q^{-\tilde{\gamma}}+k}\Delta R_1 + \frac{1}{kq^{-\tilde{\gamma}}+1}(\theta\bar{R}-\Delta R_1)\right] \\
&= \frac{q^{-\tilde{\mu}}}{q^{-\tilde{\mu}}+k}\left[\frac{(1-k^2)q^{-\tilde{\gamma}}}{(q^{-\tilde{\gamma}}+k)(kq^{-\tilde{\gamma}}+1)}\right]\Delta R_1 + \frac{kq^{-\tilde{\mu}}}{kq^{-\tilde{\mu}}+1}\left[\frac{-(1-k^2)q^{-\tilde{\gamma}}}{(q^{-\tilde{\gamma}}+k)(kq^{-\tilde{\gamma}}+1)}\right]\Delta R_1 + \mathcal{R}_q^* \\
&= \underbrace{(1-k^2)^2\frac{q^{-\tilde{\gamma}}q^{-\tilde{\mu}}}{(q^{-\tilde{\mu}}+k)(kq^{-\tilde{\mu}}+1)(q^{-\tilde{\gamma}}+k)(kq^{-\tilde{\gamma}}+1)}}_{c_R(q,k)}\Delta R_1 + \mathcal{R}_q^* \qquad \text{(E.41)}
\end{aligned}$$

where $\tilde{\mu} = \mu\varkappa$ and $\tilde{\gamma} = \varkappa\gamma^H/\gamma^L$. In this expression, note that the last term ($\mathcal{R}_q^*$) includes q, which is currently fixed, and this term is strictly positive. Specifically, we have

$$\mathcal{R}_q^* = \theta\underbrace{\left[\frac{kq^{-\tilde{\mu}}q^{-\tilde{\gamma}}}{(q^{-\tilde{\mu}}+k)(kq^{-\tilde{\gamma}}+1)} + \frac{kq^{-\tilde{\mu}}}{(kq^{-\tilde{\mu}}+1)(kq^{-\tilde{\gamma}}+1)}\right]}_{d_R(q,k)}\overline{R}$$

In addition, the term $c_R(q,k)$ lies between 0 and 1 given q for any $k \in (0,1)$. Then, we obtain:

$$[1-c_R(q,k)]\Delta R_1 = \theta d_R(q,k)\overline{R} \implies r = (1-\theta)\bar{r} + \theta\frac{d_R(q,k)}{1-c_R(q,k)} \qquad \text{(E.42)}$$

Thus, holding q fixed, r increases in the initial condition $\bar{r}$. The same argument is applicable for employment distribution, and ℓ is increasing in the initial condition $\bar{\ell}$.

Next, we consider the endogenous floor space prices, q. We may have a possibility that l and r decrease if the floor space price ratio q increases as its dispersion force prevents people from living or working in location 1 (i.e., small value of r). However, we show that this is not the case in equilibrium by contradiction. Suppose that $r' < r$ when $\bar{r}' > \bar{r}$ in equilibrium, where the prime symbol is used for a different equilibrium.

From the discussion above, this only happens when q becomes sufficiently large (i.e., $q' >> q$). When $\alpha = \beta = 0$, equation (E.35) implies:

$$q\frac{(1-\psi)\overline{H}_1 + q^{\eta}Q_2^{\eta}}{(1-\psi)\overline{H}_2 + Q_2^{\eta}} = \frac{\mu(1-\theta)(1-\overline{\lambda}_1^{\ell})\overline{r} + \mu\frac{k}{q^{-\tilde{\gamma}}+k}\left(\frac{r}{\overline{r}}\frac{1+\overline{r}}{1+r} - (1-\theta)\right)\overline{r} + \frac{\gamma^H}{\gamma^L}\frac{\ell}{1+\ell}q^{-\frac{\gamma^H}{\gamma^L}}}{\mu(1-\theta)\overline{\lambda}_2^{\ell} + \mu\frac{1}{kq^{-\tilde{\gamma}}+1}\left(\frac{1+\overline{r}}{1+r} - (1-\theta)\right) + \frac{\gamma^H}{\gamma^L}\frac{1}{1+\ell}} \tag{E.43}$$

The small value of $r' < r$ implies that the right-hand side of this equation decreases as its numerator decreases and the denominator increases. Under the conditions of Proposition E.2, the right-hand side is a decreasing function of q, and the left-hand side is an increasing function of q, implying that the equilibrium value is lower than the original one: $q' < q$. Therefore, if $r' < r$ holds in equilibrium, then q must decrease. However, the lower floor space cost implies that more people choose to live in location 1, which is a contradiction. We can make an analogous argument for ℓ. ∎

Proposition E.3 shows that the equilibrium population and employment increase in the initial population and employment when the equilibrium is unique and there is no agglomeration force. This implies that the equilibrium population and employment are always positively correlated with the initial population and employment, thereby indicating that the ranking of population and employment never reverses. Nevertheless, the location that was destroyed has a lower initial population and employment, which means that the location with a *lower* initial population and employment now has a *higher* population and employment than the peripheral location with a relatively higher initial population and employment. Thus, Proposition E.3 suggests that the resurgence of the destroyed old city center is not an equilibrium outcome in the absence of agglomeration forces. Therefore, agglomeration forces are *necessary* for explaining the recovery of the destroyed city center in the absence of the fundamental advantages of the old city center, which are not taken into account in this section.

Lastly, we consider the analytical result for another parameter θ, which controls the speed of the adjustment between two periods in the dynamic equilibrium. In particular, we focus on the case where θ is close to zero in the following proposition:

Proposition E.4. *Suppose that θ is sufficiently close to zero and the floor space prices are uniquely determined given the initial population $\overline{r}$ and employment $\overline{\ell}$. Then, the dynamic equilibrium is unique for any value of the agglomeration force parameters α and β.*

Proof. We take the initial conditions of $(\overline{r}, \overline{l}, \overline{H}_1, \overline{H}_2)$ as given. Then, we suppose that there exist the unique solutions q and Q_2 that solve the equations (E.34), and (E.35) when $\theta = 0$. Specifically, they solve:

$$Q_2^{1+\frac{\gamma^H}{\gamma^L}}\left[(1-\psi)\overline{H}_2 + Q_2^{\eta}\right] = \left(\frac{1}{1+\overline{\ell}}\right)^{\frac{\alpha}{\gamma^L}}\left[\mu\mathcal{I}_2(\overline{\ell}, q, \overline{\lambda}_2^{\ell})\frac{1}{1+\overline{r}} + \frac{\gamma^H}{\gamma^L}\frac{1}{1+\overline{\ell}}\right]$$

and

$$q\frac{(1-\psi)\overline{H}_1 + q^{\eta}Q_2^{\eta}}{(1-\psi)\overline{H}_2 + Q_2^{\eta}} = \frac{\mu\mathcal{I}_1(\overline{\ell}, q, \overline{\lambda}_1^{\ell})\overline{r} + \frac{\gamma^H}{\gamma^L}\frac{\overline{\ell}}{1+\overline{\ell}}\overline{\ell}^{\frac{\alpha}{\gamma^L}}q^{-\frac{\gamma^H}{\gamma^L}}}{\mu\mathcal{I}_2(\overline{\ell}, q, \overline{\lambda}_2^{\ell}) + \frac{\gamma^H}{\gamma^L}\frac{1}{1+\overline{\ell}}}$$

We let $\overline{q}$ and $\overline{Q}_2$ refer to such unique solutions. Note that the sufficient conditions of Proposition E.2 for the unique floor space prices ensure the unique solution. Then, the implicit function theorem implies that the solution for the system of equations (E.28), (E.29), (E.34), and (E.35) is unique in the neighborhood of the values $(\bar{r}, \bar{l}, \overline{H}_1, \overline{H}_2, \overline{q}, \overline{Q}_2)$. ■

The above proposition shows that the dynamic equilibrium is unique when the rate of adjustment (θ) is low. What is remarkable about Proposition E.4 is that even with strong agglomeration forces that might cause multiple equilibria, as stated in Proposition E.2, the equilibrium will still be unique if the mobility friction is high enough. Intuitively, when mobility friction is severe, the future economy cannot look very different from the current one. Since people expect such inertia, their optimal behavior is the best response to the current equilibrium, so the economy does not move away from the current equilibrium. In particular, note that the recovery of the destroyed city center never occurs when Proposition E.4 applies because the economy cannot deviate much from the initial condition under low θ, which has virtually no population and employment in the destroyed city center. Therefore, low mobility friction is a necessary condition for the recovery equilibrium to emerge. The uniqueness of the equilibrium under high mobility frictions is also consistent with the findings in the earlier theoretical literature (e.g., Krugman 1991; Matsuyama 1991; Baldwin 2001; Ottaviano 2001).

Summarizing the key takeaways of this section, we have uncovered that the dynamic equilibrium would be unique when there are no agglomeration forces ($\alpha = \beta = 0$) or the mobility friction is high ($\theta \simeq 0$). Furthermore, we show that such a unique equilibrium cannot predict the recovery of a destroyed city center with little initial population, employment, and floor space stock. In the next section, we numerically demonstrate that a recovery equilibrium may occur in which the destroyed city center reestablishes as the center of population and employment when the agglomeration forces are relatively strong and the mobility friction is more moderate.

E.3 *Numerical Illustration of Equilibria for the Two-Location Case*

In this section, we provide numerical illustrations of the dynamic equilibrium for the two-location case, which was analyzed in the previous section. In particular, we illustrate that (i) there could exist multiple equilibria when the friction of mobility is small and agglomeration forces are strong, and (ii) in addition to the "no recovery equilibrium" in which population and employment remain lower in the destroyed city center, there could exist a "recovery equilibrium" in which a totally-destroyed location becomes the center of population and employment despite having zero population and employment in the initial condition. Note that in this recovery equilibrium, since our model assumes rational expectations, people anticipate that the destroyed city center will recover, and such optimistic expectations are self-fulfilling. Overall, when agglomeration forces are relatively strong and mobility frictions are relatively moderate, which is what we empirically find in the context of Hiroshima, then the totally destroyed city center could recover in equilibrium as the center of population and employment.

We set the parameters of the model for the simulation as follows. The initial condition of the economy is similar to that after the bombing. Specifically, we suppose that all the population and employment are concentrated in location 2, and there is no floor space in location 1 in the initial condition:

$$\overline{R}_1 = \overline{L}_1 = 0, \quad \overline{R}_2 = \overline{L}_2 = 1, \quad \overline{H}_1 = 0$$

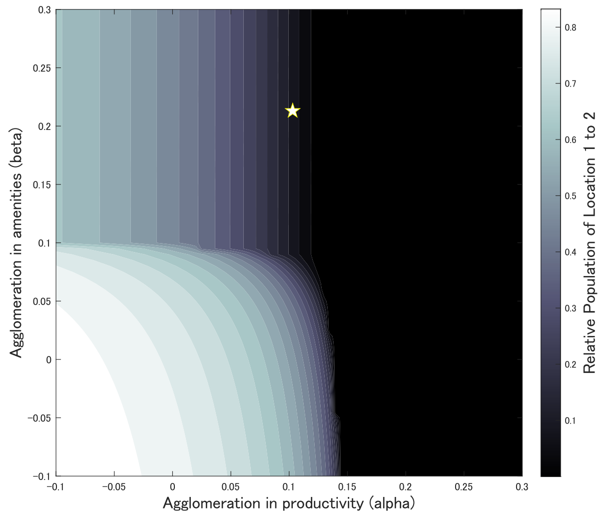
For the initial floor space in location 2, we set $\overline{H}_2 = 0.1$. Using this value accommodates the possibility that the destroyed location 1 can again become the center of population and employment, while the too large floor space endowment in location 2 trivially makes it the center of population and employment due to lower floor space cost. We set other parameters consistent with the values in our main text: the commuting elasticity $\varkappa = 8$; cost share of labor in production $\gamma^L = 0.7$; cost share of floor space in production $\gamma^H = 0.1$; expenditure share for residential floor space $\mu = 0.15$; floor space supply elasticity $\eta = 4$; and floor space depreciation rate $\psi = 0.1$. For the commuting costs, we set $k = 0.4$, which implies $\kappa \approx 1.12$.

Our focus is on different values of agglomeration in productivity (α) and amenities (β) and mobility friction θ, which are important for considering the recovery equilibrium based on our theoretical characterization in Appendix E.2. First, for the former, we solve the model for different values of the agglomeration parameters. Specifically, we consider $81 \times 81 = 6561$ combinations of parameters (α, β) in which each parameter takes values between -0.1 and 0.3. For each combination, we solve the system of equations given the initial condition. Regarding the mobility friction, we solve the model for $\theta = 0.9$ in the baseline, which resembles the mobility friction immediately after the bombing in Hiroshima. In the case of lower mobility, we use $\theta = 0.5$, which is similar to the value in Hiroshima after the recovery process ended. Given the set of parameters and the initial condition, we solve the system of equations (E.13); (E.14); (E.15); (E.16); (E.17); (E.18); and (E.19).

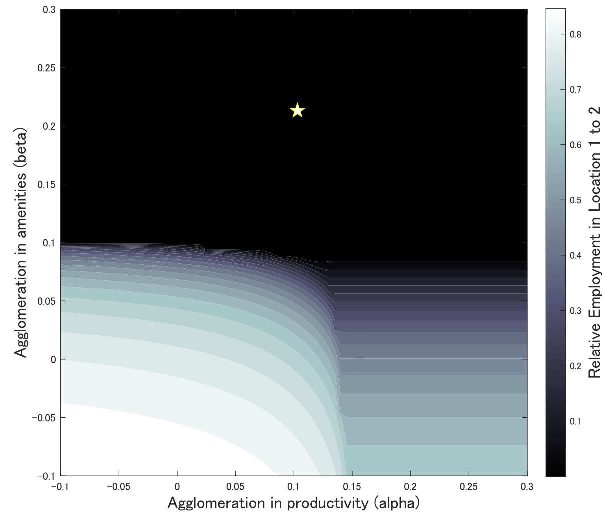
We start with the first solution for the dynamic equilibrium. Figure E.1 displays the ratio of population ($r = R_1/R_2$) and employment ($\ell = L_1/L_2$) on a two-dimensional map of different parameter values (α, β). In this simulation, we solve the system of equations using the initial guess such that the population and employment ratio is one (i.e., $R_1 = R_2 = 1/2$ and $L_1 = L_2 = 1/2$) and the same floor space price ($Q_1 = Q_2 = 1$) between the two locations. The star in Figure E.1 shows the combination of parameter values, which is estimated in our empirical setting ($\alpha = 0.103$ and $\beta = 0.213$) for reference. At the star point, both population and employment are relatively concentrated in location 2, implying that location 1 does not recover as the center of population and employment. Since location 2 initially has more population and employment, the relatively strong agglomeration forces ($\alpha = 0.103$ and $\beta = 0.213$) favor the productivity and amenities of location 2 as long as people expect that population and employment distributions do not change much. Combined with the mobility friction, this leads to higher population and employment in location 2. As a result, although floor space prices and idiosyncratic tastes act as dispersion forces so that location 1 obtains some population and employment, location 2 still has a higher population and employment, and location 1 does not recover as the center of population and employment.

Next, Figure E.2 shows population and employment distribution in another equilibrium. In this sim-

Figure E.1: Equilibrium 1: Population and Employment Ratio without Recovery



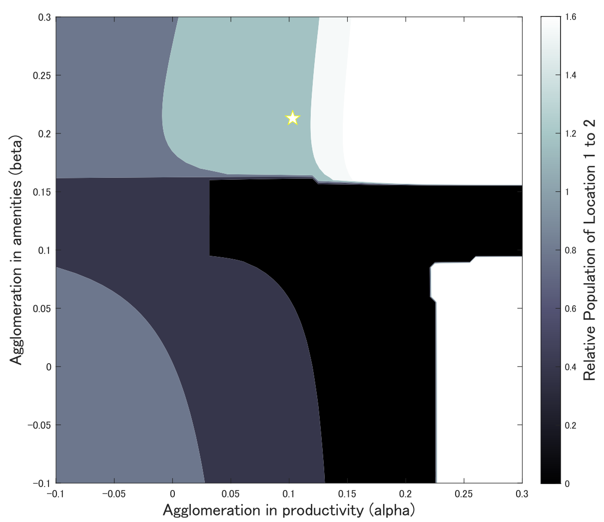
(a) Population



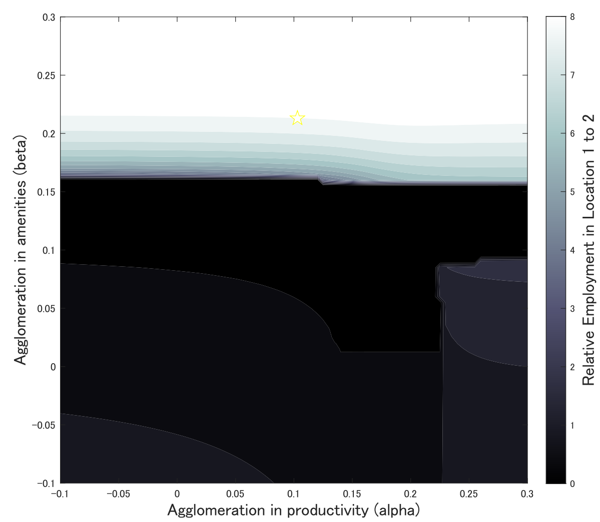
(b) Employment

Note: Figure E.1a shows location 1's population relative to location 2 in equilibrium, and Figure E.1b shows the same for employment. We use the initial guess $R_1 = R_2 = 1/2$, $L_1 = L_2 = 1/2$, and $Q_1 = Q_2 = 1$ to solve the equilibrium in this figure. The star symbol indicates the combination of agglomeration parameter values, which is estimated in our empirical setting ($\alpha = 0.103$ and $\beta = 0.213$).

Figure E.2: Equilibrium 2: Population and Employment with Recovery



(a) Population

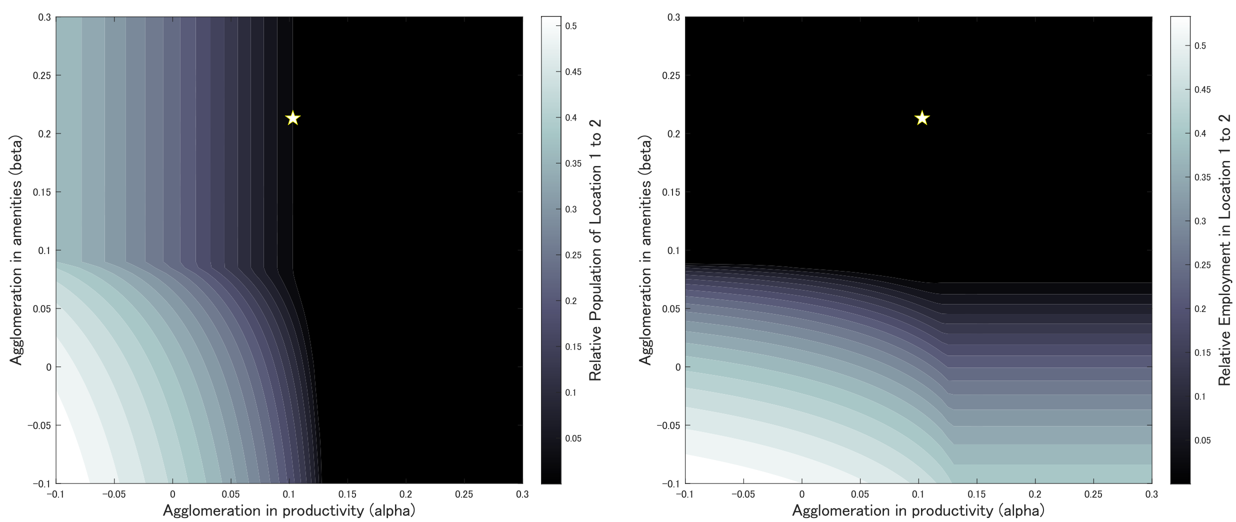


(b) Employment

Note: Figure E.2a shows location 1's population relative to location 2 in equilibrium, and Figure E.2b shows the same for employment. We use the initial guess $R_1 = L_1 = 0.8$, $R_2 = L_2 = 0.2$, and $Q_1 = Q_2 = 1$ to solve the equilibrium in this figure. The star symbol indicates the combination of agglomeration parameter values, which is estimated in our empirical setting ($\alpha = 0.103$ and $\beta = 0.213$).

ulation we solve equations (E.13); (E.14); (E.15); (E.16); (E.17); (E.18); and (E.19) using the initial guess of $R_1 = L_1 = 0.8$, $R_2 = L_2 = 0.2$, and $Q_1 = Q_2 = 1$, that is, we guess the recovery of the destroyed location 1. Intuitively, using the higher population and employment of location 1 as our initial guess captures the possibility that people anticipate the recovery of location 1. In this case, we obtain a starkly different equilibrium pattern compared with the equilibria reported in Figure E.2. In both population and employment, location 1 can have a significantly greater value than location 2 when the agglomeration force is strong. On the left-hand panel, the population in location 1 is greater than that in location 2 (i.e., the population ratio $r = R_1/R_2$ is greater than one) when the parameter value of agglomeration in amenities (β) is high or that for productivity (α) is sufficiently strong. Employment in location 1 increases when the agglomeration force in amenities is strong, as illustrated in the right-hand panel. Overall, we find the *recovery* in this equilibrium: the totally-destroyed location 1 can again become the center of the city, which we empirically observe in the context of Hiroshima. These results are entirely different from the pattern illustrated in Figure E.1, in which location 1 never obtains higher population and employment than location 2, implying that there are multiple equilibria. Intuitively, this is the scenario in which workers expect the reallocation of workers, and these expectations become self-fulfilling by selecting the recovery equilibrium among multiple equilibria.

Figure E.3: Equilibrium in Two Location Economy for Low θ (set by $\theta = 0.5$)



(a) Population

(b) Employment

Note: Figure E.3a shows location 1's population relative to location 2 in equilibrium, and Figure E.3b shows the same for employment. We use the initial guess $R_1 = L_1 = 0.8$, $R_2 = L_2 = 0.2$, and $Q_1 = Q_2 = 1$ to solve the equilibrium in this figure. We set $\theta = 0.5$ to capture the higher mobility friction than our baseline ($\theta = 0.9$). The star symbol indicates the combination of agglomeration parameter values, which is estimated in our empirical setting ($\alpha = 0.103$ and $\beta = 0.213$).

Finally, we highlight how mobility friction matters in achieving a strong recovery. In Figure E.3, we show the population and employment ratio between two locations when $\theta = 0.5$, even if we use the same initial guess of strong recovery (i.e., $R_1 = L_1 = 0.8$, $R_2 = L_2 = 0.2$, and $Q_1 = Q_2 = 1$) as in Figure E.2.

This assumption implies that only 50 percent of workers can change their location, which is smaller than 90 percent in the other simulations in Figures E.1 and E.2. If θ is small, the pattern is quite different from the recovery equilibrium in Figure E.2 but similar to the no recovery equilibrium in Figure E.1. This result suggests that relatively high mobility of workers is essential for the recovery since workers' incentive to change their locations cannot be realized when the mobility friction is high. We have also shown in Proposition E.4 that when mobility frictions are sufficiently severe, the equilibrium is unique, and the equilibrium outcome is similar to the initial conditions regardless of the strength of the agglomeration forces, implying that the recovery cannot happen. Figure E.3 illustrates that this possibility can emerge even if the mobility friction is not too extreme ($\theta = 0.5$). Therefore, even if the agglomeration forces are relatively strong, a relatively low mobility friction is a necessary condition for the recovery equilibrium to emerge, as in Figure E.2.

F Calibration Appendix

F.1 *Step #1: Travel Mode Choice and Gravity Equation for Commuting*

Travel Mode Choice (κ_{int}) To estimate the commuting cost, we follow Tsivanidis (2022) by extending the model to incorporate multiple travel modes. Suppose that the bilateral travel cost for an individual using travel mode m between blocks i and n, $\kappa^m_{int}(\omega)$, is given by:

$$\kappa^m_{int}(\omega) \equiv \exp\left(c^m_{int}(\omega)\right) > 0$$

with the inverse of the mode-specific travel cost:

$$-c^m_{int}(\omega) \equiv -\delta\tau^m_{int} + \bar{\gamma}^m + s^m_{int}(\omega),$$

where τ^m_{int} is the travel time in minutes between i and n; δ captures the marginal increase in travel cost when travel time increases by one minute; $\bar{\gamma}^m$ is the mode-specific fixed cost; and $s^m_{int}(\omega)$ is an unobserved idiosyncratic shock to the commuting cost by the mode m between i and n. Workers choose the travel mode m to minimize the commuting cost (i.e., maximize $-c^m_{int}$) conditional on their location choice.

We assume that $s^m_{int}(\omega)$ follows a Gumbel distribution with two nests: the nest of public modes $\mathcal{B}_{\text{pub}} \equiv \{\text{Walk, Bus, Train}\}$ and the nest of private-vehicle modes $\mathcal{B}_{\text{prv}} \equiv \{\text{Bike, Car}\}$. The former nest does not require owning a private vehicle. Using the well-known log-sum formula (Train 2009), we can write the expected commuting cost as

$$\bar{c}^{\text{car}}_{int} = -\ln\left[\exp(-\bar{c}^{\text{pub}}_{int}) + \exp(-\bar{c}^{\text{prv}}_{int})\right],$$

$$\bar{c}^{k}_{int} \equiv -\nu_k \ln\left[\sum_{m\in\mathcal{B}_k} e^{-(\delta\tau^m_{int}-\bar{\gamma}^m)/\nu_k}\right],$$

where ν_k is the dissimilarity parameter of nest $k \in [\text{pub}, \text{prv}]$.

We use the 1987 travel survey of Hiroshima to estimate $(\delta, \bar{\gamma}^m, \nu_{\text{pub}}, \nu_{\text{prv}})$ in this nested logit model using the maximum likelihood estimator.[31] We obtain $\delta = 0.019$ with standard error 0.002. We also estimate that $\nu_{\text{pub}} = 0.129$ with standard error 0.014 and $\nu_{\text{prv}} = 0.117$ with standard error 0.013, implying strong substitution within each nest since both estimates are far from 1.

Then, we have $\mathbb{E}(\ln \kappa_{int}^m) = \bar{c}_{int}$, which we use as the log bilateral travel cost ($\ln \kappa_{int}$) in our main calibration. We suppose that with probability p_{car}, a worker can choose a car as a commuting mode. Otherwise, a car is unavailable, so the private nest is modified as $\mathcal{B}_{\text{prv,nocar}} \equiv \{\text{Bike}\}$. We set the probability p_{car} based on the car ownership rate in Japan: 10 percent in 1950; 20 percent in 1955; 30 percent in 1960; 40 percent in 1965; 50 percent in 1970; and 70 percent in 1975.[32] Note that we have implicitly assumed $p_{\text{car}} = 1$ in estimating the nested logit model using the 1987 travel survey data, given the very high car ownership rate in 1987. Then, the expected commuting cost is:

$$\bar{c}_{int} = p_{\text{car}} \bar{c}_{int}^{\text{car}} + (1 - p_{\text{car}}) \bar{c}_{int}^{\text{nocar}},$$

where $\bar{c}_{int}^{\text{nocar}}$ is defined in the same way as $\bar{c}_{int}^{\text{car}}$, except that the summation in $\bar{c}_{int}^{\text{prv}}$ is over $\mathcal{B}_{\text{prv,nocar}}$ because a car is unavailable.

Gravity of Commuting (ρ/σ) In a steady state, the number of commuters from location n to i is given by (D.29). Taking the logarithm of this, we obtain:

$$\ln L_{in} = \frac{\rho}{\sigma} \left(\ln B_n + \ln w_i - \ln \bar{\kappa}_{in} \right) + \ln \bar{M}, \tag{F.1}$$

where

$$\ln \bar{M} \equiv \ln \left[M \left(\sum_{i' \in \mathcal{C}} \sum_{n' \in \mathcal{C}} \bar{u}_{i'n'}^{\rho/\sigma} \right)^{-1} \right],$$

$$-\ln \bar{\kappa}_{in} \equiv \mathbb{E} \left[\max_m \; -\ln \kappa_{in}^{m,\omega} \right] = \mathbb{E} \left[\max_m \; -c_{in}^{m,\omega} \right] = -\bar{c}_{in}$$

This corresponds to the gravity equation (19) in the main text. In estimating this gravity equation, we further suppose that there is an additional additive error term, which includes the measurement errors.

Table F.1 presents the results of the estimation of the gravity equation for commuting. Columns (1) and (2) provide the OLS results. In Columns (3) and (4), we use OLS but we add 1 to the commuting flow (L_{in}) so that we do not lose observations with zero commuting flows. To address the potential endogeneity of the transportation network, for the OLS results in Columns (1)–(4), we also conducted a two-stage least squares estimation using straight distances as an instrument for commuting costs, as in Heblich, Redding, and Sturm (2020). The estimates are slightly smaller (in absolute value) than but close to the estimates reported in Table F.1. This is expected because our average commuting cost and straight distances are strongly correlated (correlation coefficient $\simeq 0.929$). We use the PPML for Columns (5) and (6). In each case, we

[31] Although the first highway in Hiroshima opened in 1986, it would not affect our gravity estimation because we focus on commuting trips within our study area, while the first highway is outside of it.

[32] Consistent with this, about 30% of business trips were made by automobiles or motorcycles in 1967 Hiroshima person trip survey (Hiroshima-shi Toshi Kotsu Mondai Kondankai 1971)

also report the results when dropping bilateral pairs of less than 20 commuters to assess the robustness to the sampling noise. Our preferred specification is Column (5), which possesses the theoretically desirable properties of the PPML (Santos Silva and Tenreyro 2006), and we set $\rho/\sigma = 8$ in our calibration.

Table F.1: Gravity estimates for commuting

	(1)	(2)	(3)	(4)	(5)	(6)
	ln commuting flow		ln(commuting flow+1)		Commuting flow	
Average commuting cost ($\bar{c}_{in}$)	-4.082[a]	-3.976[a]	-5.758[a]	-3.931[a]	-8.019[a]	-7.031[a]
	(0.156)	(0.170)	(0.179)	(0.169)	(0.195)	(0.215)
Estimation	OLS		OLS		PPML	
IV estimates	-3.660	-3.502	-5.382	-3.459	N/A	N/A
Number of observations	2,473	1,635	4,356	1,635	4,290	1,635
More than 20 commuters		Yes		Yes		Yes
R-squared/ Pseudo R-squared	0.543	0.522	0.551	0.521	0.764	0.729

Note: We report estimates of (19) by OLS in Columns (1) and (2). In Columns (3) and (4), we use OLS but add one to the commuting flows to avoid dropping the observations with zero commuting flows. We use the PPML in Columns (5) and (6). We use the average commuting costs that we computed in the mode choice and include the origin and destination fixed effects. Note that Column (5) has slightly fewer observations than Column (3) because of the computational issues in PPML (Correia, Guimarães, and Zylkin 2020). In the "IV estimates" row, we present the two-stage-least-square estimation results using the straight-line distance as an instrumental variable (IV) for the average commuting cost. Due to the many fixed effects in our commuting gravity estimation, IV estimates are not available for the PPML specifications. Heteroskedasticity-robust standard errors are in parentheses. [a] indicates significance at the 1 percent level.

F.2 *Step #2: Inversion of Floor Space Prices*

The dynamics of floor spaces (16) leads to the relationship between floor space prices and the change in floor spaces in every location in a city. Specifically, the relationship is:

$$\eta \ln Q_{nt} = \ln \left[H_{nt} - (1-\psi) H_{nt-1} \right] - \ln S_n - \ln \bar{h}_t, \tag{F.2}$$

where, on the right-hand side, the first term captures the newly-built floor spaces in location n, and the second term is the area size of the location. Intuitively, the change in the floor spaces between period $t-1$ and t per unit of land is determined by the floor space supply elasticity η and floor space prices Q_{nt} in period t. $\bar{h}_t$ controls the scale of the floor space prices in period t.

Using this relationship, the floor space prices in period t can be backed out from the floor space supply and area size:

$$\ln Q_{nt} = \frac{1}{\eta} \ln \left[\frac{H_{nt} - (1-\psi) H_{nt-1}}{S_n} \right] - \frac{1}{\eta} \ln \bar{h}_t. \tag{F.3}$$

Given the sequence of the total floor spaces $\mathbb{H} = \left(\{H_{nt}\}_n \right)_{t=0,1,\cdots,T}$, the vector of area size $\{S_n\}$, the parameter of floor space depreciation ψ and the parameter of floor space supply elasticity η and the scalar $\bar{h}_t$, the floor space prices $\mathbb{Q} = \left(\{Q_{nt}\}_n \right)_{t=1,2,\cdots,T}$ are inferred to be consistent with the developers' problem.

For the last term on the right-hand side of (F.3) we first set $\bar{h}_t = 1$ for all periods to compute the floor space prices using equation (F.3). At the end of the calibration, we update the value of $\bar{h}_t$ to be consistent with the aggregate floor space market clearing condition. Namely, we calculate the scaling of the floor space price that is needed to make the total expenditure on floor space equal to the total value of floor spaces at the city level. Our calibration results are not affected by this adjustment because the relative floor space price differences across blocks are not changed by $\bar{h}_t$

F.3 *Step #3: Inversion of Option Values of Productivity and Amenities*

Our focus in this step is to back out the continuation value of amenities and productivity. Specifically, we define the following:

$$\begin{aligned}
\Xi_{nt} &\equiv B_{nt} \prod_{\tau=t+1}^{T} (B_{n\tau})^{\prod_{s=t+1}^{\tau} \rho(1-\theta_s)} \\
&= b_{nt} \left(\frac{R_{nt}}{S_n}\right)^{\beta} \prod_{\tau=t+1}^{T} \left[b_{n\tau} \left(\frac{R_{n\tau}}{S_n}\right)^{\beta} \right]^{\prod_{s=t+1}^{\tau} \rho(1-\theta_s)}
\end{aligned} \tag{F.4}$$

and

$$\begin{aligned}
\Omega_{it} &\equiv A_{it} \prod_{\tau=t+1}^{T} (A_{i\tau})^{\prod_{s=t+1}^{\tau} \rho(1-\theta_s)} \\
&= a_{it} \left(\frac{L_{it}}{S_i}\right)^{\alpha} \prod_{\tau=t+1}^{T} \left[a_{i\tau} \left(\frac{L_{i\tau}}{S_i}\right)^{\alpha} \right]^{\prod_{s=t+1}^{\tau} \rho(1-\theta_s)}
\end{aligned} \tag{F.5}$$

First, the probability (D.2) that individuals choose residential place n and workplace i when they have the opportunity to switch location choices becomes:

$$\lambda_{int} = \lambda_{ot} \exp\left(\mathbb{V}_{int}\right)^{\rho/\sigma} \tag{F.6}$$

with value function (D.1). Using this, the population and employment dynamics between period $t-1$ and t, (D.4) and (D.5), can be expressed by:

$$\begin{aligned}
R_{nt} - (1-\theta_t) R_{nt-1} &= \lambda_{ot} \theta_t \left[\sum_{i \in \mathcal{C}} \exp\left(\mathbb{V}_{int}\right)^{\rho/\sigma} \right] M, \\
L_{it} - (1-\theta_t) L_{it-1} &= \lambda_{ot} \theta_t \left[\sum_{n \in \mathcal{C}} \exp\left(\mathbb{V}_{int}\right)^{\rho/\sigma} \right] M
\end{aligned} \tag{F.7}$$

for all locations (i, n) in a city and periods $t = 1, \cdots, T$. Note that we suppose that the left-hand side of (F.7) is strictly positive for both population and employment as in (D.19), which implies that each location attracts a strictly positive number of residents and workers who have the opportunity to move within and across cities.

We also use the following notations:

$$\begin{aligned}
K_{int} &\equiv (\kappa_{int})^{-\rho/\sigma} \left[\prod_{\tau=t+1}^{T} (\kappa_{in\tau})^{-\prod_{s=t+1}^{\tau} \rho(1-\theta_s)} \right]^{\rho/\sigma}, \\
\mathcal{U}_t^o &\equiv (u_{ot})^{-\rho/\sigma} \left[\prod_{\tau=t+1}^{T} (u_{o\tau})^{-\prod_{s=t+1}^{\tau} \rho(1-\theta_s)} \right]^{\rho/\sigma}
\end{aligned} \tag{F.8}$$

for commuting costs and option values outside the city. The first representation K_{int} summarizes the change in commuting costs over time from period t, and the second representation $\mathcal{U}_t^o$ summarizes the change in utility outside of the city from period t. They are both exogenous in the model. We also note that they are constructed recursively: for instance, for any period $t < T$, we can express:

$$K_{int} = \kappa_{int}^{-\rho/\sigma} \left(K_{int+1}\right)^{\rho(1-\theta_{t+1})},$$
$$\mathcal{U}_t^o = u_{ot}^{-\rho/\sigma} \left(\mathcal{U}_{t+1}^o\right)^{\rho(1-\theta_{t+1})}$$

Furthermore, we define the continuation value of the floor space prices $\mathbb{Q} = \left(\{Q_{nt}\}_n\right)_{t=1,2,\cdots,T}$. In Step 2 (Subsection F.2) we have obtained the floor space prices. Then, we compute the continuation value of the floor space prices by

$$\Lambda_{nt} = Q_{nt} \left[\prod_{\tau=t+1}^{T} \left(Q_{n\tau}\right)^{\prod_{s=t+1}^{\tau} \rho(1-\theta_s)} \right] \tag{F.9}$$

This captures the evolution of floor space prices in location n from period t with discount factors $\rho(1-\theta_t)$.

Using (F.8), (F.9) and the definition of the continuation values of amenities (F.4) and productivity (F.5) together in the value function (D.1), equations (F.7) become:

$$R_{nt} - (1-\theta_t)R_{nt-1} = \lambda_{ot}\theta_t\mathcal{U}_t^o M \left(\left(\Lambda_{nt}\right)^{-\mu} \Xi_{nt} \right)^{\rho/\sigma} \sum_{i\in\mathcal{C}} K_{int} \left(\left(\Lambda_{it}\right)^{-\gamma^H/\gamma^L} \left(\Omega_{it}\right)^{1/\gamma^L} \right)^{\rho/\sigma}, \tag{F.10}$$

and

$$L_{it} - (1-\theta_t)L_{it-1} = \lambda_{ot}\theta_t\mathcal{U}_t^o M \left(\left(\Lambda_{it}\right)^{-\gamma^H/\gamma^L} \left(\Omega_{it}\right)^{1/\gamma^L} \right)^{\rho/\sigma} \sum_{n\in\mathcal{C}} K_{int} \left(\left(\Lambda_{nt}\right)^{-\mu} \Xi_{nt} \right)^{\rho/\sigma} \tag{F.11}$$

for periods $t = 1, 2, \cdots, T$. Substituting (F.11) into (F.10) yields the system of equations (22) in the main text. Specifically, the change in population in location n between periods $t-1$ and t is given by

$$R_{nt} - (1-\theta_t)R_{nt-1} = \sum_{i\in\mathcal{C}} \frac{K_{int} \left(\left(\Lambda_{nt}\right)^{-\mu} \Xi_{nt} \right)^{\rho/\sigma}}{\sum_{n'} K_{in't} \left(\left(\Lambda_{n't}\right)^{-\mu} \Xi_{n't} \right)^{\rho/\sigma}} \left[L_{it} - (1-\theta_t)L_{it-1}\right] \tag{F.12}$$

Analogously, substituting (F.10) into (F.11) leads to the change in employment in location i between period $t-1$ and t as follows:

$$L_{it} - (1-\theta_t)L_{it-1} = \sum_{n\in\mathcal{C}} \frac{K_{int} \left(\left(\Lambda_{it}\right)^{-\gamma^H/\gamma^L} \left(\Omega_{it}\right)^{1/\gamma^L} \right)^{\rho/\sigma}}{\sum_{i'\in\mathcal{C}} K_{i'nt} \left(\left(\Lambda_{i't}\right)^{-\gamma^H/\gamma^L} \left(\Omega_{i't}\right)^{1/\gamma^L} \right)^{\rho/\sigma}} \left[R_{nt} - (1-\theta_t)R_{nt-1}\right] \tag{F.13}$$

Next, we solve the system of equations (F.12) and (F.13).

Solution to (F.12) and (F.13) We show the uniqueness of the solution $\{\Xi_{nt}\}$ and $\{\Omega_{it}\}$ to (F.12) and (F.13) conditional on the following observations: population $\{R_{nt}\}$, employment $\{L_{it}\}$, floor space prices $\{\Lambda_{nt}\}$ and fundamentals $\{K_{int}\}$. Suppose that the observed population and employment satisfy:

$$\begin{aligned} R_{nt} - (1-\theta_t)R_{nt-1} > 0, \\ L_{it} - (1-\theta_t)L_{it-1} > 0 \end{aligned} \tag{F.14}$$

for any periods $t-1$ and t. We also observe the floor space prices and commuting costs; therefore, K_{int} and Λ_{it} are taken as given.

We first show that there exists a solution Ξ_{nt} to equation (F.12). To simplify the notation, we use the following notations for population and employment changes:

$$\begin{aligned}\dot{R}_{nt} &= R_{nt} - (1-\theta_t)R_{nt-1}, \\ \dot{L}_{it} &= L_{it} - (1-\theta_t)L_{it-1},\end{aligned} \tag{F.15}$$

and we also define the term absorbing floor space prices and commuting costs:

$$x_{int} = K_{int}(\Lambda_{nt})^{-\mu\rho/\sigma} \tag{F.16}$$

Then, equation (F.12) can be expressed by the following non-linear equation for $\{\Xi_{nt}\}$:

$$\Xi_{nt} = \left(\frac{1}{\dot{R}_{nt}} \sum_{i\in\mathcal{C}} \frac{x_{int}\dot{L}_{it}}{\sum_{n'\in\mathcal{C}} x_{in't}\Xi_{n't}^{\rho/\sigma}}\right)^{-\sigma/\rho} \tag{F.17}$$

Letting

$$\begin{aligned}\overline{\dot{R}}_t &\equiv \max_n \dot{R}_{nt}, \\ \overline{\dot{L}}_t &\equiv \max_i \dot{L}_{it}, \\ \underline{\dot{R}}_t &\equiv \min_n \dot{R}_{nt}, \\ \underline{\dot{L}}_t &\equiv \min_i \dot{L}_{it},\end{aligned}$$

and

$$\begin{aligned}\overline{x}_t &\equiv \max_i \max_n x_{int}, \\ \underline{x}_t &\equiv \min_i \min_n x_{int}\end{aligned}$$

We define the following:

$$\begin{aligned}\infty > \overline{\xi}_t &\equiv \left(\frac{\overline{x}_t}{\underline{x}_t}\frac{\overline{\dot{R}}_t}{\underline{\dot{L}}_t}\right)^{\sigma/\rho} > 1, \\ 0 < \underline{\xi}_t &\equiv \left(\frac{\underline{x}_t}{\overline{x}_t}\frac{\underline{\dot{R}}_t}{\overline{\dot{L}}_t}\right)^{\sigma/\rho} < 1\end{aligned} \tag{F.18}$$

Using them, we can show that

$$\underline{\xi}_t \leq \frac{\Xi_{nt}}{\widetilde{\Xi}_t} \leq \overline{\xi}_t, \quad n = 1, 2, \cdots, N \tag{F.19}$$

where we use the mean:

$$\widetilde{\Xi}_t = \left(\frac{1}{N}\sum_{n\in\mathcal{C}} \Xi_{nt}^{\rho/\sigma}\right)^{\sigma/\rho} \tag{F.20}$$

Therefore, we can define the convex set using $\underline{\xi}_t$ and $\overline{\xi}_t$ for the mapping that corresponds to equation (F.17). Because the right-hand side of equation (F.17) is continuous, we can apply Brouwer's fixed point theorem to show the existence of a fixed point for (F.17).

Next, we show that the solution Ξ_{nt} to equation (F.17) is unique when $\rho/\sigma > 0$ by contradiction. Suppose that there are two linearly *independent* vectors $\{\xi_{nt}\}$ and $\{\xi'_{nt}\}$ that are the solutions to the system of equations (F.12). We let $\nabla_j \equiv \xi'_{jt}/\xi_{jt}$ for every $j \in \mathcal{C}$ and without loss of generality we set $n \in \arg\max_j \nabla_j$. We also define $\widetilde{\xi}_t = \nabla_n \xi_t$. By construction, we have:

$$\begin{aligned}
\widetilde{\xi}_{nt} &= \xi'_{nt}, \\
\widetilde{\xi}_{jt} &= \nabla_n \xi_{jt} > \nabla_j \xi_{jt} = \xi'_{jt}
\end{aligned} \tag{F.21}$$

for other elements $j \neq n$. Then, for such element n, we can show:

$$\begin{aligned}
0 &= \dot{R}_{nt} - \sum_{i \in \mathcal{C}} \frac{x_{int}(\xi'_{nt})^{\rho/\sigma}}{\sum_{n' \in \mathcal{C}} x_{in't}(\xi'_{n't})^{\rho/\sigma}} \dot{L}_{it} \\
&< \dot{R}_{nt} - \sum_{i \in \mathcal{C}} \frac{x_{int}(\widetilde{\xi}_{nt})^{\rho/\sigma}}{\sum_{n' \in \mathcal{C}} x_{in't}(\widetilde{\xi}_{n't})^{\rho/\sigma}} \dot{L}_{it} \\
&= \dot{R}_{nt} - \sum_{i \in \mathcal{C}} \frac{x_{int}(\xi_{nt})^{\rho/\sigma}}{\sum_{n' \in \mathcal{C}} x_{in't}(\xi_{n't})^{\rho/\sigma}} \dot{L}_{it}
\end{aligned} \tag{F.22}$$

and this leads to a contradiction. Since equation (F.12) is homogeneous of degree zero in $\{\Xi_{nt}\}$, the solution for (F.12) is unique *up to scale*. We can show the existence and uniqueness of a solution $\{\Omega_{it}\}$ to the equation (F.13) in the same manner. The following proposition summarizes this step.

Proposition F.1 (Inversion of Option Values for Locations). *Conditional on the observed population changes* $\{\dot{R}_{nt}\}$*, employment changes* $\{\dot{L}_{it}\}$ *defined by* (F.15)*, the continuation value of commuting costs* K_{int} *and the continuation value of floor space prices* Λ_{nt}*, there exists a unique solution (up to scale) of the continuation value of amenities* $\{\Xi_{nt}\}$ *and productivity* $\{\Omega_{it}\}$ *to the system of equations* (F.12) *and* (F.13) *if* $\dot{L}_{it} > 0$ *and* $\dot{R}_{nt} > 0$ *hold.*

We note that this step does *not* require the parameter values of agglomeration in amenities and productivity. Intuitively, the values of overall amenities and productivity that rationalize the observed changes in population and employment are uniquely determined once we substitute exogenous location characteristics and floor prices because the option values for amenities and productivity are adjusted to make the observed population and employment change consistent with the equilibrium dynamics, respectively. In the next step, we compute the overall productivity and amenities based on the inverted option values.

F.4 *Step #4: Inversion of Amenities and Productivity*

In the above step, we have computed the continuation values of productivity $\{\Omega_{it}\}$ consistent with the observed data to be an equilibrium. By definition of the option value (F.5), in the last period T, the overall productivity equals the option value:

$$A_{iT} = \Omega_{iT}. \tag{F.23}$$

For the period $T-1$, equation (F.5) implies:

$$A_{iT-1} = \Omega_{iT}^{-[\rho(1-\theta_T)]}\Omega_{iT-1}, \tag{F.24}$$

where the right-hand side can be computed using the continuation values of productivity in periods $t-1$ and t together with the model parameters ρ and θ_T. We continue this process for all periods back to the first period to obtain the overall productivity, $\{A_{it}\}$ for $t = 1, 2, \cdots, T$. Overall productivity A_{it} in period t is consistent with the observed population and employment distribution to be in the dynamic equilibrium.

For amenities, we apply the same steps for $\{\Xi_{nt}\}$. By definition (F.4), in the last period T, the overall amenities equal the option value:

$$B_{nT} = \Xi_{nT}. \tag{F.25}$$

For the period $T-1$, equation (F.5) implies:

$$B_{nT-1} = \Xi_{nT}^{-[\rho(1-\theta_T)]}\Xi_{nT-1}, \tag{F.26}$$

where the right-hand side can be computed using the continuation values of the amenities in periods $t-1$ and t together with the model parameters ρ and θ_T. We continue this process for all periods to obtain the overall amenities, $\{B_{nt}\}$ for $t = 1, 2, \cdots, T$.

In this step, we find the unique vectors $\{A_{it}\}$ and $\{B_{nt}\}$ given the unique value of the option values obtained in Step 3 (Appendix F.3).

Proposition F.2 (**Inversion of Block-level Amenities and Productivity**). *Conditional on the observed population changes $\{\dot{R}_{nt}\}$, employment changes $\{\dot{L}_{it}\}$ defined by* (F.15)*, the continuation value of commuting costs K_{int} and the continuation value of floor space prices Λ_{nt}, there exists a unique solution (up to scale) of the value of amenities $\{B_{nt}\}$ and productivity $\{A_{it}\}$ if $\dot{L}_{it} > 0$ and $\dot{R}_{nt} > 0$ hold.*

The inverted vectors of amenities and productivity rationalize the changes in population, employment, and floor space prices across locations to be consistent with a dynamic equilibrium. In this process, we have not assumed the uniqueness of the dynamic equilibrium.

F.5 *Step #5: Estimation of Agglomeration Parameters* (α, β)

Next, we consider estimating the agglomeration forces in terms of productivity and amenities. First, we explain how we obtain the fundamental productivity (a_{it}) and amenities (b_{nt}); and second, we discuss the moment conditions for estimating the agglomeration parameters.

Fundamental Amenities and Productivity To obtain the exogenous part of amenities and productivity, we decompose the overall productivity $\{A_{it}\}$ and amenities $\{B_{nt}\}$. By definition of overall amenities, in each period t, we can invert the fundamental amenities using:

$$b_{nt} = \left(\frac{R_{nt}}{S_n}\right)^{-\beta} B_{nt} \tag{F.27}$$

Given the observed population in each period (R_{nt}), block size (S_n), and agglomeration parameter β for amenities, we can compute the fundamental amenities $\{b_{nt}\}$ for each period.

For the fundamental productivity $\{a_{it}\}$, we use:

$$a_{it} = \left(\frac{L_{it}}{S_i}\right)^{-\alpha} A_{it}, \tag{F.28}$$

where we substitute the observed employment in each period (L_{it}), block size (S_i), and agglomeration parameter α on the right-hand side. By construction, the inverted fundamental amenities and productivity are unique.

Moment Conditions Next, we consider the moment conditions for identifying the agglomeration parameters. The key identifying assumption is that any changes in the fundamental amenities and productivity over time in the period *after the initial recovery* are unrelated to the distance from the location of the CBD. Specifically, we suppose that the fundamental amenities and productivity $\{a_{it}, b_{nt}\}_{t=1,\cdots,T}$ consist of location-fixed components, time-fixed components and variant terms:

$$\begin{aligned} \ln a_{it} &= \ln a_i^F + \ln a_t^* + \ln a_{it}^{\mathrm{Var}}, \\ \ln b_{nt} &= \ln b_n^F + \ln b_t^* + \ln b_{nt}^{\mathrm{Var}}, \end{aligned} \tag{F.29}$$

where $\{a_i^F, b_n^F\}$ are location-fixed productivity and amenities; $\{a_t^*, b_t^*\}$ are the trends of productivity and amenities common to all blocks; and $\{a_{it}^{\mathrm{Var}}, b_{nt}^{\mathrm{Var}}\}$ are the idiosyncratic parts of fundamental productivity and amenities. The location-fixed productivity and amenities capture any fixed attractiveness of each location during the post-recovery period, such as natural characteristics and durable build environments.

Averaging out the trend yields the relative value of fundamental productivity and amenities in each block to the city-wide average in period t:

$$\begin{aligned} \ln\left(\frac{a_{it}}{\widetilde{a}_t}\right) &= \ln\left(\frac{a_i^F}{\widetilde{a}^F}\right) + \ln\left(\frac{a_{it}^{\mathrm{Var}}}{\widetilde{a}_t^{\mathrm{Var}}}\right), \\ \ln\left(\frac{b_{nt}}{\widetilde{b}_t}\right) &= \ln\left(\frac{b_n^F}{\widetilde{b}^F}\right) + \ln\left(\frac{b_{nt}^{\mathrm{Var}}}{\widetilde{b}_t^{\mathrm{Var}}}\right), \end{aligned} \tag{F.30}$$

where we use the geometric mean of the variables:

$$\begin{aligned} \widetilde{a}_t &\equiv \frac{1}{N}\sum_{i\in\mathcal{C}} \ln a_{it}, \\ \widetilde{b}_t &\equiv \frac{1}{N}\sum_{n\in\mathcal{C}} \ln b_{nt} \end{aligned} \tag{F.31}$$

Then, we take the difference between periods and suppose the following moment conditions:

$$\begin{aligned} \mathbb{E}\left[\Delta \ln\left(a_{it}/\widetilde{a}_t\right) \times \mathbb{1}_i(k)\right] &= 0, \\ \mathbb{E}\left[\Delta \ln\left(b_{nt}/\widetilde{b}_t\right) \times \mathbb{1}_n(k)\right] &= 0, \end{aligned} \tag{F.32}$$

where $\mathbb{1}_i(k)$ is an indicator such that location i is in grid k, which we define based on the distance from the CBD in our main estimation. We use the moment conditions (F.32) to estimate the set of parameters of the agglomeration forces (α, β).

In this identifying assumption (F.32) we require that the systematic change in the gradient of population and employment relative to the CBD in Hiroshima over every five years during 1955–75 after the initial recovery period is not primarily explained by the *change* in the residual of the exogenous part of productivity and amenities.[33] In Section 5.3, we provide various empirical results that are in support of our identification assumption. Section 5.4 conducts further robustness checks on our estimation of the agglomeration parameters.

F.6 *Calibrated Amenities and Productivity*

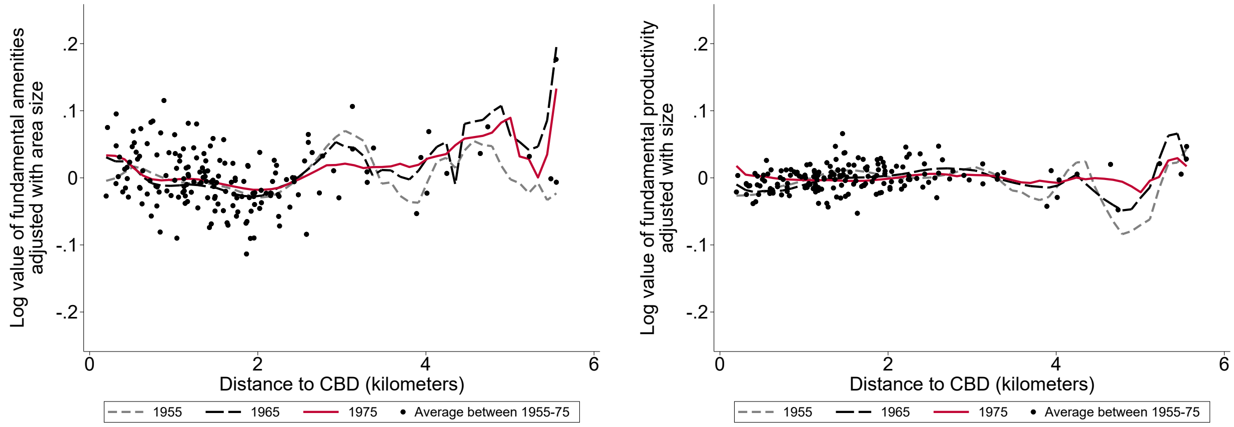
In Figure F.1 we show the polynomial fitted lines for the log of fundamental productivity (a_{it}) and amenities (b_{nt}) net block size effects for 1955, 1965, and 1975. We also show their averages between 1955 and 1975. We adjust for block size because fundamental amenities and productivity tend to be mechanically undervalued for smaller blocks. Intuitively, other things being equal, a smaller block is likely to have a higher population and employment density given the idiosyncratic preferences, irrespective of the block size. Thus, location-specific productivity and amenities may be undervalued in smaller blocks to offset such a small-block advantage. To adjust for this, we regress our estimate of the log of location-specific productivity and amenities on the log of block size, and we plot the residuals from the regressions.[34] We find that both productivity and amenities are not systematically related to the distance from the CBD. In particular, the fundamental amenities and productivity in the central area of the city are similar to those in the outskirts.

Next, we examine the moment conditions used for our estimation. In Figure F.2 we visualize the changes in the residuals of the fundamental amenities $\Delta \ln(b_{nt}/\tilde{b}_t)$ for four different periods: 1955-60, 1960-65, 1965-70, and 1970-75. The different shapes of the dots show the change in the residuals for different periods associated with their fitted lines. Our moment condition requires that on average, these changes are not correlated with the distance from the city center. Consistent with this, the changes in the residuals of amenities exhibit little variation across the city for those periods. The gradient of the changes with respect to the distance to the city center is almost flat for 1955–1960 and 1960–1965. For 1965–1970 it is slightly negatively sloped while a slight positive slope is observed for 1970–1975, but we find little evidence of systematic deviation from our moment conditions. Indeed, when we average the changes across different periods, the average changes are not correlated to the distance from the CBD, as seen in Panel (a) of Figure 5 in the main text.

[33] In particular, focusing on this period allows us to take account of the salient investments by the government after WWII in Hiroshima: the construction of the Peace Memorial Park, turning the castle area into the Hiroshima-shi Central Park, and expanding the road width (Peace Boulevard). The construction of the Peace Memorial Park was completed in April 1954, and the castle area is not included in our sample for estimation. Moreover, since we use the public transport networks of 1950 for the periods prior to 1966 and those of 1987 after them to construct the commuting time, the change in commuting access captures the impacts of the road expansion.

[34] See Train (2009), Chapter 3, for a theoretical justification of using the log of size in the adjustment.

Figure F.1: Fundamental productivity and amenities (Accounting for block size heterogeneity)

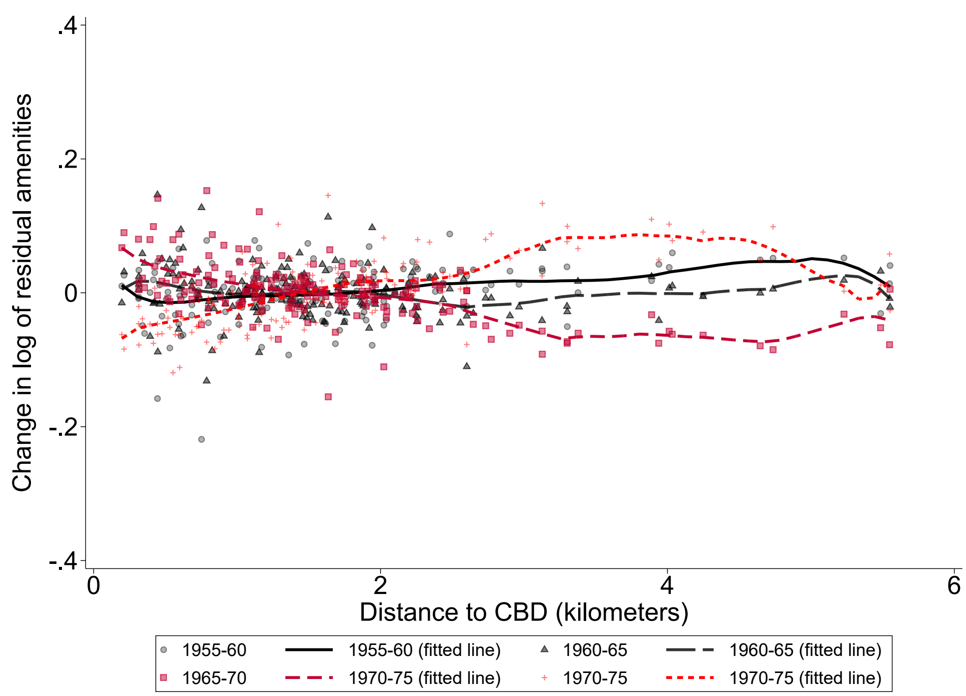


(a) Amenities

(b) Productivity

Note: These figures display the fundamental productivity (a_{it}) and amenities (b_{nt}) in our calibration after netting out the block size effects. The vertical axis shows the residuals of the linear regression of the log of fundamentals on the log of block size. We report the local polynomial fitted lines for 1955, 1965, and 1975. In addition, we plot the average of the residuals over the period 1955-1975. Each dot represents a block. The horizontal axis is the distance from the CBD. Panel (a) shows the residuals in amenities, and Panel (b) shows those in productivity.

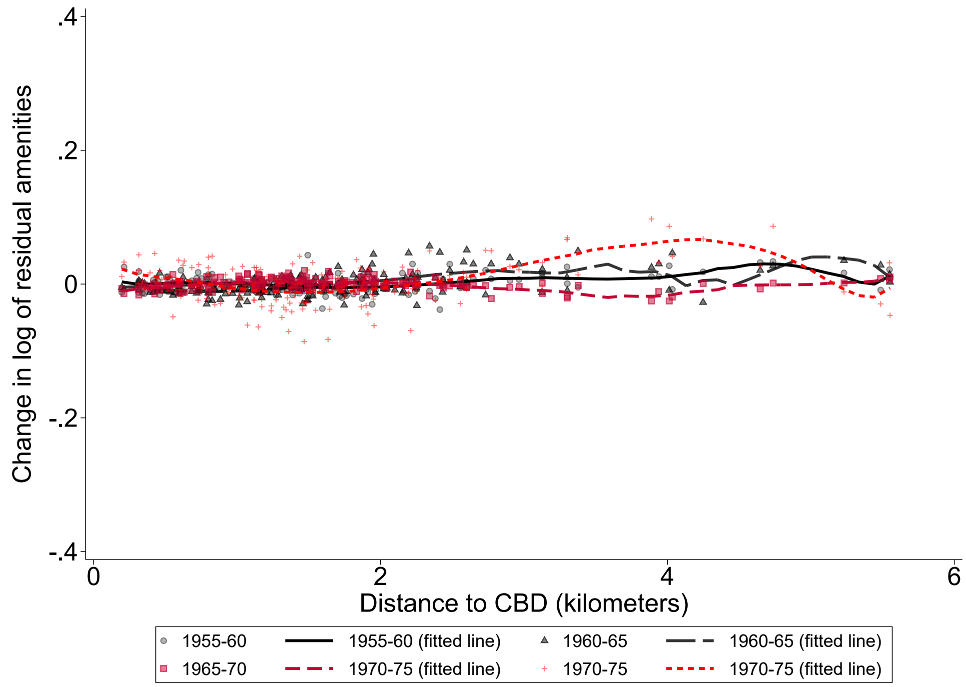
Figure F.2: Changes in the fundamental amenities for different periods



Note: These figures show changes in the residuals of the fundamental amenities $\Delta \ln(b_{nt}/\tilde{b}_t)$ for the sample periods used in the estimation: 1955–60, 1960–65, 1965–70, and 1970–75. Each marker represents a block, and different types of markers show the results for different periods. We also show the local polynomial fitted lines for each period. The horizontal axis is the distance from the CBD.

Figure F.3 shows the residuals of productivity, and their variation is relatively small within the city for all periods. This implies that idiosyncratic shocks in fundamental productivity do not account for the variation in the city employment distribution. Overall, these results for the idiosyncratic part of fundamental productivity and amenities are consistent with our identification assumption.

Figure F.3: Changes in fundamental productivity for different periods



Note: These figures show changes in the residuals of the fundamental productivity $\Delta \ln(a_{it}/\tilde{a}_t)$ for the sample periods used in the estimation: 1955–60, 1960–65, 1965–70, and 1970–75. Each marker represents a block, and different types of markers show the results for different periods. We also show the local polynomial fitted lines for each period. The horizontal axis is the distance from the CBD.

Untargeted Moment Conditions for 1950–1955 In our estimation, we use changes in fundamental amenities and productivity every five years from 1955 to 1975. Their results are shown above. We additionally consider the untargeted moment conditions for the structural residuals in the period 1950–55.

In particular, we can compute the fundamental amenities and productivity for 1950 given the estimated agglomeration parameters (α, β). For those fundamentals, we confirm that changes in the structural residuals in fundamental amenities and productivity do not show significant changes between 1950 and 1955. Letting $b_{n,50}$ and $a_{i,50}$ be estimated fundamental amenities and productivity in 1950, we compute

$$\begin{aligned} \Delta \ln\left(\frac{b_{n,55}}{\tilde{b}_{55}}\right) &= \ln\left(\frac{b_{n,55}}{\tilde{b}_{55}}\right) - \ln\left(\frac{b_{n,50}}{\tilde{b}_{50}}\right), \\ \Delta \ln\left(\frac{a_{i,55}}{\tilde{a}_{55}}\right) &= \ln\left(\frac{a_{i,55}}{\tilde{a}_{55}}\right) - \ln\left(\frac{a_{i,50}}{\tilde{a}_{50}}\right), \end{aligned} \tag{F.33}$$

where $\tilde{b}_{50}$ and $\tilde{a}_{50}$ represent the geometric means of fundamental amenities and productivity, respectively, in 1950. These can be used to construct analogous moments as per equation (25) for 1950–1955, and this can be used to test the validity of our moment conditions for 1955–1975 as the 1950–1955 moments are not used for our GMM estimation.

In Panel (b) of Figure 5 in the main text we visualize these changes relative to the distance from the CBD. Each dot shows the change in the structural residuals of amenities, and the square shows that for productivity. The component of the structural residual of amenities exhibits little change between 1950 and 1955, which suggests that the spatial variation in amenity changes was not driven by the structural residuals in this early period. For structural residuals in productivity, while we find a few outliers showing relatively large increases, overall there is minimal variation across the city. This result is consistent with our identification assumption that changes in the amenities and productivity of each block are uncorrelated with the distance from the CBD.

F.7 *Calibrated Fundamentals for the 1930s*

Here, we compute the pattern of the calibrated fundamentals using the pre-war population distribution. We use the population distribution in 1936 and the employment distribution in 1938. We suppose that the pre-war population and employment distributions are in a steady state and use the equilibrium conditions to invert the overall productivity and amenities in each block for the 1930s.

Since the floor space prices or total floor spaces in the 1930s are not observable in the data, we exploit the equilibrium conditions for the steady state to back out the wages and fundamentals for the 1930s using the observed population and employment. In the following, we explain the steps to solve the equilibrium condition for fundamental productivity and amenities in the 1930s. We use block-level population data for 1936. To be consistent with this data, the block-level employment data in 1938 is adjusted for 1936 by setting the total number of workers in the city equal to that in 1936. First, equation (D.24) implies that population and employment in 1930s satisfies:

$$L_i = \sum_{n \in \mathcal{C}} \frac{\kappa_{in}^{-\varkappa} w_i^{\varkappa}}{\sum_{i' \in \mathcal{C}} \kappa_{i'n}^{-\varkappa} w_{i'}^{\varkappa}} R_n, \tag{F.34}$$

where the transport costs (κ_{in}) are set to the same level as in 1950, as the transport network in a city did not change much between pre-war and post-war. We substitute population and employment into both sides of equation (F.34) to obtain wages $\{w_i\}$ for 1936. In addition, using the inverted wages, we compute the average labor income in each block (D.30) such that

$$v_n = \sum_{i \in \mathcal{C}} \lambda_{i|n}^L w_i = \sum_{i \in \mathcal{C}} \frac{\kappa_{in}^{-\varkappa} w_i^{\varkappa}}{\sum_{i' \in \mathcal{C}} \kappa_{i'n}^{-\varkappa} w_{i'}^{\varkappa}} w_i \tag{F.35}$$

This first step provides the average income $\{v_n\}$ in a residential location.

Next, the zero profit condition implies that the floor space prices in location n:

$$Q_n = \left(\frac{A_n}{w_n^{\gamma^L}} \right)^{1/\gamma^H} \tag{F.36}$$

Substituting this into equation (D.31) for the steady state, we obtain:

$$H_n = \frac{\bar{h}}{\psi} \left(\frac{A_n}{w_n^{\gamma^L}} \right)^{\eta/\gamma^H} S_n \tag{F.37}$$

Therefore, floor space market clearing conditions can be written by

$$\frac{\bar{h}}{\psi} \left(\frac{A_n}{w_n^{\gamma^L}} \right)^{1+\frac{\eta}{\gamma^H}} S_n = \mu v_n R_n + \frac{\gamma^H}{\gamma^L} w_n L_n, \tag{F.38}$$

where the left-hand side is the value of the floor space supply ($Q_n H_n$) and the right-hand side is the total demand for the floor spaces. Using the observed population, employment, area size and inverted wages and income, we invert the floor space market clearing condition (F.38) for overall productivity in the production location:

$$A_{n,30s} = (w_n)^{\gamma^L} \left[\frac{\psi}{\bar{h}} \frac{1}{S_n} \left(\mu v_n R_n + \frac{\gamma^H}{\gamma^L} w_n L_n \right) \right]^{\frac{1}{1+\eta/\gamma^H}} \tag{F.39}$$

Intuitively, overall productivity in 1936 is high for the location where the inverted wage is high and the total population and employment are large. In addition, we obtain the model-inferred floor space prices $\{Q_n\}$ based on equation (F.36).

Third, we consider the amenity in a residential location. The commuting market clearing condition (D.23) implies:

$$R_n = \sum_{i \in C} \frac{\kappa_{in}^{-\varkappa} B_n^{\varkappa} Q_n^{-\mu\varkappa}}{\sum_{n'} \kappa_{in'}^{-\varkappa} B_{n'}^{\varkappa} Q_{n'}^{-\mu\varkappa}} L_i \tag{F.40}$$

We substitute the population of 1936 into the left-hand side and transport costs, inverted floor space prices and employment into the right-hand side to solve these non-linear equations for the residential amenities $\{B_{n,30s}\}$ of 1936.

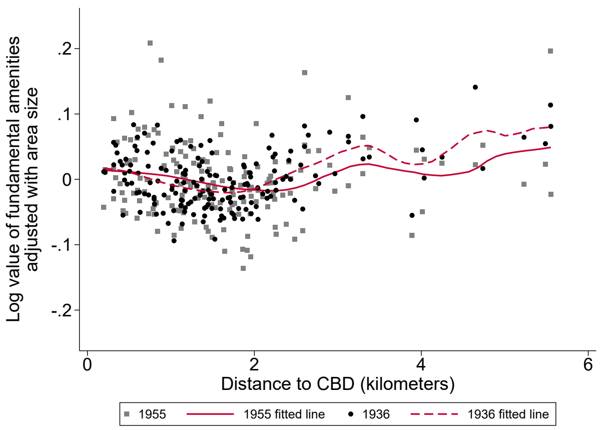
Finally, given the overall productivity $\{A_{i,30s}\}$ and amenities $\{B_{n,30s}\}$, we compute the fundamental productivity ($a_{i,30s}$) and amenities ($b_{n,30s}$) using the estimated agglomeration parameters:

$$\begin{aligned} a_{i,30s} &= \left(\frac{L_{i,36}}{S_i} \right)^{-\alpha} A_{i,30s}, \\ b_{n,30s} &= \left(\frac{R_{n,36}}{S_n} \right)^{-\beta} B_{n,30s} \end{aligned} \tag{F.41}$$

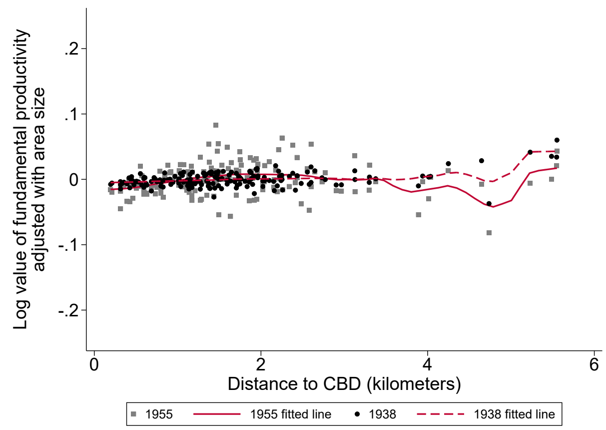
If the pattern of fundamentals in the 1930s exhibits a similar pattern to the later period, it is consistent with the idea that fundamentals were not directly affected by the destruction of the atomic bombing or investment for rebuilding after the bombing.

In Figure F.4 we visualize the fundamentals for the 1930s and 1955 after adjusting for block size as in Figure F.1. The left-hand panel shows the inverted fundamental amenities across the distance from the CBD for both periods and the right-hand panel shows the inverted fundamental productivity. We find that the overall pattern of fundamental productivity and amenities is similar between the 1930s and 1955, which confirms that these location characteristics were similar before and after the bombing. The correlation between the fundamental amenities in 1930 ($b_{n,30s}$) and those in 1955 ($b_{n,55}$) is over 0.95. For productivity $a_{i,30s}$ and $a_{i,55}$, the correlation is over 0.98. We also find that comparison with 1975 leads to similar conclusions.

Figure F.4: Fundamental amenities and productivity in the 1930s and 1955



(a) Fundamental amenities



(b) Fundamental productivity

Note: These figures display the fundamental productivity and amenities in our calibration after netting out the block size for the 1930s and 1955. The vertical axis shows the residuals of the linear regression of the log of fundamentals on the log of block size. We plot each with local polynomial fitted lines for two different periods. Each dot represents a block. The horizontal axis is the distance from the CBD.

F.8 *Robustness of the Agglomeration Parameter Estimates*

Moment Conditions In the baseline, we (i) define five grid cells according to the distance from the CBD and (ii) exploit the population and employment data from 1955 to 1975. We now conduct robustness checks for these specifications. In Table F.2, we report the two-step GMM estimates for two three robustness checks. First, in Columns (1) and (2), we define ten grid cells instead of five grid cells to examine the sensitivity of our estimates to the grouping of blocks. Second, in Columns (3) and (4), we define five grid cells according to the population density in 1936. This allows flexibility in defining the moment conditions without an arbitrary definition of the CBD.

Different Value of Discount Factor (ρ) Our estimates are robust for different values of the discount factor for individuals, ρ. As a baseline, we use the parameter equal to 0.66, which aligns with 8.5 percent of the annual discount rate. To see how our estimates are sensitive to the parameter, we use two different values for ρ. First, when we use ρ equal to 0.9, the estimated agglomeration parameter of productivity (α) is 0.107 (with standard error 0.0005) and that of amenities (β) is 0.207 (with standard error 0.0005). Second, we set ρ equal to 0.5. Then, the estimated agglomeration parameter of productivity is 0.100 (with a standard error of 0.0003), and that of amenities is 0.212 (with a standard error of 0.0003). These estimates are close to our baseline results.

Table F.2: GMM estimates for agglomeration parameters using different instruments

	(1) Productivity	(2) Amenities	(3) Productivity	(4) Amenities
Elasticity of the employment density (α)	0.104		0.096	
	(0.0002)		(0.0002)	
Elasticity of the population density (β)		0.218		0.205
		(0.0005)		(0.0015)
Sample of blocks	All blocks in the city		All blocks in the city	
Sample of periods	Every 5 years from 1955 to 1975		Every 5 years from 1955 to 1975	
Instruments	10 grids for CBD distance		5 grids for pop. density in 1936	

Note: This table reports the generalized method of moments (GMM) estimates for spillovers in productivity (α) and amenities (β). We conduct two robustness checks for our estimation. We use all 174 blocks in the city. In Columns (1) and (2), we define 10 grid cells based on the distance to the CBD and use them as instruments. In Columns (3) and (4), we define 5 grid cells based on the population density in 1936 for the instruments.

Spatial Spillovers in Productivity and Amenities Suppose that productivity and amenities have a spatial spread of spillovers. We consider functional forms similar to Ahlfeldt et al. (2015):

$$
\begin{aligned}
A_{it} &= a_{it}\left[\sum_{i'\in\mathcal{C}} e^{-\delta\tau_{ii'}}\left(\frac{L_{i't}}{S_{i'}}\right)\right]^{\alpha}, \\
B_{nt} &= b_{nt}\left[\sum_{n'\in\mathcal{C}} e^{-\delta\tau_{nn'}}\left(\frac{R_{n't}}{S_{n'}}\right)\right]^{\beta},
\end{aligned}
\tag{F.42}
$$

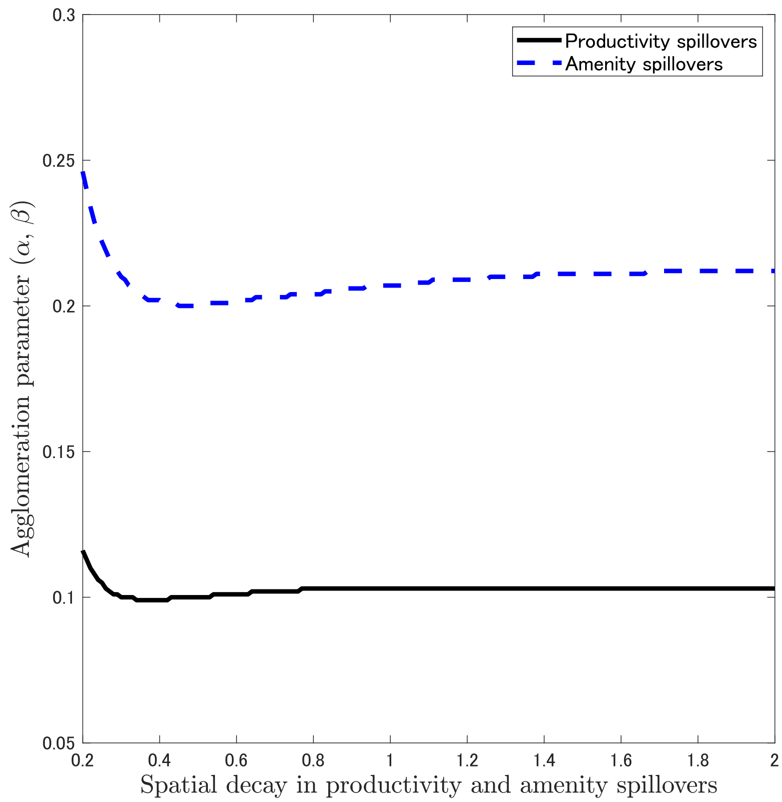
where δ governs the degree of spatial decay of spillovers; τ_{in} is travel time (walking time) between blocks; and (α, β) are the agglomeration parameters. In Figure F.5 we show the estimated values of (α, β) given different values of spatial decay (δ). The horizontal axis shows the values of the spatial decay, and the vertical axis shows the estimated values of the agglomeration parameters. The solid (dashed) line shows the estimated values of agglomeration forces in productivity (amenities), respectively.

Lagged Agglomeration Forces Following Allen and Donaldson (2022), we suppose that productivity and amenities depend on past employment and population density:

$$
\begin{aligned}
A_{it} &= a_{it}\left(\frac{L_{it}}{S_i}\right)^{\alpha_1}\left(\frac{L_{it-1}}{S_i}\right)^{\alpha_2}, \\
B_{nt} &= b_{nt}\left(\frac{R_{nt}}{S_n}\right)^{\beta_1}\left(\frac{R_{nt-1}}{S_n}\right)^{\beta_2},
\end{aligned}
\tag{F.43}
$$

where parameters (α_2, β_2) control the spillovers from the lagged density. Given the inverted option values in Step 2 in our calibration, we can compute the fundamental productivity and amenities by the relationship (F.43) in the same way as in Step 3. We use similar moment conditions to estimate parameters (α_1, α_2) for agglomeration in productivity and (β_1, β_2) for agglomeration in amenities jointly. In Table F.3 we report the results. As in our baseline results in Table 3 in the main text, Columns (1) and (2) use all blocks in the city, while Columns (3) and (4) use blocks within 3 kilometers of the CBD. Overall, we find relatively small lagged effects on productivity and amenities. The contemporaneous effects are close to the baseline results.

Figure F.5: Spatial spillovers and estimation of agglomeration forces



Note: The figure illustrates the estimated agglomeration parameters (α, β) given different values of spatial decay (δ) under the specification (F.42). The solid (dashed) line shows the estimated agglomeration force in productivity (amenities) given a particular value of spatial decay on the horizontal axis. We consider 181 different values of the spatial decay parameter from 0.2 to 2.0 with an interval of 0.01.

Table F.3: GMM estimates for agglomeration parameters with lagged effects

	(1) Productivity	(2) Amenities	(3) Productivity	(4) Amenities
Elasticity of the employment density (α_1)	0.154		0.165	
	(0.0013)		(0.0022)	
Elasticity of the past employment density (α_2)	-0.063		-0.067	
	(0.0016)		(0.0020)	
Elasticity of the population density (β_1)		0.212		0.221
		(0.0010)		(0.0007)
Elasticity of the past population density (β_2)		0.001		-0.001
		(0.0006)		(0.0013)
Sample of blocks	All blocks in the city		Blocks within 3 km to CBD	
Sample of periods	Every 5 years from 1955 to 1975		Every 5 years from 1955 to 1975	
Instruments	5 grids for CBD distance		5 grids for CBD distance	

Note: This table reports two-step GMM estimates using data for five periods (1955, 60, 65, 70 and 75). We include lagged spillover effects in productivity and amenities, controlled by two parameters (α_2, β_2). We use the same instruments as in the baseline. The standard errors are in parentheses. In Columns (1) and (2), we use all 174 blocks in the city and in Columns (3) and (4), we use the 158 blocks within 3 kilometers of the CBD.

G Appendix for Counterfactuals

G.1 *Simulating Population and Employment Density for 1945–1950*

Having estimated the model parameters (α, β) by exploiting the population and employment data from 1955 to 1975, we evaluate how well the model explains the population and employment changes in the recovery period 1945–1950. To this end, we compare the observed 1950 distributions of population and employment to the simulated ones when we abstract the structural errors.

Specifically, we compute the population and employment in 1950 using (22):

$$R_{n,50} = (1-\theta_{50})R_{n,45} + \sum_{i\in\mathcal{C}} \frac{K_{in,50}\left(\left(\Lambda_{n,50}\right)^{-\mu}\widetilde{\Xi_{n,50}}\right)^{\rho/\sigma}}{\sum_{n'\in\mathcal{C}} K_{in',50}\left(\left(\Lambda_{n',50}\right)^{-\mu}\widetilde{\Xi_{n',50}}\right)^{\rho/\sigma}}\left[L_{i,50}-(1-\theta_{50})L_{i,45}\right],$$

$$L_{i,50} = (1-\theta_{50})L_{i,45} + \sum_{n\in\mathcal{C}} \frac{K_{in,50}\left(\left(\Lambda_{i,50}\right)^{-\gamma^H/\gamma^L}\left(\widetilde{\Omega_{i,50}}\right)^{1/\gamma^L}\right)^{\rho/\sigma}}{\sum_{i'\in\mathcal{C}} K_{i'n,50}\left(\left(\Lambda_{i',50}\right)^{-\gamma^H/\gamma^L}\left(\widetilde{\Omega_{i',50}}\right)^{1/\gamma^L}\right)^{\rho/\sigma}}\left[R_{n,50}-(1-\theta_{50})R_{n,45}\right], \tag{G.1}$$

where we use the following option values:

$$\begin{aligned}\widetilde{\Xi_{n,50}} &\equiv \bar{b}_n^{\mathbb{F}}\left(\frac{R_{n,50}}{S_n}\right)^{\beta}\Xi_{n,55}^{\rho(1-\theta_{55})},\\ \widetilde{\Omega_{i,50}} &\equiv \bar{a}_i^{\mathbb{F}}\left(\frac{L_{i,50}}{S_i}\right)^{\alpha}\Omega_{i,55}^{\rho(1-\theta_{55})}\end{aligned} \tag{G.2}$$

These option values are constructed in the same way as equations (20) and (21), except that (a_{it}, b_{nt}) are replaced by the average amenities and productivity over 1955-75 ($\bar{a}_i^{\mathbb{F}}$, $\bar{b}_n^{\mathbb{F}}$), which are our estimates of the block-specific amenities and productivity in (F.29):

$$\bar{b}_n^{\mathbb{F}} = \frac{1}{5}\sum_{t=55}^{75} b_{nt}, \quad \bar{a}_i^{\mathbb{F}} = \frac{1}{5}\sum_{t=55}^{75} a_{it}$$

Since (a_{it}, b_{nt}) include structural errors in amenities (b_{it}^{Var}) and productivity (a_{it}^{Var}), using them exactly rationalizes the observed 1950 distributions of population and employment as the equilibrium outcome. Relative to this benchmark, we assess how well the endogenous forces of our model can explain the 1950 distribution by using ($\bar{a}_i^{\mathbb{F}}$, $\bar{b}_n^{\mathbb{F}}$), which omits the idiosyncratic structural errors.[35] Note that using $\Xi_{n,55}$ and $\Omega_{i,55}$ as option values for 1955 implies that when making migration decisions for 1950, people are assumed to correctly anticipate what happens from 1955 and onward.[36] This assumption is in line with the perfect foresight assumption in our calibration.

[35] The year-fixed amenities and productivity ($\bar{a}_t^*, \bar{b}_t^*$) in (F.29) are also excluded from (G.2), but this does not affect the model prediction because they appear both in the denominator and the numerator of (G.1).

[36] While using ($\widetilde{a}_i$, $\widetilde{b}_n$) instead of (a_{it}, b_{nt}) implies that the model no longer predicts the observed population and employment distributions ($R_{n,50}, L_{i,50}$), we still assume in this analysis that people expect the observed population and employment ($R_{n,50}, L_{i,50}$) would realize. This is because we aim to assess how much the endogenous forces of our model contribute to predicting the observed population and employment distribution in 1950 without structural errors, relative to our main perfect-foresight model that incorporates structural errors and predicts the observed 1950 population and employment distribution.

In addition, during the period after the war, 1945–50, available evidence suggests that most workers were mobile in their locations (see Appendix A). Therefore, we set $\theta_{50} = 0.9$. Finally, we use the observed floor space prices to compute the continuation values of floor space prices $\Lambda_{n,50}$ and we set the commuting cost $K_{in,50}$ in the same way as our calibration.[37] Finally, to focus on changes in the city structure, we assume that the outside utility is adjusted in every period such that the total population in the city equals the observed total population.

Since the structural errors in our model allow us to perfectly match the observed population and employment distributions, we can compare the importance of the endogenous forces of the model and structural errors in predicting the recovery by comparing the observed population and employment distributions and their predictions from equations (G.1) and (G.2). We discuss the results in Subsection 5.5 in the main text.

G.2 *No Agglomeration Forces*

In Subsection 6.1 we can similarly obtain the model prediction when there are no agglomeration forces by setting $\alpha = \beta = 0$ in equation (G.2). When there are no agglomeration forces, the option values attached to the residential and production location (F.4) and (F.5) are:

$$\Xi_{nt}^{\mathbb{N}} = b_{nt} \prod_{\tau=t+1}^{T} \left(b_{n\tau}\right)^{\prod_{s=t+1}^{\tau} \rho(1-\theta_s)}, \tag{G.3}$$

and

$$\Omega_{it}^{\mathbb{N}} = a_{it} \prod_{\tau=t+1}^{T} \left(a_{i\tau}\right)^{\prod_{s=t+1}^{\tau} \rho(1-\theta_s)}, \tag{G.4}$$

where superscript $\mathbb{N}$ stands for our construction of option values with "no agglomeration". While the model could still predict recovery if the recovery is driven by the fundamental location advantages of the destroyed city center, the model could not predict recovery if it is driven by agglomeration forces. In this sense, the comparison of model predictions with and without agglomeration forces indicates their importance in accounting for the recovery of central Hiroshima.

In this counterfactual exercise, we focus on evaluating the importance of agglomeration forces during 1945–50. Therefore, we solve the counterfactual population and employment distribution in 1950 given the future path of location fundamentals from 1955 to 1975. Given the option values of production and residential location ($\Xi_{nt}^{\mathbb{N}}, \Omega_{it}^{\mathbb{N}}$) for $t = 1950, 55, \cdots, 75$ defined by (G.3) and (G.4), we solve the population and employment distribution ($R_{nt}^{\mathbb{N}}, L_{it}^{\mathbb{N}}$) and floor space prices ($Q_{nt}^{\mathbb{N}}$) in 1950, 55, $\cdots$, 1975 in the counterfactual equilibrium when there are no agglomeration forces. We use the same continuation values for travel time, as given in (F.8), and we assume that the outside utility is adjusted in every period such that the total population in the city equals the observed total population. The following explains the steps to solve the counterfactual equilibrium.

[37] When we allow floor space prices in 1950 to be adjusted to clear the floor space market clearing condition, we obtain a similar result.

First, we guess the counterfactual floor space prices $\{Q_{nt}^{\mathbb{N}}\}_{t=50,\cdots,75}$. This allows us to compute the continuation values of the floor space prices $\{\Lambda_{nt}^{\mathbb{N}}\}_{t=50,\cdots,75}$ using (F.9). As in Subsection G.1 we set $\theta_{50} = 0.9$ since workers are mobile in their locations during 1945–50. Then, the system of equations (22) for 1950 becomes:

$$
\begin{aligned}
R_{n,50}^{\mathbb{N}} &= (1-\theta_{50})R_{n,45} + \sum_{i\in\mathcal{C}} \frac{K_{in,50}\left(\left(\Lambda_{n,50}^{\mathbb{N}}\right)^{-\mu}\Xi_{n,50}^{\mathbb{N}}\right)^{\rho/\sigma}}{\sum_{n'\in\mathcal{C}} K_{in',50}\left(\left(\Lambda_{n',50}^{\mathbb{N}}\right)^{-\mu}\Xi_{n',50}^{\mathbb{N}}\right)^{\rho/\sigma}}\left[L_{i,50}^{\mathbb{N}} - (1-\theta_{50})L_{i,45}\right], \\
L_{i,50}^{\mathbb{N}} &= (1-\theta_{50})L_{i,45} + \sum_{n\in\mathcal{C}} \frac{K_{in,50}\left(\left(\Lambda_{i,50}^{\mathbb{N}}\right)^{-\gamma^H/\gamma^L}\left(\Omega_{i,50}^{\mathbb{N}}\right)^{1/\gamma^L}\right)^{\rho/\sigma}}{\sum_{i'\in\mathcal{C}} K_{i'n,50}\left(\left(\Lambda_{i',50}^{\mathbb{N}}\right)^{-\gamma^H/\gamma^L}\left(\Omega_{i',50}^{\mathbb{N}}\right)^{1/\gamma^L}\right)^{\rho/\sigma}}\left[R_{n,50}^{\mathbb{N}} - (1-\theta_{50})R_{n,45}\right],
\end{aligned}
\tag{G.5}
$$

Solving the system of equations obtains the unique vectors of population $R_{n,50}^{\mathbb{N}}$ and employment $L_{i,50}^{\mathbb{N}}$.

Before moving to the floor space market clearing condition, we estimate the commuting pattern in 1945 that is required to compute the average labor income of workers in the model. Since we cannot observe the commuting pattern immediately after the bombing, we exploit the gravity equation to infer the commuting pattern in 1945. In particular, we solve the system of equations:

$$
L_{i,45} = \sum_{n\in\mathcal{C}} \frac{K_{in,45}\left(\mathcal{E}_{i,45}\right)^{\rho/\sigma}}{\sum_{i'\in\mathcal{C}} K_{i'n,45}\left(\mathcal{E}_{i',45}\right)^{\rho/\sigma}} R_{n,45}, \tag{G.6}
$$

for $\{\mathcal{E}_{i,45}\}$ given residential population $\{R_{n,45}\}$, workplace employment $\{L_{i,45}\}$ and commuting costs $\{K_{in,45}\}$. Given the parameters, we obtain a unique vector of the workplace attractiveness $\{\mathcal{E}_{i,45}\}$ that rationalizes the population distribution in the city. Using the inverted vector of workplace attractiveness, we infer commuting from n to i in 1945 ($L_{in,45}$) by

$$
L_{in,45} = \frac{K_{in,45}\left(\mathcal{E}_{i,45}\right)^{\rho/\sigma}}{\sum_{i'\in\mathcal{C}} K_{i'n,45}\left(\mathcal{E}_{i',45}\right)^{\rho/\sigma}} R_{n,45} \tag{G.7}
$$

Consistent with available anecdotal evidence, the obtained commuting pattern in 1945 shows that a large share of people working in the city center commute from the outskirts of the city.[38]

Now, we compute the counterfactual wage vector using the zero profit condition (D.6):

$$
w_{i,50}^{\mathbb{N}} = \left[\frac{a_{i,50}}{(Q_{i,50}^{\mathbb{N}})^{\gamma^H}}\right]^{1/\gamma^L} \tag{G.8}
$$

and the number of commuters between blocks in the city in the counterfactual:

$$
L_{in,50}^{\mathbb{N}} = (1-\theta_{50})L_{in,45} + \lambda_{i|n,50}^{L,\mathbb{N}}\left[R_{n,50}^{\mathbb{N}} - (1-\theta_{50})R_{n,45}\right], \tag{G.9}
$$

[38] For example, Hiroshima City Government (1983) states that right after the bombing, "there was no house in the city center, and people commuted from surrounding areas."

where $L_{in,45}$ is given by (G.7) and

$$\lambda^{L,\mathbb{N}}_{i|n,50} = \frac{K_{in,50}\left(\left(\Lambda^{\mathbb{N}}_{i,50}\right)^{-\gamma^H/\gamma^L}\left(\Omega^{\mathbb{N}}_{i,50}\right)^{1/\gamma^L}\right)^{\rho/\sigma}}{\sum_{i'\in\mathcal{C}} K_{i'n,50}\left(\left(\Lambda^{\mathbb{N}}_{i',50}\right)^{-\gamma^H/\gamma^L}\left(\Omega^{\mathbb{N}}_{i',50}\right)^{1/\gamma^L}\right)^{\rho/\sigma}} \tag{G.10}$$

refers to the conditional probability that workers work in location i given residential place n. Using the commuting patterns (G.20) we compute the counterfactual average income in residential places:

$$v^{\mathbb{N}}_{n,50} = \sum_{i\in\mathcal{C}} \frac{L^{\mathbb{N}}_{in,50}}{R^{\mathbb{N}}_{n,50}} w^{\mathbb{N}}_{i,50} \tag{G.11}$$

Turning to the floor spaces, equation (D.7) for developers' problem implies that the floor spaces in 1950 equals:

$$H^{\mathbb{N}}_{n,50} = (1-\psi)H_{n,45} + \bar{h}_{50}\left(Q^{\mathbb{N}}_{n,50}\right)^{\eta} S_n \tag{G.12}$$

On the right-hand side, we use the stock of floor spaces in 1945 that survived the bombing in the first term, and the second term is the supply of floor spaces during 1945-50 in the counterfactual. Then, we use the floor space market clearing condition (D.8):

$$H^{\mathbb{N}}_{n,50} Q^{\mathbb{N}}_{n,50} = \mu v^{\mathbb{N}}_{n,50} R^{\mathbb{N}}_{n,50} + \frac{\gamma^H}{\gamma^L} w^{\mathbb{N}}_{n,50} L^{\mathbb{N}}_{n,50} \tag{G.13}$$

On the left-hand side, we use (G.12). This leads to the floor space prices in the counterfactual equilibrium, and we let $\widetilde{Q}^{\mathbb{N}}_{n,50}$ refer to the updated floor prices for 1950.

Second, we solve the model for the counterfactual floor space prices from $t = 1955, 60, \cdots, 75$. From the above step, we obtain the floor spaces (G.12) and commuters (G.20) in 1950. For period t, we compute the unique vectors of population $R^{\mathbb{N}}_{nt}$ and employment $L^{\mathbb{N}}_{it}$ that simultaneously solve:

$$\begin{aligned} R^{\mathbb{N}}_{nt} &= (1-\theta_t)R^{\mathbb{N}}_{nt-1} + \sum_{i\in\mathcal{C}} \frac{K_{int}\left(\left(\Lambda^{\mathbb{N}}_{nt}\right)^{-\mu}\Xi^{\mathbb{N}}_{nt}\right)^{\rho/\sigma}}{\sum_{n'\in\mathcal{C}} K_{in't}\left(\left(\Lambda^{\mathbb{N}}_{n't}\right)^{-\mu}\Xi^{\mathbb{N}}_{n't}\right)^{\rho/\sigma}}\left[L^{\mathbb{N}}_{it} - (1-\theta_t)L^{\mathbb{N}}_{it-1}\right], \\ L^{\mathbb{N}}_{it} &= (1-\theta_t)L^{\mathbb{N}}_{it-1} + \sum_{n\in\mathcal{C}} \frac{K_{int}\left(\left(\Lambda^{\mathbb{N}}_{it}\right)^{-\gamma^H/\gamma^L}\left(\Omega^{\mathbb{N}}_{it}\right)^{1/\gamma^L}\right)^{\rho/\sigma}}{\sum_{i'\in\mathcal{C}} K_{i'nt}\left(\left(\Lambda^{\mathbb{N}}_{i't}\right)^{-\gamma^H/\gamma^L}\left(\Omega^{\mathbb{N}}_{i't}\right)^{1/\gamma^L}\right)^{\rho/\sigma}}\left[R^{\mathbb{N}}_{nt} - (1-\theta_t)R^{\mathbb{N}}_{nt-1}\right], \end{aligned} \tag{G.14}$$

Given the pre-period population $R^{\mathbb{N}}_{nt-1}$ and employment $L^{\mathbb{N}}_{it-1}$ and continuation values of the floor space prices $\Lambda^{\mathbb{N}}_{nt}$, we obtain $R^{\mathbb{N}}_{nt}$ and $L^{\mathbb{N}}_{it}$ for 1955, 60, $\cdots$, 75. In the computation, we use the same set of parameters θ_t, ρ, and σ used in the calibration. We compute $\{w^{\mathbb{N}}_{it}\}$ for 1955, 60, $\cdots$, 75, as in (G.8). The number of commuters for those periods is given by

$$L^{\mathbb{N}}_{int} = (1-\theta_t)L^{\mathbb{N}}_{int-1} + \lambda^{L,\mathbb{N}}_{i|nt}\left[R^{\mathbb{N}}_{nt} - (1-\theta_t)R^{\mathbb{N}}_{nt-1}\right], \tag{G.15}$$

where the first term on the right-hand side is the number of commuters who continue to stay in the same residential and workplace blocks as they do not have the opportunity to move. In the second term $R^{\mathbb{N}}_{nt} -$

$(1-\theta_t)R^{\mathbb{N}}_{nt-1}$ is the number of workers who have the opportunity to change location (including inflow of new workers to the city) and settle in block n, and $\lambda^{L,\mathbb{N}}_{i|nt}$ is the conditional probability that those workers commute to the workplace i. Given the pre-period commuters and population changes, (G.15) leads to the counterfactual commuters in $t = 1955, 60, \cdots, 75$. Once we have the commuting patterns, we compute the average income (D.9) in the counterfactual:

$$v^{\mathbb{N}}_{nt} = \sum_{i\in\mathcal{C}} \frac{L^{\mathbb{N}}_{int}}{\sum_{i'\in\mathcal{C}} L^{\mathbb{N}}_{i'nt}} w^{\mathbb{N}}_{it} \tag{G.16}$$

The floor spaces $H^{\mathbb{N}}_{nt}$ for $t = 1955, 60, \cdots, 75$ are computed by using their dynamics (D.7). Lastly, the floor space prices are updated by solving the floor space market clearing condition:

$$\widetilde{Q}^{\mathbb{N}}_{nt} H^{\mathbb{N}}_{nt} = \mu v^{\mathbb{N}}_{nt} R^{\mathbb{N}}_{nt} + \frac{\gamma^H}{\gamma^L} w^{\mathbb{N}}_{nt} L^{\mathbb{N}}_{nt}, \tag{G.17}$$

where we substitute wages $(w^{\mathbb{N}}_{nt})$, average income (G.16), population $(R^{\mathbb{N}}_{nt})$ and employment $(L^{\mathbb{N}}_{nt})$ into the right-hand side. We let $\widetilde{Q}^{\mathbb{N}}_{nt}$ refer to the updated floor prices for 1955-75. We continue the above process until the residential population, workplace population and floor space prices converge:

$$\left|\widetilde{Q}^{\mathbb{N}}_{nt} - Q^{\mathbb{N}}_{nt}\right| < \zeta,$$
$$\left|\widetilde{R}^{\mathbb{N}}_{nt} - R^{\mathbb{N}}_{nt}\right| < \zeta,$$
$$\left|\widetilde{L}^{\mathbb{N}}_{nt} - L^{\mathbb{N}}_{nt}\right| < \zeta$$

where $\zeta \approx 0$ is a small number.

G.3 *Alternative Equilibria*

We let $\mathcal{R}^* = \{R^*_{nt}\}_{t=50,\cdots,75}$, $\mathcal{L}^* = \{L^*_{it}\}_{t=50,\cdots,75}$ and $\mathbb{Q}^* = \{Q^*_{nt}\}_{t=50,\cdots,75}$ refer to, respectively, the population distribution, employment distribution and floor space prices in a different equilibrium from 1950 to 1975. The star, as a superscript of the variables, represents the alternative equilibrium. We first guess these values. Specifically, we use the observed 1945 population and employment distributions as our initial guess.[39] This allows us to compute the option value of amenities $\{\Xi^*_{nt}\}_{t=50,\cdots,75}$ and productivity $\{\Omega^*_{it}\}_{t=50,\cdots,75}$ attached to each block along with the continuation values of floor space prices $\{\Lambda^*_{nt}\}_{t=50,\cdots,75}$ by exploiting (F.4), (F.5) and (F.9).

We first compute the equilibrium in 1950 given our guesses. As in Subsection G.1 we set $\theta_{50} = 0.9$ since workers are mobile in their locations in 1945–50. Therefore, we solve the following system of equations for population and employment in 1950:

$$R_{n,50} = (1-\theta_{50})R_{n,45} + \sum_{i\in\mathcal{C}} \frac{K_{in,50}\left(\left(\Lambda^*_{n,50}\right)^{-\mu}\Xi^*_{n,50}\right)^{\rho/\sigma}}{\sum_{n'} K_{in',50}\left(\left(\Lambda^*_{n',50}\right)^{-\mu}\Xi^*_{n',50}\right)^{\rho/\sigma}} \left[L_{i,50} - (1-\theta_{50})L_{i,45}\right] \tag{G.18}$$

[39]More precisely, we normalize the 1945 population and employment distribution to form the guessed population and employment distribution in year $t \geq 1950$.

and

$$L_{i,50} = (1-\theta_{50})L_{i,45} + \sum_{n\in\mathcal{C}} \frac{K_{in,50}\left(\left(\Lambda^*_{i,50}\right)^{-\gamma^H/\gamma^L}\left(\Omega^*_{i,50}\right)^{1/\gamma^L}\right)^{\rho/\sigma}}{\sum_{i'\in\mathcal{C}} K_{i'n,50}\left(\left(\Lambda^*_{i',50}\right)^{-\gamma^H/\gamma^L}\left(\Omega^*_{i',50}\right)^{1/\gamma^L}\right)^{\rho/\sigma}}\left[R_{n,50} - (1-\theta_{50})R_{n,45}\right] \tag{G.19}$$

Solving this system of equations yields the vector of population $\widetilde{R}^*_{n,50}$ and employment $\widetilde{L}^*_{i,50}$. The counterfactual commuting pattern is:

$$L^*_{in,50} = (1-\theta_{50})L_{in,45} + \lambda^{L,*}_{i|n,50}\left[R^{\mathbb{N}}_{n,50} - (1-\theta_{50})R_{n,45}\right], \tag{G.20}$$

where the conditional probability that workers work in location i given the residential place n in the counterfactual equilibria is:

$$\lambda^{L,*}_{i|n,50} = \frac{K_{in,50}\left(\left(\Lambda^*_{i,50}\right)^{-\gamma^H/\gamma^L}\left(\Omega^*_{i,50}\right)^{1/\gamma^L}\right)^{\rho/\sigma}}{\sum_{i'\in\mathcal{C}} K_{i'n,50}\left(\left(\Lambda^*_{i',50}\right)^{-\gamma^H/\gamma^L}\left(\Omega^*_{i',50}\right)^{1/\gamma^L}\right)^{\rho/\sigma}} \tag{G.21}$$

The zero profit condition implies that the wage vector in the different equilibrium in 1950 is:

$$\begin{aligned} w^*_{i,50} &= \left[\frac{A_{i,50}}{\left(Q^*_{i,50}\right)^{\gamma^H}}\right]^{1/\gamma^L} \\ &= \left(a_{i,50}\right)^{1/\gamma^L}\left[\frac{\left(L^*_{i,50}/S_i\right)^{\alpha}}{\left(Q^*_{i,50}\right)^{\gamma^H}}\right]^{1/\gamma^L} \end{aligned} \tag{G.22}$$

Using this, we can compute the counterfactual average income in residential places:

$$v^*_{n,50} = \sum_{i\in\mathcal{C}} \frac{L^*_{in,50}}{\sum_{i'\in\mathcal{C}} L^*_{i'n,50}} w^*_{i,50}, \tag{G.23}$$

The floor spaces in the counterfactual equilibrium in 1950 are given by:

$$H^*_{n,50} = (1-\psi)H_{n,45} + \bar{h}_{50}\left(Q^*_{n,50}\right)^{\eta} S_n, \tag{G.24}$$

where we plug the data into the stock of floor spaces in 1945 that survived the bombing. The floor space market clearing condition (D.8) becomes:

$$H^*_{n,50}Q^*_{n,50} = \mu v^*_{n,50}R^*_{n,50} + \frac{\gamma^H}{\gamma^L} w^*_{n,50}L^*_{n,50} \tag{G.25}$$

Substituting (G.24) into the left-hand side of (G.25), we obtain the floor space prices in the counterfactual equilibrium, and we let $\widetilde{Q}^*_{n,50}$ refer to the updated counterfactual floor space prices for 1950.

Next, we compute the population $\{R^*_{nt}\}$ and employment $\{L^*_{it}\}$ for $t = 1955, 60, \cdots, 75$ by solving the following system of equations:

$$
\begin{aligned}
R^*_{nt} &= (1-\theta_t)R^*_{nt-1} + \sum_{i\in\mathcal{C}} \frac{K_{int}\left(\left(\Lambda^*_{nt}\right)^{-\mu}\Xi^*_{nt}\right)^{\rho/\sigma}}{\sum_{n'\in\mathcal{C}} K_{in't}\left(\left(\Lambda^*_{n't}\right)^{-\mu}\Xi^*_{n't}\right)^{\rho/\sigma}}\left[L^*_{it} - (1-\theta_t)L^*_{it-1}\right], \\
L^*_{it} &= (1-\theta_t)L^*_{it-1} + \sum_{n\in\mathcal{C}} \frac{K_{int}\left(\left(\Lambda^*_{it}\right)^{-\gamma^H/\gamma^L}\left(\Omega^*_{it}\right)^{1/\gamma^L}\right)^{\rho/\sigma}}{\sum_{i'\in\mathcal{C}} K_{i'nt}\left(\left(\Lambda^*_{i't}\right)^{-\gamma^H/\gamma^L}\left(\Omega^*_{i't}\right)^{1/\gamma^L}\right)^{\rho/\sigma}}\left[R^*_{nt} - (1-\theta_t)R^*_{nt-1}\right],
\end{aligned}
\tag{G.26}
$$

given the pre-period population R^*_{nt-1} and employment L^*_{it-1} and continuation values of the floor space prices Λ^*_{nt}. In the computation, we use the same set of parameters θ_t, ρ, and σ used in the calibration. This step provides the updated population and employment distribution $\{\widetilde{R}^*_{nt}\}$ and $\{\widetilde{L}^*_{it}\}$.

The zero profit condition pins down the counterfactual wages $\{w^*_{it}\}$ for 1955, 60, $\cdots$, 75 as in equation (G.22); and the number of commuters for those periods is computed by:

$$
L^*_{int} = (1-\theta_t)L^*_{int-1} + \lambda^{L,*}_{i|nt}\left[R^*_{nt} - (1-\theta_t)R^*_{nt-1}\right], \tag{G.27}
$$

where the conditional probabilities $\lambda^{L,*}_{i|nt}$ are:

$$
\lambda^{L,*}_{i|nt} = \frac{K_{int}\left(\left(\Lambda^*_{it}\right)^{-\gamma^H/\gamma^L}\left(\Omega^*_{it}\right)^{1/\gamma^L}\right)^{\rho/\sigma}}{\sum_{i'\in\mathcal{C}} K_{i'nt}\left(\left(\Lambda^*_{i't}\right)^{-\gamma^H/\gamma^L}\left(\Omega^*_{i't}\right)^{1/\gamma^L}\right)^{\rho/\sigma}} \tag{G.28}
$$

Given the number of commuters in 1950 and population changes, (G.27) leads to the counterfactual commuters in $t = 1955, 60, \cdots, 75$. Then, we compute the average income in residential places in the counterfactual equilibria:

$$
v^*_{nt} = \sum_{i\in\mathcal{C}} \frac{L^*_{int}}{\sum_{i'\in\mathcal{C}} L^*_{i'nt}} w^*_{it}, \tag{G.29}
$$

where the counterfactual wages are

$$
w^*_{it} = \left(a_{it}\right)^{1/\gamma^L}\left[\frac{\left(L^*_{it}/S_i\right)^{\alpha}}{\left(Q^*_{it}\right)^{\gamma^H}}\right]^{1/\gamma^L} \tag{G.30}
$$

The counterfactual floor spaces $\{H^*_{nt}\}_{t=55,\cdots,75}$ are computed by using the following developer problem:

$$
H^*_{nt} = (1-\psi)H^*_{nt-1} + \bar{h}_t\left(Q^*_{nt}\right)^{\eta} S_n, \tag{G.31}
$$

where we substitute the initial stock of floor spaces into the first term on the right-hand side.

Lastly, the floor space prices are updated by solving the floor space market clearing condition in each period:

$$
\widetilde{Q}^*_{nt}H^*_{nt} = \mu v^*_{nt}R^*_{nt} + \frac{\gamma^H}{\gamma^L} w^*_{nt}L^*_{nt}, \tag{G.32}
$$

where we plug the average income in residential places (G.29), population, wages (G.30) and employment into the right-hand side. This yields the updated floor space prices for 1955-75, which we denote $\{\widetilde{Q}^*_{nt}\}$. We continue the above process until the residential population, workplace population and floor space prices converge:

$$\left|\widetilde{Q}^*_{nt} - Q^*_{nt}\right| < \zeta,$$
$$\left|\widetilde{R}^*_{nt} - R^*_{nt}\right| < \zeta,$$
$$\left|\widetilde{L}^*_{nt} - L^*_{nt}\right| < \zeta$$

where $\zeta \approx 0$ is a small number.

G.4 *Welfare Comparison*

The utility outside the city $\{u_{ot}\}$ is adjusted to keep the total city population consistent with the realization, so as $\{V_{ot}\}$. Our counterfactual exercise is supposed to fix the total city population in order to focus on the internal city structure. Therefore, given the utility outside of the city, we focus on workers in the city, $\{V_{int}\}$. Using equations (9) and (11) together, the value function is computed by

$$V_{int} = \sum_{\tau=t}^{T} \rho^{\tau-t} \ln u_{in\tau} - \sigma \sum_{\tau=t}^{T-1} \rho^{\tau-t} \theta_{\tau+1} \ln \lambda_{in\tau+1} \tag{G.33}$$

Then, we compute the expected value of living and working in the city in period t in the baseline and counterfactual economy (denoted by a prime) by:

$$\mathcal{V}_t \equiv \sigma \ln \left[\sum_{i \in \mathcal{C}} \sum_{n \in \mathcal{C}} \frac{L_{int}}{L_t} \exp\left(V_{int}\right)^{\rho/\sigma} \right], \tag{G.34}$$

and

$$\mathcal{V}'_t \equiv \sigma \ln \left[\sum_{i \in \mathcal{C}} \sum_{n \in \mathcal{C}} \frac{L'_{int}}{L_t} \exp\left(V'_{int}\right)^{\rho/\sigma} \right], \tag{G.35}$$

where the weights depend on the population shares of the residential (n) and workplace (i) pairs.

We compute the welfare for the observed economy in (G.34) and the counterfactual equilibrium in (G.35) for the equilibrium found in Section 6.2 (also see Appendix G.3). We find that the welfare in the counterfactual equilibrium is higher than that in the observed pattern. We also compute the welfare of workers in the CBD area. Specifically, we compute (G.34) and (G.35) using commuters between blocks within 2 kilometers from the ex-ante CBD. We find that the welfare of workers in the city center is lower in the counterfactual equilibrium than in the observed pattern.

Overall, the quantification suggests that the welfare of workers in the central area of the city is lower in the counterfactual equilibrium since employment and population density there becomes low, while the city-wide welfare is high in the counterfactual equilibrium.

G.5 *Potential CBDs for Multiple Equilibria*

In the main text, we present one counterfactual dynamic equilibrium in Subsection 6.2 and we show that a block far from the city center (*Niho machi* in Figure G.1a) exhibits the highest density for both employment and population in the counterfactual equilibrium, so the block is regarded as a counterfactual CBD. However, we may also have a more counterfactual dynamic equilibria in which different blocks in the city can show the highest population and employment density. To understand the possibility of other blocks being the CBD, we run the following quantitative exercise.

First, we identify nine blocks that are located more than 4 kilometers away from the pre-war city center. These blocks include: *Niho machi*; *Minami-Kannon machi*; *Furuta machi*; *Koi machi*; *Kôgo mchi*; *Eba machi*; *Kusatsu-Honn machi*; *Kusatsu-Kita machi*; and *Kusatsu-Hama machi*. Second, we randomly construct 500 different population and employment distributions of 1945, where we keep the population and employment of observation for all blocks except for the nine blocks above and shuffle the population and employment between blocks for those in the nine blocks.[40] After scaling up 500 different hypothetical population and employment distributions using the total population after 1950, we use the population and employment distributions from 1950 to 1975 as an initial guess to solve for the dynamic equilibrium.

Among 500 simulations, we can identify the locations that show the highest population or employment density multiple times. In particular, we list the locations showing the highest population and employment density more than 10 times with the feature and map of the locations:

1. *Ujina machi* (in Figure G.1b) – the block has a large area size, Hiroshima port, multiple tram lines to the city center and *Ujina*-line (Japanese National Railways) to Hiroshima station before 1972 and was less damaged by the bombing.

2. *Akebono machi* and *Minami-Kaniya machi* (in Figure G.1c) – these blocks are located close to the Hiroshima station and are less damaged by the bombing. Akebono-machi has the highest population density and Minami-Kaniya machi has the highest employment density.

3. *Koi machi* (in Figure G.1d) – the block has *Koi* station for both the tram and the National Railway and is the main gateway to the western part of the city.

G.6 *Additional Analyses through Counterfactuals*

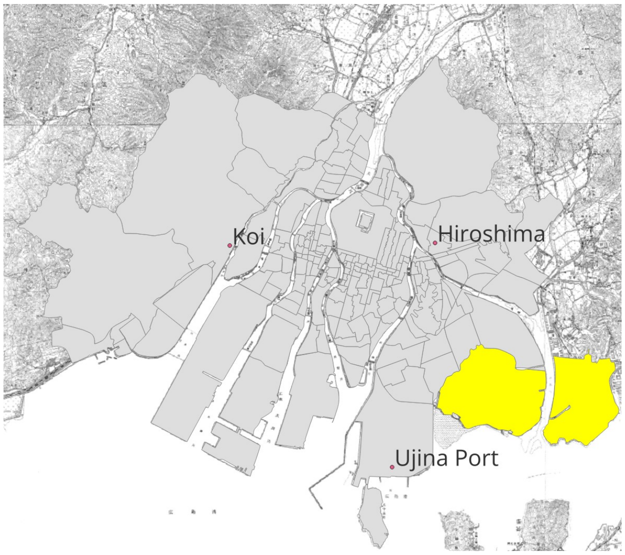
In this section, we undertake additional counterfactual analyses to see other potential explanations for the recovery of the city.

Locational Attachment of Landowners As we discussed in Section 7, surviving landowners may have returned home after the war due to their locational attachment. This may result in more population in the city center, as in the pre-war population distribution, even without strong agglomeration forces. This mechanism based on the landowners' locational attachment is plausible if workers who own the land in

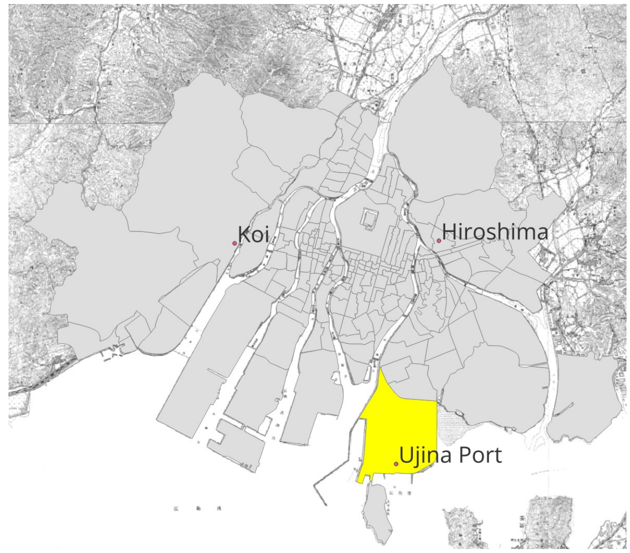
[40] Technically, we have 362,880 (=9!) patterns for the shuffle of population and employment among the nine blocks.

Figure G.1: City center in counterfactual equilibria

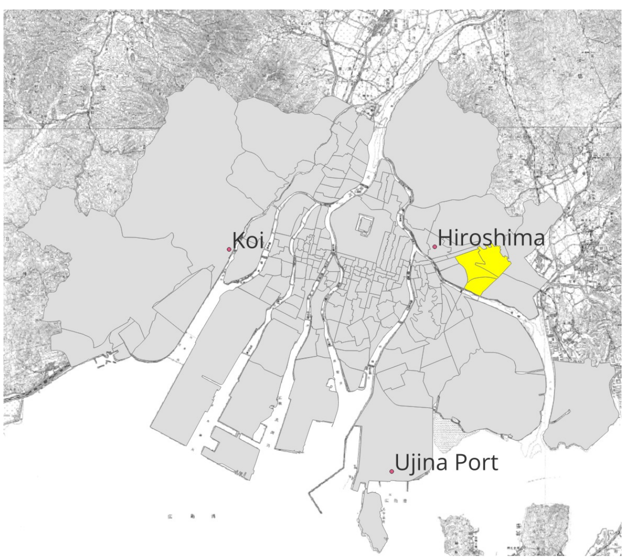
(a) Pattern 1 (*Niho machi*)



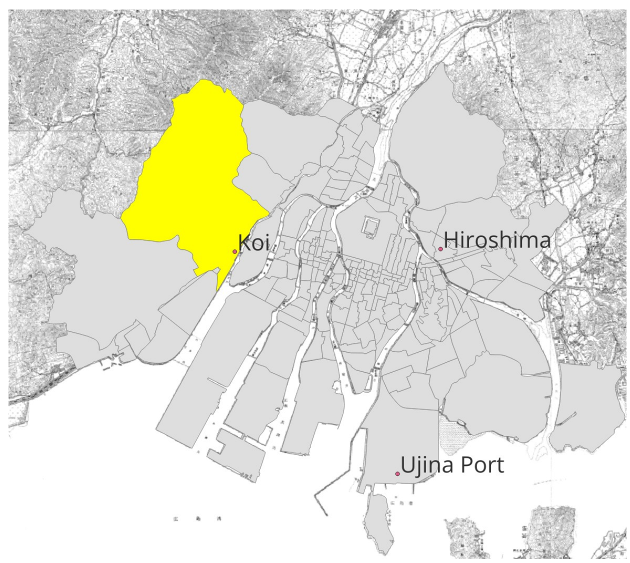
(b) Pattern 2 (*Ujina machi*)



(c) Pattern 3 (*Akebono machi* and *Kaniya machi*)



(d) Pattern 4 (*Koi machi*)



Note: We color city blocks in yellow that have the highest employment or population density in the counterfactual equilibria identified in the procedure outlined in Appendix G.5. In panels G.1a, G.1b and G.1d, the city block with the highest employment and population density coincides. In panel G.1c *Akebono machi* (the upper-right yellow block) has the highest population density and *Minami-Kaniya machi* (the lower yellow block) has the highest employment density. For visualization, we also mark in yellow *Higashi-kaniya machi* that are sandwiched by these two blocks. We also plot the location of Hiroshima Station, Koi Station, and Ujina Port, which are all important hubs of transportation in Hiroshima.

the city reallocated to a different place before the bombing but returned to the same place after the war due to their preferences or property rights.

To assess this potential explanation of the recovery, we consider a counterfactual in which we assume that (i) the number of landowners in 1936 (pre-war) were 20 percent of the city population; (ii) landowners were distributed within the city proportionally to the population distribution in 1936; and (iii) landowners who survived the atomic bombing returned to their homes and worked in their home location in 1950. We set 20 percent for the landownership rate for robustness, but it may overstate the importance of landowners, given that Kato (1988) suggests a 10 percent landownership rate in this period. We additionally use the survival rate of people from *Hiroshima shisei youran* published in 1947, which documents the survival rate of people in April 1946 according to their distance from the center. Using the numbers, we calculate the number of landowners who survived the bombing.

Our counterfactual exercise follows the same steps in the Appendix G.2. We suppose that there are no agglomeration forces ($\alpha = 0$ and $\beta = 0$). We let $\{\bar{R}_n^{\mathbb{O}}\}$ refer to the number of landowners in location n that is equal to the 20 percent of residential population in 1936 for the location. As we assume (iii) above, these landowners lived and worked in their home location in 1950. With the fixed number of landowners who return to the location, the system of equations (G.5) is transformed to

$$\begin{aligned} R_{n,50}^{\mathbb{N}} &= \bar{R}_n^{\mathbb{O}} + (1-\theta_{50})R_{n,45} \\ &+ \sum_{i \in \mathcal{C}} \frac{K_{in,50}\left(\left(\Lambda_{n,50}^{\mathbb{N}}\right)^{-\mu}\Xi_{n,50}^{\mathbb{N}}\right)^{\rho/\sigma}}{\sum_{n' \in \mathcal{C}} K_{in',50}\left(\left(\Lambda_{n',50}^{\mathbb{N}}\right)^{-\mu}\Xi_{n',50}^{\mathbb{N}}\right)^{\rho/\sigma}}\left[L_{i,50}^{\mathbb{N}} - (1-\theta_{50})L_{i,45} - \bar{R}_i^{\mathbb{O}}\right], \end{aligned} \tag{G.36}$$

where the first term on the right-hand side is the return of landowners in residential place n; the second term is the residential population who lived in the same location in 1945 and did not move; and the last term is the workers who live in location n conditional on that they had a chance to change the location, $L_{i,50}^{\mathbb{N}} - (1-\theta_{50})L_{i,45}$, and they were not landowners in location, $\bar{R}_i^{\mathbb{O}}$, who did not commute. Similarly, we have:

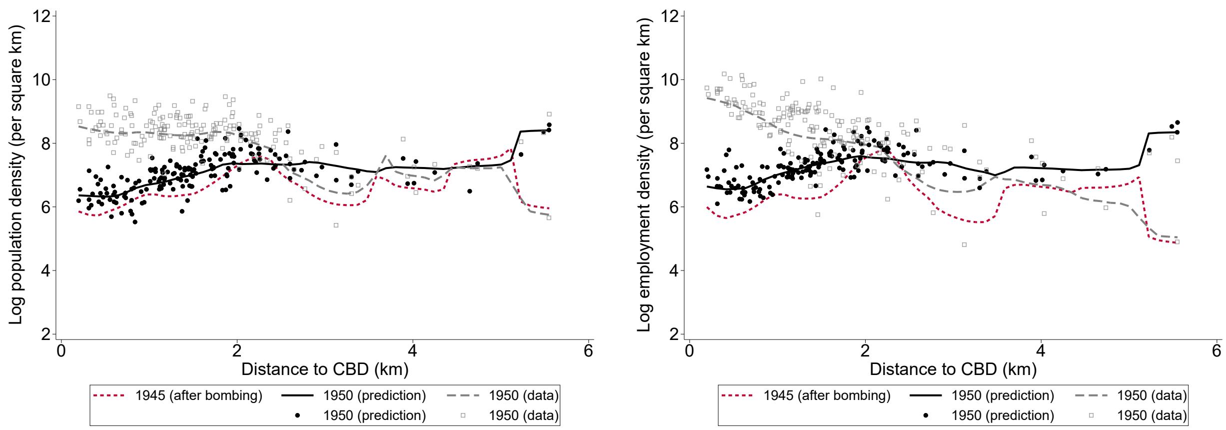
$$\begin{aligned} L_{i,50}^{\mathbb{N}} &= \bar{R}_i^{\mathbb{O}} + (1-\theta_{50})L_{i,45} \\ &+ \sum_{n \in \mathcal{C}} \frac{K_{in,50}\left(\left(\Lambda_{i,50}^{\mathbb{N}}\right)^{-\gamma^H/\gamma^L}\left(\Omega_{i,50}^{\mathbb{N}}\right)^{1/\gamma^L}\right)^{\rho/\sigma}}{\sum_{i' \in \mathcal{C}} K_{i'n,50}\left(\left(\Lambda_{i',50}^{\mathbb{N}}\right)^{-\gamma^H/\gamma^L}\left(\Omega_{i',50}^{\mathbb{N}}\right)^{1/\gamma^L}\right)^{\rho/\sigma}}\left[R_{n,50}^{\mathbb{N}} - (1-\theta_{50})R_{n,45} - \bar{R}_n^{\mathbb{O}}\right] \end{aligned} \tag{G.37}$$

We solve the equations (G.36) and (G.37) together and follow the same steps as in the Appendix G.2.

We now turn to the result. Figure G.2 shows results for the population and employment distributions in 1950 for this counterfactual analysis. Compared to Figure 7 in the main text, we can see that both population and employment density close to the city center are somewhat higher in this counterfactual, which is expected because a fixed amount of landowners return to their place. However, the levels are significantly lower than the observed population and employment density. Overall, it seems difficult to explain the recovery of the central area solely based on land ownership and its direct effects. We have discussions based on these results in Section 7 of the paper.

Figure G.2: Population and employment distributions when landowners return

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



Note: Each figure plots the log population density (Panel a) and employment density (Panel b) with local polynomial regressions of each on the distance from the CBD. We run three separate regressions: one for the observed 1945 population and employment densities (small dashed line), one for the observed 1950 population and employment densities (long dashed line), and one for the counterfactual (solid line). Each dot represents a block, with different colors for the predicted density and the observed density.

Myopic Pessimistic Expectation When individuals are myopic in their location choices and pessimistic about recovery, the destroyed area of the city is less likely to recover since they anticipate that the current population and employment distribution will persist in the next period. To evaluate the quantitative gap between the equilibrium pattern under such myopic behavior and the observed pattern, we solve the model under the assumptions that (i) individuals decide their residential and workplace locations in 1950 based on the *belief* that the productivity and amenities in 1950 are determined by the population and employment distribution in 1945; and (ii) individuals are myopic and decide their locations in 1950, taking into account only the next period and not future periods from 1955.

We focus on the population and employment distribution in 1950 under the myopic expectation with no recovery, as in Subsection 5.5 (and Appendix G.1). Using the distribution of economic activities in 1945 and the calibrated fundamentals, we compute the option values as follows:

$$\begin{aligned} \Xi^P_{n,50} &= b_{n,50}\left(\frac{R_{n,45}}{S_n}\right)^{\beta}, \\ \Omega^P_{i,50} &= a_{i,50}\left(\frac{L_{i,45}}{S_i}\right)^{\alpha}, \end{aligned} \tag{G.38}$$

where the superscript P stands for the option values with ”pessimistic” expectation. We first guess the population $(R^P_{n,50})$, employment $(L^P_{i,50})$ and floor space prices $(Q^P_{n,50})$ in 1950. The system of equations

(22) for 1950 are:

$$R^P_{n,50} = (1-\theta_{50})R_{n,45} + \sum_{i\in\mathcal{C}} \frac{K_{in,50}\left(\left(Q^P_{n,50}\right)^{-\mu}\Xi^P_{n,50}\right)^{\rho/\sigma}}{\sum_{n'\in\mathcal{C}} K_{in',50}\left(\left(Q^P_{n',50}\right)^{-\mu}\Xi^P_{n',50}\right)^{\rho/\sigma}}\left[L^P_{i,50} - (1-\theta_{50})L_{i,45}\right],$$

$$L^P_{i,50} = (1-\theta_{50})L_{i,45} + \sum_{n\in\mathcal{C}} \frac{K_{in,50}\left(\left(Q^P_{i,50}\right)^{-\gamma^H/\gamma^L}\left(\Omega^P_{i,50}\right)^{1/\gamma^L}\right)^{\rho/\sigma}}{\sum_{i'\in\mathcal{C}} K_{i'n,50}\left(\left(Q^P_{i',50}\right)^{-\gamma^H/\gamma^L}\left(\Omega^P_{i',50}\right)^{1/\gamma^L}\right)^{\rho/\sigma}}\left[R^P_{n,50} - (1-\theta_{50})R_{n,45}\right] \tag{G.39}$$

The counterfactual wage vector using the zero profit condition (D.6):

$$w^P_{i,50} = \left[\frac{a_{i,50}}{\left(Q^P_{i,50}\right)^{\gamma^H}}\right]^{1/\gamma^L} \tag{G.40}$$

The number of commuters between blocks in the city in the counterfactual:

$$L^P_{in,50} = (1-\theta_{50})L_{in,45} + \frac{K_{in,50}\left(\left(Q^P_{i,50}\right)^{-\gamma^H/\gamma^L}\left(\Omega^P_{i,50}\right)^{1/\gamma^L}\right)^{\rho/\sigma}}{\sum_{i'\in\mathcal{C}} K_{i'n,50}\left(\left(Q^P_{i',50}\right)^{-\gamma^H/\gamma^L}\left(\Omega^P_{i',50}\right)^{1/\gamma^L}\right)^{\rho/\sigma}}\left[R^P_{n,50} - (1-\theta_{50})R_{n,45}\right], \tag{G.41}$$

where we use the commuting pattern in 1945 given by (G.7). Then, the counterfactual average income in residential places are:

$$v^P_{n,50} = \sum_{i\in\mathcal{C}} \frac{L^P_{in,50}}{R^P_{n,50}} w^P_{i,50} \tag{G.42}$$

Using this, the floor space market clearing condition is:

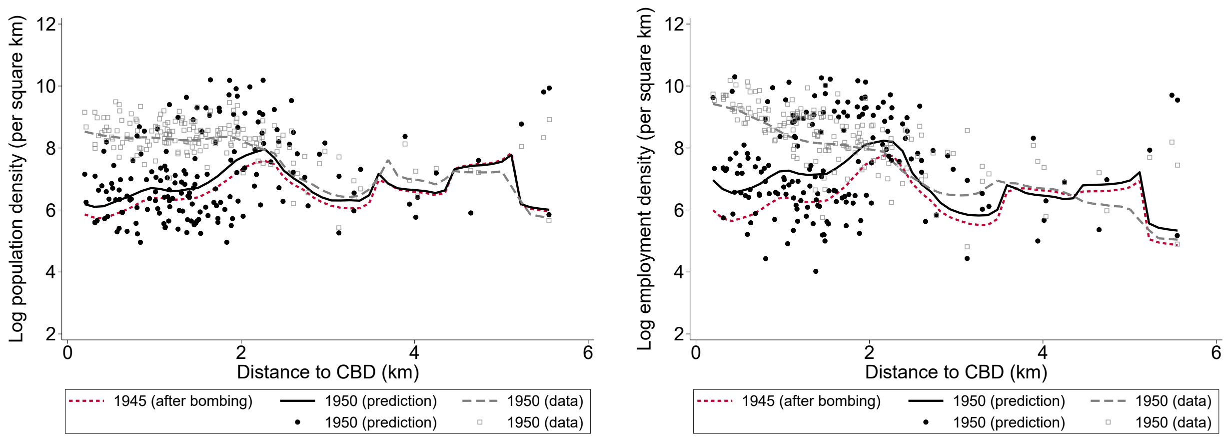
$$H^P_{n,50}Q^P_{n,50} = \mu v^P_{n,50}R^P_{n,50} + \frac{\gamma^H}{\gamma^L} w^P_{n,50}L^P_{n,50}, \tag{G.43}$$

where the floor space supply is given by (D.7).

In sum, we solve the equations (G.39) and (G.43) and update the vectors $\{R^P_{n,50}, L^P_{i,50}, Q^P_{n,50}\}$ until convergence. Figure G.3 displays the population and employment patterns in this equilibrium. Both the population and employment density in the city center are significantly low relative to the observation, while areas around 2 to 3 kilometers from the CBD obtain relatively high density. Intuitively, these areas are just outside of the destroyed area and show relatively higher density in 1945; therefore, productivity and amenities in the areas are anticipated to be high when people are myopic and expect a slow recovery. Overall, the population and employment distribution exhibits a similar pattern to those in 1945.

Figure G.3: Population and employment distributions under myopic pessimistic expectations

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



Note: Each figure plots the log population density (Panel a) and employment density (Panel b) with local polynomial regressions of each on the distance from the CBD. We run three separate regressions: one for the observed 1945 population and employment densities (small dashed line), one for the observed 1950 population and employment densities (long dashed line), and one for the counterfactual (solid line). Each dot represents a block, with different colors for the predicted density and the observed density.

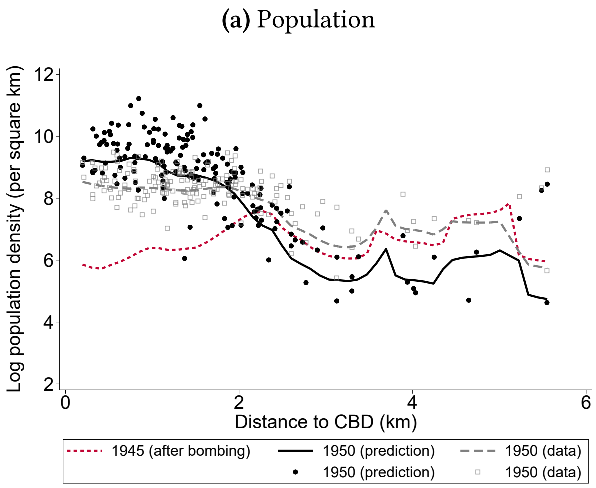
Myopic Optimistic (Memory-based) Expectation Next, we examine how the *memory-based* expectations can lead to the recovery of the destroyed area that individuals remember as the central place prior to the shock. In our context, the destroyed area is close to the city center and shows the highest population and employment density in the 1930s before the war. Hence, after the bombing, individuals may formulate their expectations for the future city structure based on their memory of the past. In this scenario, the city structure can recover strongly to that of the 1930s.

In order to understand this possibility, we solve the model under the assumptions that (i) individuals decide their residential and workplace locations in 1950 based on the *belief* that the productivity and amenities in 1950 are comparable to those determined by population and employment distribution in the 1930s; and (ii) individuals are myopic, as in the previous analysis. Since we assume that individuals are myopic, the difference in this analysis with the previous analysis for the myopic expectation with no recovery is that we compute the option values as follows:

$$\begin{aligned} \Xi^{\mathcal{M}}_{n,50} &= b_{n,50}\left(\frac{R_{n,36}}{S_n}\right)^{\beta}, \\ \Omega^{\mathcal{M}}_{i,50} &= a_{i,50}\left(\frac{L_{i,38}}{S_i}\right)^{\alpha} \end{aligned} \tag{G.44}$$

We use the population distribution in 1936 $\{R_{n,36}\}$ and employment distribution in 1938 $\{L_{i,36}\}$ after the adjustment that the total population equals to employment in 1936. Following the same steps in the previous analysis, we compute the population, employment and floor space prices by solving the system of equations (G.39) and (G.43) using option values (G.44).

Figure G.4: Population and employment distributions under myopic optimistic (memory-based) expectation



Note: Each figure plots the log population density (Panel a) and employment density (Panel b) with local polynomial regressions of each on the distance from the CBD. We run three separate regressions: one for the observed 1945 population and employment densities (small dashed line), one for the observed 1950 population and employment densities (long dashed line), and one for the counterfactual (solid line). Each dot represents a block, with different colors for the predicted density and the observed density.

The population and employment distributions for this scenario are illustrated in Figure G.4. Since the option values (G.44) imply that individuals believe the central area, where the population and employment were concentrated in the 1930s, is associated with high productivity and amenities in 1950, both population and employment recover in blocks near the CBD. In particular, blocks within 2 kilometers from the CBD show *higher* population density compared to the observation. On the other hand, the population and employment in blocks located more than 2 kilometers from the CBD are significantly lower than the observed values. Note that such a recovery prediction is in contrast to Figure G.3, where we use myopic but pessimistic expectations to predict the city structure. Overall, our result suggests that myopic optimistic (memory-based) expectations of individuals could lead to a substantial recovery of the city center.

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