Neighborhood Effects: Evidence from Wartime Destruction in London∗

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Abstract

We use the German bombing of London during the Second World War as an exogenous source of variation to provide evidence on neighborhood effects. We construct a newly-digitized dataset at the level of individual buildings on wartime destruction, property values, and socioeconomic composition in London before and after the Second World War. We develop a quantitative spatial model, in which heterogeneous groups of individuals endogenously sort across locations in response to differences in fundamentals and neighborhood effects. We find substantial and highly localized neighborhood effects, which magnify the direct impact of wartime bombing on property values, and make a substantial contribution to observed patterns of spatial sorting across locations.

JEL CLASSIFICATION: F16, N9, R23
KEYWORDS: Agglomeration, Neighborhood effects, Second World War, Spatial Sorting

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1 Introduction

A key research question in economics is the explanation of the large observed differences in house prices, incomes and socioeconomic composition across neighborhoods. At one end of the spectrum, there are prosperous areas, such as parts of Hampstead in London. At the other extreme, there are poorer areas, such as parts of nearby Haringey in London. One class of explanations emphasizes differences in location fundamentals, such as green areas and scenic views. According to this perspective, Hampstead has attractive fundamentals, in the form of a hilltop location and park, which bids up house prices, such that only the rich can afford to live there. In contrast, another group of hypotheses stresses neighborhood effects, in which individual behavior is influenced by socioeconomic composition. These neighborhood effects can arise either because individuals directly have preferences over neighborhood composition, or because neighborhood composition indirectly affects local public goods, such as schools or crime. In both cases, rich people value living near other rich people, which bids up house prices, such that only rich can afford to live in neighborhoods containing other rich people.

We use the German bombing of London during the Second World War as a natural experiment to distinguish between these two classes of explanations. Our approach exploits two key features of this empirical setting. First, we show that wartime destruction provides an exogenous shock, in the sense that is uncorrelated with the pre-war characteristics of locations within geographical grid cells in London. This finding is consistent with the primitive bomb-aiming technology at the time and the fact that much of the bombing occurred at night. Second, we show that wartime destruction has long-lasting effects on building structures. Reconstruction occurred at a time of rationing, shortages, financial constraints, and pressure to expand social housing. Therefore, the new buildings were lower quality than those that were destroyed.

We use these two features of wartime destruction to estimate the strength of neighborhood effects. The main idea behind our empirical approach is as follows. If high-income residents care more about the quality of buildings than low-income residents, the reduction in the quality of buildings in bombed locations has the direct effect of making them relatively less attractive to high-income residents. If there are neighborhood effects, such that high-income residents value living near other high-income residents, this change in socioeconomic composition has the additional indirect effect of making these bombed locations less attractive to high-income residents. To the extent that these neighborhood effects extend in space, this change in socioeconomic composition affects surrounding locations, making them less attractive to high-income residents. Therefore, the strength of these spillover effects from bombed locations to surrounding locations

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1Recent research on these neighborhood effects includes Galiani, Murphy, and Pantano (2015), Bayer, McMillan, Murphy, and Timmins (2016), Chetty and Hendren (2018), and Chetty, Friedman, Hendren, Jones, and Porter (2018).
can be used to estimate the strength of neighborhood effects.

To implement this idea, we construct a newly-digitized and highly-spatially-disaggregated dataset on war-time destruction, property values and socioeconomic composition in London before and after the Second World War. We digitize and geolocate the bomb damage maps compiled by the London County Council (LCC), and use these maps to measure to pre-war built-up area and levels of wartime destruction for individual buildings. We combine this information on wartime destruction with data on commercial and residential property values for these individual buildings before the Second World War. We determine socioeconomic status of the inhabitants of each building before the Second World War using data on socioeconomic composition by street segment from the New Survey of London Life and Labour (NSOL).

To examine the long-run effects of wartime destruction, we combine these pre-war data with contemporary information on property values and socioeconomic composition. We measure post-war residential property values using transactions-level data for individual properties from 1995-2020. We measure post-war socioeconomic composition using data from the 2001 population census, which are reported for 9,041 Output Areas that cover the LCC area. We aggregate our building-level data on wartime destruction, pre-war socioeconomic outcomes and post-war property values to these Output Areas. We use the 2001 population census, because it is the first census after the Second World War to report representative data on socioeconomic composition at such a fine spatial scale, and it plausibly allows us to capture the long-run adjustment of patterns of spatial sorting to the shock of wartime destruction. We confirm that our results are capturing long-run effects using data from the 2011 population census.

We begin by validating our use of the German bombing of London as an exogenous source of variation. For London as a whole, we find that war destruction was heavier in poorer areas. This pattern of results is consistent with the German air force initially targeting the docks in the East of London, and with the Eastern parts of London historically being poorer. However, once we control for geographical location within London using a 1,000 meter hexagonal grid, we find that wartime bombing is uncorrelated with pre-war property values and socioeconomic composition within these hexagons. These findings are consistent with it being challenging to target individual buildings or streets using the available bomb-aiming technology, especially when much of the bombing occurred at night under conditions of a wartime blackout.

We next show that wartime destruction has long-lived effects on post-war property values and socioeconomic composition in bombed locations. Even after controlling for geographical location within London using our 1,000 meter hexagonal grid, we find a negative and highly statistically significant effect on post-war property values: Comparing undamaged and completely destroyed output areas, we find a decline in post-war property values from 11-18 percent. We also find statistically significant impacts on post-war socioeconomic composition: as we move from an
output area with no destruction to one completely destroyed, we find a decrease in the share of high-income residents of 4 percentage points, and an increase in the share of low-income residents of 6 percentage points. As a result, we find a decline of 5 percent in an overall index of socioeconomic composition that weights the shares of low, middle and high-income residents by their cumulative shares of the population.²

We then establish that wartime destruction has spillover effects on neighboring locations. After again controlling for geographical location within London using our 1,000 meter hexagonal grid, we find negative, statistically significant and highly-localized effects of wartime destruction on post-war property values and socioeconomic composition in neighboring locations. As destruction in a neighboring location within 100 meters increases from no to complete destruction, we find that property values decline by 7-10 percent, and our index of socioeconomic composition falls by 3 percentage points. These spillover effects decline rapidly with distance, with no evidence of statistically significant spillover effects beyond 300 meters.

To interpret these empirical findings, we develop a quantitative model of the spatial sorting of workers from different socioeconomic groups across locations. We consider a city consisting of workers from three different occupations (low, middle and high-income). Workers in each occupation choose a residence and workplace within London, taking into account their wages, residential amenities, the cost of living and commuting costs. These three groups of workers are imperfect substitutes in production and hence receive different wages. They can also differ in the share of their income that they spend on housing and the responsiveness of their location decisions to spatial variation in the cost of living. There is a single final good that is costlessly traded across locations. Productivity depends on locational fundamentals and agglomeration forces that depend on the density of employment for each occupation. Residential amenities depend on the physical characteristics of each location (e.g. scenic views and the quality of buildings) and neighborhood effects (surrounding socioeconomic composition).

We interpret wartime destruction as an exogenous shock that destroys buildings and reduces residential amenities, because the reconstructed buildings are of lower quality than those destroyed. Since high-income workers spend a smaller share of their income on housing and value higher amenities more than low-income workers, they are more willing to pay the higher housing prices for living in locations with higher amenities. Therefore, the reduction in residential amenities from wartime destruction affects patterns of spatial sorting, as high-income residents sort away from bombed locations, and low-income residents sort into these locations. In the presence of neighborhood effects, these changes in socioeconomic composition in bombed locations have spillover effects on surrounding locations. As high-income residents sort away from bombed locations, this reduces the attractiveness of neighboring locations to high-income residents.

²The shares of high and low-income residents in our data in 2001 are 20 and 22 percent, respectively.

We also contribute to the broader literature on the internal organization of economic activity within cities, including Fujita, Krugman, and Venables (1999), Fujita and Thisse (2002), Lucas and Rossi-Hansberg (2002), Ahlfeldt, Redding, Sturm, and Wolf (2015), Allen, Arkolakis, and Li (2016), Monte, Redding, and Rossi-Hansberg (2018), Davis and Dingel (2019) and Owens, Rossi-Hansberg, and Sarte (2020), as reviewed in Duranton and Puga (2004), Rosenthal and Strange (2004), Combes and Gobillon (2015), Redding and Rossi-Hansberg (2017) and Redding (2023). One strand of this research has considered the spatial sorting of heterogeneous agents, including Tsivanidis (2019), Fajgelbaum and Gaubert (2020), and Davis and Dingel (2020). Another related vein of this research has analyzed endogenous amenities, such as Couture (2016), Davis, Dingel, Monras, and Morales (2019), Almagro and Domínguez-lino (2020), Allen, Fuchs, Ganapati, Graziano, Madera, and Montoriol-Garriga (2022), and Couture, Gaubert, Handbury, and Hurst (2023). Our main contribution relative to this literature is to combine a quantitative urban model with the exogenous variation from wartime destruction to estimate neighborhood effects.

Our paper also contributes to the literature that has used natural experiments to examine the determinants of economic development, including Peru’s Mining Mitra (Dell 2010), the division of Germany (Redding and Sturm 2008, Redding, Sturm, and Wolf 2011 and Burchardi and Hassan 2012), the Dust Bowl (Hornbeck 2012), the Tennessee Valley Authority (Kline and Moretti 2014), portage (Bleakley and Lin 2012), natural amenities as a source of persistence (Lee and Lin 2018), the Boston and San Francisco Fires (Hornbeck and Keniston 2017 and Siodla 2015), and the Kuba Kingdom (Lowes, Nunn, Robinson, and Weigel 2017). One strand of this literature has used wartime bombing as a source of exogenous variation, including Davis and Weinstein (2002, 2008), Brakman, Garretsen, and Schramm (2004), Bosker, Brakman, Garretsen, and Schramm (2007), Miguel and Roland (2011), Dericks and Koster (2021), Harada, Ito, and Smith (2022), and Takeda and Yamagishi (2022). Our main contribution relative to this research is to develop a quantitative model of spatial sorting that can be used together with our spatially-disaggregated data on socioeconomic composition to structurally estimate neighborhood effects.

The remainder of the paper is structured as follows. Section 2 discusses the historical background. Section 3 introduces our data. Section 4 presents reduced-form evidence on the impact of Second World War destruction. Section 5 develops our theoretical framework. Section 6 undertakes a quantitative analysis of the model. Section 7 summarizes our conclusions.

2 Historical Background

With London’s rapid growth during the 19th century, an increasing awareness emerged of the great disparity in living standards between its most and least prosperous districts.\(^3\) Motivated by this disparity, Charles Booth undertook a pioneering inquiry of the standard of living in London, which was summarized in 17 volumes published from 1889-1903.\(^4\) As part of this inquiry, he recorded the socioeconomic status of the households in each street segment in London on a series of maps, using seven discrete categories based on occupation and income, which ranged from extreme poverty to the wealthy. These maps document substantial variation in socioeconomic status at a fine spatial scale within London.

By the early 1930s, more than forty years had elapsed since Booth’s original inquiry, a period that spanned considerable urban development in London. To examine the implications of this urban development for the disparity in living standards, one of Booth’s assistants, Hubert Llewellyn Smith at the London School of Economics, replicated his analysis as the New Survey of London Life and Labor (NSOL), published in 9 volumes in Smith (1930). Using the same methodology, households in each street segment in London were classified into discrete categories based on occupation and income. Again the results were displayed in a series of maps, in which street segments were color coded according to this classification, as illustrated for the area around Regent’s Park in Central London in Figure 1.

\(^3\)For a historical discussion of London’s development, see Ball and Sunderland (2001) and White (2007, 2008).

\(^4\)The research archive for Booth’s inquiry is held at the London School of Economics: https://booth.lse.ac.uk/learn-more/the-booth-archive-at-lse-library. A classic historical discussion is O’Day and Englander (1993).
During the Second World War, London experienced heavy aerial bombardment. Following the Fall of France in May 1940, initial attacks by the German air force sought to destroy the British Royal Air Force (RAF). However, over time, there was shift to a strategic bombing campaign centered on London, and aimed at breaking the will of the British people to resist. This intense bombardment of London (the “Blitz”) lasted from 7 September 1940 to 21 May 1941. Destruction occurred as a result of both high-explosive bombs (which directly damaged buildings) and incendiary bombs (which caused fires that damaged buildings). In the face of heavy day-time aircraft losses, the German air force switched to night-bombing from October 1940 onwards.

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5By comparison, there was little bombing or destruction during the First World War from 1914-8, because of the limitations of the aircraft and airship technology available at that time, as discussed in White (2008).

6For further discussion of the London Blitz, see for example Ziegler (1995) and Ray (2004).
Following Germany’s invasion of the Soviet Union in June 1941, conventional air attacks on London were greatly reduced, but continued periodically. By the closing stages of the war, the German military had developed long-range missiles. The first of these weapons, the V-1 (“Doodlebug”), was a pulsejet predecessor of the cruise missile. The second, the V-2, was the first ballistic missile. These missiles fell in a dartboard pattern throughout the LCC area (and Southern England), because of the primitive targeting system, the challenges of developing this new technology, problems of manufacturing quality, and variation in atmospheric conditions.7

Figure 2: Excerpt of London County Council (LCC) Bomb Damage Map for the Area Around Regent’s Park in Central London

Notes: Excerpt from London Sheet V.5 of the LCC Bomb Damage Maps. Buildings color-coded by level of bomb damage: minor blast damage (yellow); general blast damage (orange); seriously damaged but repairable at cost (light red); seriously damaged and doubtful if repairable (dark red); damaged beyond repair (purple); and total destruction (black). Large black circle in Regent’s Park shows a V-1 missile impact.

To keep a record of the destruction of the built-up area and manage the provision of public services in response, the LCC used detailed pre-war Ordnance Survey (OS) maps at 1:2,500 scale to record bomb damage to individual buildings. These buildings were color coded with 7 discrete levels of bomb damage ranging from minor blast damage (yellow) to total destruction (black).9

7For the history of the development of the V-1 and V-2, see Johnson (1981) and Campbell (2012).
8V-2 rockets were produced in the Mittelwerk factory using forced labor from the Mittelbau-Dora concentration camp, with documented heroic acts of sabotage to manufacturing components.
9The LCC bomb damage maps were recently re-published in Ward (2016).
The maps also indicated the point of impact of each V-1 and V-2 missile, with a V-1 strike denoted by a large black circle and a V-2 strike shown by a smaller black circle. In Figure 2, we display part of one of these maps for the same area around Regent’s Park as for the NSOL map above. As apparent from the figure, there is considerable variation in the extent of destruction, even for buildings in close proximity, consistent with the idea that the differences in destruction at a fine spatial scale largely reflect idiosyncratic factors, such as the difficulties of accurate targeting and wind direction and speed.

Before the Second World War, a UK Cabinet Committee in 1937 estimated that an attacker dropping 600 tons of bombs each day could cause 200,000 casualties a week, of which 66,000 would be killed. In reality, while levels of destruction and casualties from wartime bombing were substantial, they were smaller than anticipated. According to the official post-war report of the UK government, 60,595 civilians were killed over the entire course of the war from enemy action, with roughly half of these deaths occurring in the London Civil Defense region, which was substantially larger than the LCC area. In our data for the LCC area, we find that around 20 percent of the pre-war built-up area experienced serious destruction.

Historically, London had lacked a central municipal authority responsible for the entire of the built-up area, and the city’s growth had been largely haphazard. As the Second World War progressed, it became clear that the substantial destruction of the built-up area presented an opportunity to rebuild in a more planned fashion. With this goal in mind, three separate plans were commissioned during the war for the historical City of London (the Square Mile or old Roman city), the Country of London (which included most of the built-up area), and the larger Greater London region. However, after the end of the Second World War, these abstract plans ran up against the reality of the severe financial burden of Britain’s war debt, a desperate need to quickly construct housing to replace destroyed dwellings, and a scarcity of raw materials. As a result, most of the ideas in these plans were never implemented. Rebuilding largely occurred through private initiative and social housing constructed by local governments.

3 Data

We construct a new spatially-disaggregated dataset that combines property values and socioeco-
nomic composition before and after the Second World War together with information on war-
time destruction. A detailed exposition of the data sources and definitions is contained in Online

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10 In response to the public health challenges of a growing population, the Metropolitan Board of Works was founded in 1855, but its responsibilities were largely limited to infrastructure. The LCC was founded in 1889.
11 See Holden and Holford (1951), Forshaw and Abercrombie (1943) and Abercrombie (1945), respectively. Large-scale urban planning in London did not begin until the Barlow Commission of 1940, as discussed in Foley (1963).
12 For further discussion of the challenges of post-war reconstruction, see Kynaston (2008) and Boughton (2018).
Appendix D. Our data cover the administrative area of London County Council (LCC), which encompassed the city center and inner suburbs, with a total geographical area of just over 300 kilometers squared, and a total population of 4.4 million in 1931.\footnote{London County Council (LCC) was the principal local government body for London from 1889 to 1965.} We measure the pre-war built-up area and wartime destruction using the LCC Bomb Damage maps, which are based on pre-war Ordnance Survey (OS) maps at 1:2,500 scale, and delineate individual buildings. We use a variety of other sources of pre-war data, as discussed further below. For the post-war period, we use data on socioeconomic composition from the 2001 and 2011 censuses and property values from transactions data from 1995-2020, assuming that by then economic activity has reached a new steady-state following the destruction during the Second World War.\footnote{The 2001 census is the first post-war population census for which detailed data on socioeconomic status was enumerated for the full population, rather than for a 10 percent sample in earlier post-war censuses. Most rebuilding occurred in the 1950s and 1960s, although some construction on former bomb sites from the Second World War continued to occur into the 1970s, as discussed for example in Clapson and Larkham (2013).}

**Spatial Units**

We use Output Areas (OAs) from the 2001 population census as our spatial unit of analysis. These Output Areas have a target size of 125 households in 2001 and there are 9,041 of them within the County of London. Output Areas can be aggregated to wards and boroughs (e.g., City of Westminster), where wards and boroughs differ substantially in geographical area. To construct consistent spatial aggregations of the Output Areas, we overlay hexagonal grids of different sizes over the County of London, with hexagon diameters varying from 1,000 meters (380 hexagons) to 4,000 meters (34 hexagons), as discussed further in the Online Appendix.\footnote{We choose hexagons (rather than squares or triangles) because of their advantages for partitions of geographical space, as discussed for example in Carr and Pickle (2010).}

**Property Values**

We measure residential and commercial property values before the Second World War using data on rateable values, which correspond to “The annual rent which a tenant might reasonably be expected, taking one year with one another, to pay for a hereditament, if the tenant undertook to pay all usual tenant’s rates and taxes .. after deducting the probable annual average cost of the repairs, insurance and other expenses.” These rateable values have a long history in England and Wales, dating back to the 1601 Poor Relief Act, and were used to raise revenue for local public goods.

We use data from the handwritten valuation list for the LCC area from 1936, which runs to approximately 50,000 pages. Each valuation entry on the list reports a street and property number, brief description of the property characteristics (e.g., house, flat, factory, wharf, shop, etc.), and the rateable value. In a first step, we photographed and digitized the 1936 valuation list. In a second step, we used historical maps showing each building and its corresponding street number to geolocate and assign the more than 1 million properties to buildings. In a third step, we distinguish between commercial, residential and mixed use buildings using the reported...
property characteristics. For mixed use buildings, we allocate the total rateable value of the building between commercial and residential use based on the reported property characteristics. In a fourth and final step, we estimate a commercial and residential property value for each output area as the location fixed effect in a hedonic regression including property characteristics.

In Figure 3, we show the distribution of pre-war residential property values in the LCC area. We find the highest values in the historical City of London, sometimes referred to as the Square Mile, which corresponds approximately to the boundaries of the Roman city. We find an East-West gradient in property values, with higher values in the West End than in the East End, but substantial variation even within narrow geographical areas.

Figure 3: Pre-War Property Values by LCC Output Area

Notes: Property values in the LCC area in 1936 based on the market rental value (rateable value) of property for tax purposes. The property values are the Output Area fixed effects from a hedonic regression of the logarithm of rateable values on observed property characteristics. Red denotes high values; blue denotes low values.

We measure residential property values after the Second World War using property transactions data from the U.K. Land Registry, which reports prices paid, postcodes and property characteristics. For the period 1995 to 2020, there are 1,186,317 transactions registered within the LCC area. We match each property transaction to our 2001 Output Areas using the centroid of the property’s postcode, where there are an average of 133 transactions per Output Area. We esti-
mate a residential property value for each Output Area as the location fixed effect in a hedonic regression including the property characteristics.

**Population** We measure pre-war population using the 1931 population census of England and Wales. The smallest spatial units for which population is reported in the census are the 316 wards of the LCC area. We allocate population across residential buildings within wards using their shares of the total residential built-up area within wards. As a specification check on this procedure, we implement an analogous procedure for boroughs and wards, where population is reported in the population census for both of these levels of aggregation. Allocating borough population across wards using their shares of the total residential built-up area within boroughs, we show that the resulting estimated ward population closely approximates the ward population reported in the population census, as discussed further in the Online Appendix.

**Socioeconomic Status** We measure socioeconomic status before the Second World War using the New Survey of London (NSOL) maps. We digitized and georeferenced the more than 25,000 street segments. We assign a socioeconomic status to each residential and mixed use building based on the socioeconomic status of its street segment. Combining this information with the population data for each building discussed above, we obtain the total number of people with that socioeconomic status at the building level. Summing across buildings within Output Areas, we obtain the total number of people with each socioeconomic status at the Output Area level. To construct consistent measures of socioeconomic status before and after the Second World War, we aggregate the NSOL categories into the three groups of low, middle and high-income, as summarized in Table 1 below.

We also construct an index of overall socioeconomic composition at the Output Area level following Orford, Dorling, Mitchell, Shawn, and Smith (2002). We first assign a score to each socioeconomic group (low, middle and high) based on the mid-point of the cumulative distribution of workers for the LCC area as a whole:

\[
\begin{align*}
\bar{I}^L &= \frac{S^L}{2}, \\
\bar{I}^M &= S^L + \frac{S^M}{2}, \\
\bar{I}^H &= S^L + S^M + \frac{S^H}{2}
\end{align*}
\]

where \(S^L\), \(S^M\) and \(S^H\) are the shares of low, middle and high-income workers for the LCC area as a whole, respectively. We next calculate the socioeconomic status \(\bar{I}_i\) of each Output Area \(i\) as the weighted average of these scores, using the shares of people in each group for each Output Area \(\omega^L_i, \omega^M_i, \omega^H_i\) as weights:

\[
\bar{I}_i = \left( \omega^L_i \times \bar{I}^L \right) + \left( \omega^M_i \times \bar{I}^M \right) + \left( \omega^H_i \times \bar{I}^H \right).
\] (1)

Finally, we rescale this socioeconomic index such that it varies between zero (all residents are low income) to one (all residents are high income).
Table 1: Pre-War and Post-War Socioeconomic Status

<table>
<thead>
<tr>
<th>Socioeconomic Status</th>
<th>NSOL Groups</th>
<th>NSOL Share</th>
<th>Census 2001 Groups</th>
<th>Census 2001 Share</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>Extreme Poverty</td>
<td>0.24</td>
<td>Long-Term Unemployed</td>
<td>0.22</td>
</tr>
<tr>
<td></td>
<td>Below Poverty Line</td>
<td></td>
<td>Routine and Semi-Routine</td>
<td></td>
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<tr>
<td></td>
<td>Unskilled Workers</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Middle</td>
<td>Skilled Workers</td>
<td>0.47</td>
<td>Lower-Managerial</td>
<td>0.58</td>
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<td></td>
<td>Intermediate Occupations</td>
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<td>Own Account Workers</td>
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<tr>
<td></td>
<td>Technical Occupations</td>
<td></td>
<td>Higher-Managerial</td>
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<td>Middle-Class and Wealthy</td>
<td>0.28</td>
<td>Higher-Professional</td>
<td>0.20</td>
</tr>
</tbody>
</table>

Notes: The table shows how we aggregate the different socioeconomic groups in the NSOL (Smith 1930) and the 2001 UK population census into our three socioeconomic groups. The shares do not always add up to one due to rounding errors.

In Figure 4, we show the distribution of this index of socioeconomic status in the LCC area. We find a strong pattern of spatial sorting, with the areas characterized by higher property values in Figure 3 typically having higher socioeconomic status in Figure 4. As a result, we also find a clear East-West gradient in socioeconomic status, with higher values in the West End than in the East End. Nevertheless, again, we observe substantial variation in socioeconomic status even within narrow geographical areas.

We measure socioeconomic status after the Second World War using the population census for 2001, which reports the number of people in each disaggregated occupation at the Output Area level. We aggregate these disaggregated occupations into the three categories of low, middle and high-income, as shown in Table 1 above. We find a relatively similar distribution of the share of the population across these three categories before and after the Second World War. This finding is consistent the fact that the occupation classification in the population census was heavily influenced by the Booth and NSOL studies of socioeconomic status.

Second World War Destruction We measure wartime destruction using the LCC bomb damage maps. We georeferenced the 110 map sheets, drew the outline of the 1939 built-up area for each map sheet, and recorded the level of damage to each building, as indicated by the color-coding on the maps. This measure of destruction includes damage caused by both conventional aircraft and V-1 and V-2 missiles. As our baseline measure of war destruction, we use the frac-

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16 We employed research assistants to draw the built-up area and damage to each building on georeferenced versions of the bomb damage maps. In contrast, Fetter (2023) applies automated color-recognition algorithms to digital scans of these maps to construct an instrument for building energy efficiency based on wartime destruction. Our data from administrative bomb damage maps differ substantially from the crowd-sourced BombSight data used in Dericks
Figure 4: Pre-War Index of Socioeconomic Status by Building in the LCC Area

Notes: Socioeconomic status by building in the LCC area based on the New Survey of London Life and Labor 1928-31. The colour of each building corresponds to the socioeconomic index of the residents of the building with red denoting high and blue low socioeconomic status. Non-residential buildings such as factories or churches are shown in gray.

The damage affecting the pre-war built-up area in each Output Area that experienced serious repairable damage (light red) or worse. We exclude minor and general blast damage, which are non-structural, and unlikely to permanently affect building structures. We include serious repairable damage, un-repairable damage and total destruction, because whether damage is classified repairable or not could be endogenous to economic considerations. Finally, as an alternative measure of war destruction, we construct an overall index of bomb damage. We first score levels of damage to each building from 0 to 6 (from no to total destruction). We next compute the index of bomb damage for each Output Area as the weighted average of these scores, using shares of the pre-war built-up area within the Output Area with each level of destruction.

In Figure 5, we show each building in the LCC area and its level of destruction, using the same color scheme as the original bomb damage maps. We find that war destruction was extensive: and Koster (2021), which claim to record the locations where German bombs landed. The BombSight data does not record building damage. Furthermore, we find many areas where destruction occurred, but no bomb impacts are recorded in the Bombsight data (in part because of the spread of fire), as discussed further in Online Appendix D2.5.
Notes: The map shows the bomb damage for each building in the LCC area using the colour scheme used by the original bomb
damage maps: minor blast damage (yellow); general blast damage (orange); seriously damaged but repairable at cost (light red);
seriously damaged and doubtful if repairable (dark red); damaged beyond repair (purple); and total destruction (black). Buildings
that suffered no damage are shown in grey and clearance areas are in green.

more than 40 percent of the pre-war built-up area experienced some level of bomb damage (yellow or worse), and around 20 percent experienced serious damage according to our measure.\(^{17}\) There is a clear gradient in damage: Areas in the East and close to the river experiencing more
damage than those in the West and far from the river. But the extent of idiosyncratic variation
within narrow geographic areas is striking: even in the Western outer parts of London, we find
substantial destruction. This pattern of idiosyncratic variation is consistent with our identifying
assumption that war destruction is exogenous within narrow geographic areas.

Other Geographical Data We combine our data on property values, socioeconomic status and
Second World War destruction with a variety of other census and geographical data, including
the height of buildings and the fraction of people of living in social (council) housing.

\(^{17}\) Clearance areas (green) were areas cleared by the local authorities with a view for post-war development, and
typically included both bombed areas and nearby areas with no destruction. We exclude these areas from our war
destruction measures, since the choice to label parts of the city as clearance areas is endogenous.
4 Reduced-Form Evidence

We now present reduced-form evidence on the economic impact of war destruction that guides our theoretical model and provides moments for its structural estimation. In Subsection 4.1, we show that Second World War destruction is uncorrelated with pre-war socioeconomic status and property values within small geographical grid cells, supporting the idea that it provides an exogenous shock to different locations within these grid cells. In Subsection 4.2, we report estimates of the causal effect of Second World War destruction on post-war socioeconomic status and property values. In Subsection 4.3, we show that these causal effects of bomb damage spill over to neighboring locations. Finally, in Subsection 4.4, we provide further evidence on the mechanisms through which these effects of wartime destruction occur.

4.1 Randomness of Second World War Destruction

We begin by validating wartime destruction as an exogenous source of variation. We estimate the following regression specification between economic outcomes before the Second World War and subsequent wartime destruction:

\[
Y_{i,\text{Pre-War}} = \beta D_{i,\text{War}} + \eta_k + u_i, \tag{2}
\]

where \(i\) indexes Output Areas; \(Y_{i,\text{Pre-War}}\) is either pre-war socioeconomic status or property values; \(D_{i,\text{War}}\) is measure of bomb damage during the Second World War; \(\eta_k\) are fixed effects for hexagonal grid cells; and \(u_i\) is stochastic error. In our baseline specification, we report standard errors clustered by 1,000 meter hexagons, which allows spatial correlation across Output Areas within these hexagons. As a robustness test, Table C.1 in Online Appendix C1 reports Heteroskedasticity and Autocorrelation Consistent (HAC) standard errors following Conley (1999).

Table 2 reports the estimation results. Each cell of the table corresponds to a separate regression. The columns report results using different left-hand side variables. Columns (1)-(3) use the fraction of the population who are high, middle and low status, respectively; Column (4) uses our index of socioeconomic status; Column (5) uses the unconditional average property value; Column (6) uses the average property value conditional on a set of observed property characteristics, as described in more detail in Online Appendix D3. The two panels report results using different measures of wartime destruction for the right-hand side variable. The top panel uses the fraction of the built-up area that experienced serious damage. The bottom panel uses our damage index. Within each panel, the first row reports results with no fixed effects; the second row presents estimates using fixed effects for hexagons of 4,000 meter diameter; and the third row gives results using fixed effects for hexagons of 1,000 meter diameter.

\[\text{Bertrand, Duflo, and Mullainathan (2004) examine several approaches to control for serial correlation. They show that clustering the standard errors performs well in settings with at least 50 clusters as in our application.}\]
The primitive bomb-aiming technology and night-time bombing, which precluded the precise targeting of targets, was entirely unrelated to pre-war socioeconomic outcomes. This pattern of results is consistent with the findings of Figures 3-5 above, where there is a West-East gradient in property values, socioeconomic status and wartime destruction. Once we include fixed effects for 4,000 meter hexagons in the middle row of each panel, much of this correlation goes away, such that the regression coefficients fall by more than one half in absolute magnitude. Nevertheless, 4,000 meter hexagons still cover a relatively large geographical area, and are still likely affected by the West-East gradients noted above. Once we include fixed effects for 1,000 meter hexagons in the bottom row of each panel, the coefficients fall close to zero and are entirely statistically insignificant.

In the specification including no fixed effects in the top row of each panel, we find a correlation between pre-war socioeconomic outcomes and subsequent wartime destruction. Output areas that had larger pre-war shares of the population with lower socioeconomic status and lower pre-war property values experienced more destruction during the Second World War. This pattern of results is consistent with the findings of Figures 3-5 above, where there is a West-East gradient in property values, socioeconomic status and wartime destruction. Once we include fixed effects for 4,000 meter hexagons in the middle row of each panel, much of this correlation goes away, such that the regression coefficients fall by more than one half in absolute magnitude. Nevertheless, 4,000 meter hexagons still cover a relatively large geographical area, and are still likely affected by the West-East gradients noted above. Once we include fixed effects for 1,000 meter hexagons in the bottom row of each panel, the coefficients fall close to zero and are entirely statistically insignificant.

Therefore, once we focus on variation within narrow geographical grid cells, wartime damage is entirely unrelated to pre-war socioeconomic outcomes. This pattern of results is consistent with the primitive bomb-aiming technology and night-time bombing, which precluded the precise targeting of targets.
targeting of locations.\textsuperscript{19}

Overall, these results provide strong support for our identifying assumption that wartime destruction provides an exogenous source of variation within narrow geographical areas.

### 4.2 Direct Effects of Second World War Destruction

We next provide evidence on the causal impact of wartime destruction. We estimate the following regression specification for the direct effect of a location being bombed during the war on its own post-war economic outcomes:

\[
Y_{t, \text{Post-War}} = \beta D_{t, \text{War}} + \eta_k + u_i
\]

where $Y_{t, \text{Post-War}}$ is an economic outcome after the end of the Second World War; the other variables are defined as in the previous subsection; and our baseline specification again reports standard errors clustered by 1,000 hexagons.

Table 3 reports the estimation results. The structure of the table is the same as for Table 2 above: Each cell corresponds to a separate regression; the columns report results for different post-war outcomes ($Y_{t, \text{Post-War}}$); the two panels report results for different measures of wartime destruction ($D_{t, \text{War}}$); and the rows within each panel report results with different sets of fixed effects. Even when we include fixed effects for 1,000 meter hexagons, we find that Output Areas that experienced more wartime destruction have lower shares of the population who are high and middle status (Columns (1) and (2)); higher shares of the population who are low status (Column (3)); a lower value for our index of socioeconomic status (Column (4)); and lower property values, without and with hedonic controls for property characteristics (Columns (5) and (6), respectively).

We find marginally smaller estimated coefficients in Column (6) including hedonic controls than in Column (5) without these controls, which is consistent with the idea that wartime destruction led to a downgrading in property characteristics.

These estimated causal impacts of wartime destruction are not only statistically significant but also economically relevant. Comparing undamaged and completely destroyed output areas, we find a decline in property values from 11-18 percent; a decrease in the share of high-income residents of 4 percentage points; an increase in the share of low-income residents of 6 percentage points; and a decline of 5 percent in our index of socioeconomic composition.

Therefore, whereas there is no correlation between pre-war economic outcomes and subsequent wartime bombing within narrow geographical grid cells (previous subsection), we find a

\textsuperscript{19}Given the primitive bomb-aiming technology, the British Royal Air Force (RAF) largely gave up trying to strike specific targets in Germany and instead pursued the area bombing of German cities. Only with the development of more advanced bomb sights by the American Army Airforce (AAAF) late in the war was a degree of success achieved in striking specific targets by day, although even then accuracy was poor (e.g., Overy 2013).
and demonstrate similar results within each sub-period, which is again consistent with persistent Appendix C3, we break out our post-war property prices data from 1995-2020 into sub-periods, with wartime destruction having an impact of steady-state outcomes. In Table C.8 of Online composition results using the population census for 2011 instead of 2001, which is consistent standard errors. In Table C.5 of Online Appendix C2, we show that we /f_ind similar socioeconomic of different speci/f_ications. In Table C.2 of Online Appendix C1, we demonstrate the robustness in the pattern of estimated coefficients between the pre-war and post-war periods is consistent and wartime bombing within these narrow geographical grid cells (this subsection). This change strong negative and statistically signiﬁcant correlation between post-war economic outcomes and wartime bombing within these narrow geographical grid cells (this subsection). This change in the pattern of estimated coefficients between the pre-war and post-war periods is consistent with a direct negative causal impact of a location being bombed on its own economic outcomes.

In the online appendix, we show that this pattern of results is robust across a wide range of different specifications. In Table C.2 of Online Appendix C1, we demonstrate the robustness of our results to using Conley (1999) Heteroskedasticity and Autocorrelation Consistent (HAC) standard errors. In Table C.5 of Online Appendix C2, we show that we find similar socioeconomic composition results using the population census for 2011 instead of 2001, which is consistent with wartime destruction having an impact of steady-state outcomes. In Table C.8 of Online Appendix C3, we break out our post-war property prices data from 1995-2020 into sub-periods, and demonstrate similar results within each sub-period, which is again consistent with persistent

<table>
<thead>
<tr>
<th>Damage Measure</th>
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<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
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<tr>
<td></td>
<td></td>
<td>Fraction</td>
<td>Fraction</td>
<td>Fraction</td>
<td>Socio-</td>
<td>Log of</td>
<td>Log of</td>
</tr>
<tr>
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<td></td>
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<td>Middle Status</td>
<td>Low Status</td>
<td>Economic</td>
<td>Property Value</td>
<td>Property Value</td>
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<td>−0.040***</td>
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<td>(0.007)</td>
<td>(0.015)</td>
<td>(0.014)</td>
<td>(0.054)</td>
<td>(0.059)</td>
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<td>−0.023***</td>
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<tr>
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<td>−0.008***</td>
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<td>(0.003)</td>
<td>(0.003)</td>
<td>(0.011)</td>
<td>(0.012)</td>
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<tr>
<td>1km Hexagons</td>
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<td>−0.009***</td>
<td>−0.005***</td>
<td>0.014***</td>
<td>−0.011***</td>
<td>−0.053***</td>
<td>−0.036***</td>
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<tr>
<td>4km Hexagons</td>
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<td>−0.008***</td>
<td>−0.004***</td>
<td>0.012***</td>
<td>−0.010***</td>
<td>−0.036***</td>
<td>−0.022***</td>
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<td>(0.002)</td>
<td>(0.002)</td>
<td>(0.005)</td>
<td>(0.004)</td>
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Notes: Each cell reports the results of a separate regression and the unit of observation is an output area as defined in the 2001 UK census. Dependent variables in columns (1) to (4) consist of a measure of social status from the 2001 UK census (fraction of population that has low, middle and high socioeconomic status and an index of socioeconomic status). In column (5) the dependent variable is the logarithm of the average property transaction price while in column (6) it is the logarithm of the average property transaction price conditional on a set of property characteristics. The explanatory variable in rows (1) to (3) is the percentage of the built-up area seriously damaged and in rows (4) to (6) it is our damage index. Each regression includes different levels of spatial fixed effects as indicated in the second column. Regressions in columns (1) to (4) have 8912 observations and include 34 and 382 fixed effects for the 4 kilometer and 1 kilometer hexagons respectively. Regressions in columns (5) and (6) have 8797 observations and include 34 and 382 fixed effects for the 4 kilometer and 1 kilometer hexagons respectively. The difference in observations is due to some output areas not having any observed property transactions in the period from 1995 to 2020. Standard errors are clustered at the 1 kilometer hexagon level. * denotes significance at 10% level; ** denotes significance at 5% level; *** denotes significance at 1% level.
long-run impacts. In Table C.10 of Online Appendix C4, we establish the same pattern of results if we exclude the City of London and the City of Westminster as the main centers of commercial activity, highlighting that our results are not driven by these boroughs, and primarily capture the impacts of wartime destruction on residential neighborhoods.

4.3 Spillover Effects of Second World War Destruction

We next provide evidence on the extent to which wartime destruction not only directly affects bombed locations, but also spills over to neighboring locations. We measure these spillovers using 100-meter buffers around the built-up area of each Output Area.20

Using this definition of buffers, we estimate the following regression specification between a location’s socioeconomic outcomes after the Second World War, its own wartime destruction, and the wartime destruction in surrounding areas:

$$Y_{i}^{\text{Post-War}} = \beta D_{i}^{\text{War}} + \sum_{g=1}^{G} \gamma_{g} D_{ig}^{\text{War}} + \eta_{k} + u_{i} \quad (4)$$

where we index buffers by $g \in \{1, \ldots, G\}$; $D_{ig}^{\text{War}}$ is the fraction of the built-up area seriously damaged in the buffer $g$ surrounding location $i$; the other variables are defined above; and our baseline specification again reports standard errors clustered by 1,000 hexagons.

In Table 4, we report the estimation results for our preferred specification including fixed effects for 1,000 meter hexagons. We focus for brevity on our baseline wartime destruction measure of the fraction of the built-up area seriously damaged. The columns report results for different post-war outcomes ($Y_{i}^{\text{Post-War}}$); the first row reports the coefficient estimates for own destruction ($\beta$); the remaining rows report results for surrounding destruction ($\gamma_{g}$). Columns (1), (3) and (5) replicate our baseline results for own destruction from the previous table. Columns (2), (4) and (6) augment these specifications with our measures of destruction in surrounding areas.

Comparing the results across these columns, we find that the estimated coefficient on own destruction is marginally lower once we control for surrounding destruction. In Columns (2), (4) and (6), we find statistically significant spillover effects from wartime destruction. These spillover effects are large in magnitude, with estimated coefficients within 100 meters that are substantial relative to the own effects. These spillover effects are also highly localized, with the estimated coefficients declining in distance, and becoming statistically insignificant beyond at most 300 meters. In Online Appendix C, we show that these empirical findings of spillover effects of wartime destruction are robust across the same set of specifications considered for the direct effect of wartime destruction in the previous subsection.

---

20We provide an example of these 100-meter buffers in Figure D.2 in Online Appendix D1.
Table 4: The Spillover Effect of Wartime Bombing

|                  | (1) Socio-
<table>
<thead>
<tr>
<th></th>
<th>Economic Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Destruction in own area</td>
<td>-0.051*** (0.007)</td>
</tr>
</tbody>
</table>
|                  | (2) Socio-
|                  | Economic Index |
| Destruction in 100m buffer | -0.030** (0.013) |
|                  | (3) Log of Property Value |
| Destruction in 200m buffer | -0.026 (0.018) |
|                  | (4) Log of Property Value |
| Destruction in 300m buffer | -0.026 (0.018) |
|                  | (5) Log of Property Value |
| Destruction in 400m buffer | 0.004 (0.026) |
|                  | (6) Log of Property Value |

Nr of fixed effects 382 382 382 382 382 382
Observations 8912 8910 8797 8795 8797 8795
R-squared 0.483 0.485 0.637 0.638 0.782 0.782

Notes: Each column reports the results of a separate regression and the unit of observation is an output area as defined in the 2001 UK census. The dependent variable in columns (1) and (2) is an index of socioeconomic status. In columns (3) and (4) the dependent variable is the logarithm of the average property transaction price while in column (5) and (6) it is the logarithm of the average property transaction price conditional on a set of property characteristics. The explanatory variable in columns (1), (3) and (5) is the percentage of built-up area seriously damaged. Columns (2), (4) and (6) additionally control for the percentage of built-up area seriously damaged in each of four buffers of 100 meter width around each output area. Every regression includes 1 kilometer hexagon fixed effects. Standard errors are clustered at the 1 kilometer hexagon level. * denotes significance at 10% level; ** denotes significance at 5% level; *** denotes significance at 1% level.

Taken together, these findings suggest that even if a location is not itself directly bombed, it is affected by wartime destruction in immediately surrounding areas.

4.4 Mechanisms for Second World War Destruction

We now provide evidence on the mechanisms through which the direct and spillover effects of wartime destruction occur. In Table 5, we estimate the same regression specification (4) as in the previous subsection using additional left-hand side variables.

First, we provide evidence that wartime destruction has a persistent impact on the type of buildings. Column (1) uses the share of buildings that are post-war; Column (2) considers the height of modern buildings; Column (3) examines the share of the land area that is built up. As reported in the first row, we find substantial direct effects of wartime destruction on each of these building outcomes. Mechanically, wartime destruction increases the share of buildings that are post-war. More substantively, wartime destruction increases the height of buildings by around
7.8 percent, and reduces the share of the land area that is built up by 4.1 percent, which is in line with post-war architectural trends towards high-rise tower blocks surrounded by open areas. As reported in the second to fourth rows, we find no systematic evidence of spillover effects of wartime destruction on these building outcomes. Therefore, destruction in neighboring locations does not change the types of buildings in the own location. This pattern of results suggests that the spillover effects in the previous subsection are not capturing the correlated rebuilding of surrounding areas in response to wartime destruction.

Table 5: The Mechanisms of Wartime Bombing

<table>
<thead>
<tr>
<th></th>
<th>(1)</th>
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<th>(3)</th>
<th>(4)</th>
<th>(5)</th>
<th>(6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Destruction in Own Area</td>
<td>0.243***</td>
<td>0.078***</td>
<td>−0.041***</td>
<td>0.135***</td>
<td>0.246***</td>
<td>−0.207***</td>
</tr>
<tr>
<td></td>
<td>(0.024)</td>
<td>(0.019)</td>
<td>(0.005)</td>
<td>(0.017)</td>
<td>(0.030)</td>
<td>(0.064)</td>
</tr>
<tr>
<td>Destruction in 100m Buffer</td>
<td>0.035</td>
<td>−0.018</td>
<td>0.004</td>
<td>0.028</td>
<td>0.036</td>
<td>−0.013</td>
</tr>
<tr>
<td></td>
<td>(0.044)</td>
<td>(0.039)</td>
<td>(0.012)</td>
<td>(0.034)</td>
<td>(0.058)</td>
<td>(0.130)</td>
</tr>
<tr>
<td>Destruction in 200m Buffer</td>
<td>−0.049</td>
<td>0.041</td>
<td>0.007</td>
<td>0.031</td>
<td>0.071</td>
<td>0.148</td>
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<td></td>
<td>(0.055)</td>
<td>(0.053)</td>
<td>(0.015)</td>
<td>(0.046)</td>
<td>(0.076)</td>
<td>(0.159)</td>
</tr>
<tr>
<td>Destruction in 300m Buffer</td>
<td>0.086</td>
<td>−0.081</td>
<td>0.017</td>
<td>−0.017</td>
<td>0.035</td>
<td>0.061</td>
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<tr>
<td></td>
<td>(0.060)</td>
<td>(0.050)</td>
<td>(0.016)</td>
<td>(0.045)</td>
<td>(0.075)</td>
<td>(0.168)</td>
</tr>
<tr>
<td>Destruction in 400m Buffer</td>
<td>−0.112*</td>
<td>−0.127**</td>
<td>0.021</td>
<td>−0.069</td>
<td>−0.206**</td>
<td>0.113</td>
</tr>
<tr>
<td></td>
<td>(0.067)</td>
<td>(0.065)</td>
<td>(0.019)</td>
<td>(0.056)</td>
<td>(0.094)</td>
<td>(0.201)</td>
</tr>
</tbody>
</table>

Nr of FE | 382 | 382 | 382 | 382 | 369 | 382
Observations | 8910 | 8910 | 8910 | 8910 | 6698 | 8904
R-squared | 0.333 | 0.477 | 0.464 | 0.396 | 0.444 | 0.479

Notes: Each column reports the results of a separate regression. The unit of observation in columns (1), (2), (3), (4) and (6) is an output area as defined in the 2001 UK census; in column (5) it is an enumeration district as defined in the 1981 census. The dependent variable in column (1) is the fraction of post-war buildings; in column (2) it is the logarithm of the average building height; in column (3) the fraction of total area of an Output Area that is built up; in columns (4) and (5) the fraction of households that reside in council housing in 2001 and 1981 respectively and in column (6) the logarithm of employment density. The explanatory variables in all columns are the percentage of the built-up area seriously damaged within the unit of observation as well as four buffers of 100 meter width around each unit of observation. Every regression includes 1 kilometer hexagon fixed effects. Standard errors are clustered at the 1 kilometer hexagon level. " denotes significance at 10% level; "" denotes significance at 5% level; *** denotes significance at 1% level.

Second, we provide further evidence on the changes in socioeconomic composition caused by wartime bombing. Column (4) uses the share of households living in social (council) housing in the 2001 population census. We find that areas that experienced more own destruction have higher council housing shares in 2001. This pattern is consistent with the space created by
wartime destruction being used to accommodate the large post-war expansion in council housing. In 1980, Margaret Thatcher’s Housing Act gave council tenants the “right to buy” their properties at considerable discounts on the market price, which led to a large large-scale transfer to private ownership. By 2022, 1.88 million council properties in England had been sold under this scheme, corresponding to 36.9 percent of the 1980 stock of council housing. To capture the impact of wartime destruction on council housing before this large-scale transfer, Column (5) repeats the same regression using data from the 1981 census, and finds an even larger effect on the share of households living in council housing. In both Columns (4) and (5), we find no systematic evidence of spillover effects of wartime destruction on the share of households living in council housing. Therefore, destruction in neighboring locations does not change the likelihood that council housing is constructed in the own location, providing further evidence that spillover effects are not occurring through the correlated rebuilding of surrounding areas.

Third, we provide evidence on the impact of wartime bombing on the specialization of areas in commercial versus residential activity. Column (7) uses the log of employment density (employment by workplace per land area). We find a negative and statistically significant direct effect of wartime destruction, with no evidence of statistically significant spillover effects. This pattern of results suggests that if anything wartime destruction shifted economic activity towards residential use, which supports our focus on residential externalities. In Table C.4 of Online Appendix C1, we show that these findings are robust to using HAC standard errors. In Table C.7 of Online Appendix C2, we show that we find similar results using data from the 2011 census.

Taken together, the findings of this section provide evidence that the direct effects of wartime destruction on property values and socioeconomic composition in earlier subsections reflect changes in the type of buildings, including the construction of social housing. Additionally, these results provide evidence against the correlated rebuilding of surrounding areas as a potential explanation for spillover effects of wartime destruction. Finally, these results are consistent with neighborhood effects: Wartime destruction in neighboring locations affects a location’s own socioeconomic composition, because bombing changes the types of buildings and hence the socioeconomic composition in neighboring locations, and residential decisions for the own location are affected by the socioeconomic composition of neighboring locations.

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21 Although “right to buy” sales transferred ownership to the private sector, demolitions were relatively rare, with only 140,000 council units demolished in England since 1997, when official data on demolitions were first published. The 1988 Housing Act reduced the barriers for local authorities to transfer council housing units to housing associations and led to a number of such transfers. To control for this policy change, we re-estimated Columns (4) and (5) in Table 5 counting housing association tenants as council tenants, and find similar results.
5 Theoretical Framework

Guided by these empirical findings, we now develop our theoretical model of neighborhood effects. We consider a setting in which workers from different socioeconomic groups (low, middle and high-income) endogenously sort across residences and workplaces. Residential choices for each group of workers depend on amenities, which are determined by location characteristics (including building quality) and neighborhood effects (the socioeconomic composition of the surrounding areas). We suppose that higher income workers value high-quality buildings and high-socioeconomic status more than lower-income workers. We interpret wartime bombing as an exogenous shock that permanently changes building quality, which affects patterns of spatial sorting, both directly (through preferences for building quality), and indirectly (though preferences over the resulting changes in socioeconomic composition). We focus on steady-state comparisons of a pre-war equilibrium (during the 1930s) and a post-war equilibrium (during the 2000s), in line with the availability of our data for these two time periods.

We consider a city (London) that is embedded in a wider economy (Britain). The city consists of a discrete set of locations \( n, i \in \mathbb{N} \), which correspond to the Output Areas in our data, where the total number of these locations is \( N = |\mathbb{N}| \). Time is discrete and is indexed by \( t \). The three socioeconomic groups correspond to different occupations indexed by \( o \in \mathbb{O} = \{L, M, H\} \): low-income \((L)\), middle-income \((M)\) and high-income \((H)\). Workers are perfectly mobile within the city and the wider economy. Therefore, the wider economy provides a reservation level of utility for each occupation \( (U^o_t) \), which determines the total population of workers from each occupation in the city \( (\tilde{L}^o_t) \). Firms produce a single final good, which is costlessly traded within the city and the larger economy, and is chosen as the numeraire \( (P^Y_{nt} = 1) \). We allow locations to differ from one another in terms of their attractiveness for production and residence, as determined by productivity, amenities, the supply of floor space, and transport connections, where each of these location characteristics can change over time. Throughout the following, we use bold math font to denote vectors or matrices.

5.1 Preferences

The instantaneous indirect utility for worker \( \psi \) from occupation \( o \) residing in location \( n \) and working in location \( i \) is assumed to depend on her wage \( (w^o_{nt}) \), the price of the homogenous final consumption good \( (P^Y_{nt}) \), the price of residential floor space \( (Q^o_{nt}) \) adjusted for building quality \( (\zeta^o_{nt}) \), commuting costs \( (\kappa^o_{nt}) \), amenities that are common for all workers from the same occupation \( (B^o_n) \), and an idiosyncratic amenity draw \( (z^o_{nt}(\psi)) \) for each individual worker, according to the

\[ U^o_t(n, i, \psi) = w^o_{nt} + \sum_{i} (P^Y_{nt} + Q^o_{nt} \zeta^o_{nt} + \kappa^o_{nt} + B^o_n + z^o_{nt}(\psi)) \]

See Online Appendix B for the derivation of all theoretical results in this section of the paper.
following Cobb-Douglas functional form:

\[ U_{nit}^{\alpha_o}(\psi) = \frac{B_{nit}^{\alpha_o}(\psi) w_{it}^{\alpha_o}}{\kappa_{nit}^{\alpha_o}(\psi) (Q_n^{\alpha_o})^{1-\alpha_o}}. \quad 0 < \alpha_o < 1, \quad (5) \]

where \( Q_n \) is the price of residential floor space and we assume that bilateral commuting costs \((\kappa_{nit})\) are increasing in bilateral travel times \((\tau_{nit})\). We allow the share of residential floor space to vary across occupations, such that for example residential floor space can account for a larger share of expenditure for lower-income workers: \( 1 - \alpha_L > 1 - \alpha_M > 1 - \alpha_H \).

We assume that common amenities \( (B_{nit}^{\alpha_o}) \) depend on three components: (i) the fraction of the pre-war built-up area destroyed \((D_{nit} \in [0, 1])\); (ii) neighborhood effects from surrounding socioeconomic composition \((B_{nt})\); (iii) exogenous fundamentals \((b_{nt})\):

\[ B_{nit}^{\alpha_o} = \exp(\eta_{D}^{\alpha_o} D_{nit}) \frac{\eta_{R}^{\alpha_o}}{B_{nit}} b_{nt}^{\alpha_o}. \quad (6) \]

We allow fundamentals, wartime destruction and neighborhood effects to be valued differently across occupations, as captured by \( \eta_{D}, \eta_{R}^{\alpha_o} \) and \( b_{nt}^{\alpha_o} \). A negative direct impact of wartime destruction on amenities through a lower quality of reconstructed buildings corresponds to \( \eta_{D} < 0 \).

We model neighborhood effects as depending on the measure of residents in each occupation in each location \((\tilde{R}_o)\) through the function \( B_{nt} = B_{nt} \{ \tilde{R}_o \}_{o \in O, i \in N} \). Stronger neighborhood effects from surrounding socioeconomic composition correspond to larger \( \eta_{R}^{\alpha_o} \).

Idiosyncratic amenities \( (z_{nit}^{\alpha_o}(\psi)) \) are assumed to be drawn from an independent extreme value (Fréchet) distribution each period for each worker \( \psi \), occupation \( o \), residence \( n \) and workplace \( i \):

\[ G_{nit}^{\alpha_o}(z) = e^{-e^{\alpha_o} \cdot z}, \quad \epsilon^{\alpha_o} > 1, \quad (7) \]

where we normalize the Fréchet scale parameter in equation (7) to one, because it enters worker choice probabilities isomorphically to common amenities \( (B_{nit}^{\alpha_o}) \) from equation (5); a larger value for the Fréchet shape parameter \( \epsilon^{\alpha_o} \) implies less dispersion in idiosyncratic amenities, which in turn implies that workers’ location decisions are more responsive to economic variables relative to idiosyncratic amenities. Therefore, lower-income workers’ location decisions are more sensitive to economic variables if \( \epsilon^L > \epsilon^M > \epsilon^H \).

### 5.2 Production

Production occurs under conditions of perfect competition and constant returns to scale. We assume that the tradable final good is produced using labor and commercial floor space according to a Cobb-Douglas technology. Therefore, the following zero-profit condition must hold in each location with positive production of the tradable final good:

\[ 1 = \frac{1}{A_{it}^{\beta} q_{it}^{1-\beta}}, \quad 0 < \beta < 1, \quad (8) \]
where $A_{it}$ is productivity; $q_{it}$ is the price of commercial floor space; and $W_{it} = W_{it} (\{w_{it}^o\}_{o \in O})$ is a constant returns to scale labor cost index in wages for each occupation ($w_{it}^o$).

We assume that productivity ($A_{it}$) depends on three components: (i) the fraction of the pre-war built-up area destroyed ($D_{it} \in [0, 1]$); (ii) agglomeration forces from the surrounding concentration of employment ($A_{it}$); (iii) exogenous fundamentals ($a_{it}$):

$$A_{it} = \exp(v_D D_{it}) A_{it}^E a_{it}.$$  \hfill (9)

The parameters $v_D$ and $v_E$ control the relative importance for productivity of wartime destruction and agglomeration forces. We allow agglomeration forces to depend on employment in each occupation in each location ($E_{it}^o$) through the function $A_{it} = A_{it}^E \left( \{E_{it}^o\}_{o \in O, t \in N} \right)$.

### 5.3 Residence and Workplace Decisions

Workers from each occupation choose their residence and workplace to maximize their utility. Using the properties of the Fréchet distribution, the probability that a worker from occupation $o$ chooses to live in location $n$ and work in location $i$ is given by:

$$\lambda_{nit}^o = \frac{E_{nit}^o}{E_{it}^o} = \frac{(B_{it}^o w_{it}^o)^{e_o} \left( \kappa_{nit}^o Q_{nt}^{1-\alpha^o} \right)^{-e_o}}{\sum_{k \in N} \sum_{t \in N} (B_{kt}^o w_{kt}^o)^{e_o} \left( \kappa_{kt}^o Q_{kt}^{1-\alpha^o} \right)^{-e_o}}, \quad n, i \in N,$$  \hfill (10)

where $E_{nit}^o$ is the measure of commuters from residence $n$ to workplace $i$ in occupation $o$, and we have used our choice of numeraire ($P_{nt}^Y = 1$).

Therefore, bilateral commuting flows satisfy a gravity equation, consistent with a wide range of empirical evidence. In our specification, this gravity equation holds by occupation, such that workers from different occupations sort endogenously across residence-workplace pairs, based on differences in amenities ($B_{it}^o$), wages ($w_{it}^o$), expenditure shares on residence floor space ($1 - \alpha^o$), and responsiveness to economic variables relative to idiosyncratic amenities ($e^o$).

Summing across workplaces $i$, we obtain the probability that a worker from occupation $o$ lives in each residence $n$ ($\lambda_{nt}^{Ro} = R_{nt}^o / E_{it}^o$) can be written as:

$$\lambda_{nt}^{Ro} = \frac{R_{nt}^o}{E_{it}^o} = \frac{(B_{nt}^o RMA_{nt}^o)^{e_o} \left( Q_{nt}^{1-\alpha^o} \right)^{-e_o}}{\sum_{k \in N} (B_{kt}^o RMA_{kt}^o)^{e_o} \left( Q_{kt}^{1-\alpha^o} \right)^{-e_o}}, \quad RMA_{nt}^o \equiv \left[ \sum_{t \in N} \left( w_{nt}^o / \kappa_{nit}^o \right)^{e_o} \right]^{\frac{1}{e_o}}.$$  \hfill (11)

Intuitively, a location attracts more residents within an occupation if it offers higher amenities ($B_{nt}^o$), higher residential commuting market access ($RMA_{nt}^o$), and a lower price of residential floor space ($Q_{nt}$). Residential commuting market access ($RMA_{nt}^o$) is a commuting-cost weighted average of wages in each employment location.

\[\text{See for example} \text{ McFadden (1974), Fortheringham and O’Kelly (1989), and McDonald and McMillen (2010).}\]
Summing across residences $n$, we obtain the probability that a worker from occupation $o$ is employed in each workplace $i$ ($\lambda_{it}^{Eo} = E_{it}^{o}/\widehat{E}_{i}$):

$$\lambda_{it}^{Eo} = \frac{E_{it}^{o}}{\widehat{E}_{i}} = \frac{(w_{it}^{o}WMA_{it})^{\epsilon^{o}}}{\sum_{\ell \in \mathbb{N}} (w_{it}^{o}WMA_{it})^{\epsilon^{o}}}, \quad WMA_{it}^{o} \equiv \left[ \sum_{n \in \mathbb{N}} (B_{nt}^{o})^{\epsilon^{o}} (\kappa_{nt}^{o} Q_{nt}^{1-\alpha^{o}})^{-\epsilon^{o}} \right]^{\frac{1}{\epsilon^{o}}} . \quad (12)$$

Intuitively, a location’s attracts a larger share of employment within an occupation if it offers higher wages ($w_{it}^{o}$) and higher workplace market access ($WMA_{it}^{o}$). Workplace market access ($WMA_{it}^{o}$) is a commuting-cost weighted average of amenities and the price of residential floor space ($Q_{nt}$) in each residential location.

Finally, expected utility conditional on choosing a residence-workplace pair for each occupation is equalized across all residence-workplace pairs and equal to the reservation level of utility in the wider economy ($\bar{U}_{i}^{o}$) for that occupation:

$$\bar{U}_{i}^{o} = \vartheta^{o} \left[ \sum_{k \in \mathbb{N}} \sum_{\ell \in \mathbb{N}} (B_{kt}^{o} w_{lt}^{o})^{\epsilon^{o}} (\kappa_{kt}^{o} Q_{kt}^{1-\alpha^{o}})^{-\epsilon^{o}} \right]^{\frac{1}{\epsilon^{o}}} , \quad (13)$$

where $\vartheta^{o} \equiv \Gamma\left(\frac{\epsilon^{o} - 1}{\epsilon^{o}}\right)$; and $\Gamma(\cdot)$ is the Gamma function. Intuitively, bilateral commutes with attractive characteristics (high workplace wages and low residence cost of living) attract additional commuters with lower idiosyncratic amenities, until expected utility (taking into account idiosyncratic amenities) is the same across all bilateral commutes.

Commuter market clearing requires that the measure of employment in each occupation in each location ($E_{it}^{o}$) equals the measure of workers from that occupation commuting there:

$$E_{it}^{o} = \sum_{n \in \mathbb{N}} \lambda_{nit|n}^{Ro} R_{nt}^{o} , \quad (14)$$

where $\lambda_{nit|n}^{Ro}$ is the probability that workers in occupation $o$ commute to workplace $i$ conditional on living in residence $n$:

$$\lambda_{nit|n}^{Ro} = \frac{\lambda_{nit}^{o}}{\lambda_{nt}^{o}} = \frac{(w_{it}^{o} / \kappa_{nt}^{o})^{\epsilon^{o}}}{\sum_{\ell \in \mathbb{N}} (w_{lt}^{o} / \kappa_{nt}^{o})^{\epsilon^{o}}}. \quad (15)$$

Commuter market clearing also implies that per capita income by residence for a worker from occupation $o$ in location $n$ is a weighted average of the wages in all locations, where the weights are these conditional commuting probabilities by residence ($\lambda_{nit|n}^{Ro}$):

$$\lambda_{nt}^{o} = \sum_{i \in \mathbb{N}} \lambda_{nit|n}^{Ro} w_{it}^{o} . \quad (16)$$
5.4 Floor Space Market Clearing

Floor space market clearing requires no-arbitrage between alternative uses of floor space. The share of floor space used commercially \((\theta_{it})\) is:

\[
\theta_{it} = \begin{cases} 
1 & \text{if } q_{it} > \xi_{it} Q_{it}, \\
\in [0, 1] & \text{if } q_{it} = \xi_{it} Q_{it}, \\
0 & \text{if } q_{it} < \xi_{it} Q_{it},
\end{cases}
\]

where \(\xi_{it} \geq 1\) captures the tax equivalent of land use regulations that restrict commercial land use relative to residential land use; we allow this wedge to vary across locations and over time.

We assume that the observed price of floor space in the data is the maximum of the commercial and residential price of floor space: \(Q_{it} = \max \{ q_{it}, Q_{it} \}\). Hence the relationship between observed, commercial and residential floor prices can be summarized as:

\[
Q_{it} = q_{it}, \quad q_{it} > \xi_{it} Q_{it}, \quad \theta_{it} = 1, \\
Q_{it} = q_{it}, \quad q_{it} = \xi_{it} Q_{it}, \quad \theta_{it} \in [0, 1], \\
Q_{it} = Q_{it}, \quad q_{it} < \xi_{it} Q_{it}, \quad \theta_{it} = 0.
\]

We assume that floor space \((F_{it})\) is supplied by a competitive construction sector using physical capital \((M_{it})\) and land \((K_{it})\) according to a Cobb-Douglas technology: \(F_{it} = M_{it}^{\mu} K_{it}^{1-\mu}\). Therefore, the dual cost function for floor space is \(Q_{i} = \mu^{-\mu} (1 - \mu)^{-(1-\mu)} (p_{it}^{M})^{\mu} (p_{it}^{K})^{1-\mu}\), where we assume that capital \((M_{it})\) is supplied perfectly elastically from the wider economy at an exogenous price that is common across all locations \((p_{it}^{M})\), and we use \(p_{it}^{K}\) to denote the price of land \((K_{it})\) in each location. Since the price for capital is the same across all locations, the relationships between the quantities and prices of floor space and land can be summarized as:

\[
F_{i} = \varphi_{i} K_{i}^{1-\mu}, \\
Q_{i} = \chi (p_{i}^{K})^{1-\mu}
\]

where we refer to \(\varphi_{i} = M_{i}^{\mu}\) as the density of development (since it determines the relationship between floor space and land area) and \(\chi\) is a constant.

Residential floor space market clearing implies that payments for the use of residential floor space equal the income from the allocation of floor space to residential use:

\[
\sum_{o \in \Omega} (1 - \alpha_{o}) v_{it}^{o} R_{it}^{o} = Q_{it} \left(1 - \theta_{it}\right) F_{it}.
\]

Similarly, commercial floor space market clearing requires that payments for the use of commercial floor space equal the income from the allocation of floor space to commercial use:

\[
(1 - \beta) \left[ \sum_{o \in \Omega} w_{it}^{o} E_{it}^{o} + q_{it} \theta_{it} F_{it} \right] = q_{it} \theta_{it} F_{it}.
\]

Summing equations (21) and (22), overall floor space market clearing requires that the sum of residential and commercial demand for floor space equals the overall supply of floor space.
5.5 General Equilibrium

We now characterize the general equilibrium of the model. To obtain sharp analytical results, we begin by considering a benchmark version of the model, in which location characteristics are exogenous, and occupations are perfect substitutes up to a vertical shifter for productivity differences. In our quantitative analysis below, we generalize this specification to allow for neighborhood effects, and for occupations to be imperfect substitutes. To simplify notation, we suppress the dependence of variables on time $t$ from now onwards.

In our benchmark version of the model, productivity, amenities and the supply of floor space are exogenous:

$$B^o_n = \exp(\eta^o_D D_n) b^o_n, \text{ with } \eta^o_R = 0; \quad A_n = \exp(\nu_D D_n) a_n, \text{ with } \nu_E = 0; \quad \text{and } F_i = \varphi K_i^{1-\mu}.$$ Therefore, we can characterize general equilibrium using the overall exogenous values of amenities ($B^o_n$) and productivity ($A_n$), without needing to disaggregate them into their components of wartime destruction and fundamentals. We can thus restrict attention to a subset of model parameters ($\alpha^o, \beta, \varepsilon, \mu$), since the other non-zero model parameters ($\eta^o_D, \nu_D$) only affect economic activity through exogenous amenities ($B^o_n$) and productivity ($A_n$).

Additionally, the assumption that occupations are perfect substitutes up to a vertical productivity shifter ($\varsigma^o_i$) simplifies the characterization of equilibrium wages, because the labor cost index is $\mathbb{W}_i = \min_{o \in \mathcal{O}} \{w^o_i / \varsigma^o_i \}$. Therefore, cost minimization implies that the wage for each occupation in each location equals its productivity shifter multiplied by the labor cost index if employment is positive for that occupation and location: $w^o_i = \varsigma^o_i \mathbb{W}_i$ for $E^o_i > 0$.

Given the exogenous fundamentals ($B^o, A, \varphi, K, \varsigma^o$), commuting costs ($\kappa^o$), the reservation levels of utility ($\bar{U}^o$), and the model parameters ($\alpha^o, \beta, \varepsilon^o, \mu$), the general equilibrium of the model is referenced by the residence and workplace choice probabilities for each occupation ($\lambda^{Ro}, \lambda^{Eo}$), wages for each occupation ($w^o$), the prices for residential and commercial floor space ($Q, q$), the fraction of floor space allocated to commercial use ($\theta$), and total city population for each occupation ($\bar{E}_o$). We now establish the following result.

**Proposition 1** Assume exogenous fundamentals and that occupations are perfect substitutes up to vertical productivity differences ($\varsigma^o$). Given the exogenous fundamentals ($B^o, A, \varphi, K, \varsigma^o$), commuting costs ($\kappa^o$), the reservation levels of utility ($\bar{U}^o$), and the model parameters ($\alpha^o, \beta, \varepsilon^o, \mu$), there exists a unique general equilibrium ($\lambda^{Ro}, \lambda^{Eo}, w^o, Q, q, \bar{E}_o$).

**Proof.** See Online Appendix B5.2. ■

Intuitively, in this benchmark case with exogenous location characteristics, there are no agglomeration forces. Therefore, the model’s congestion forces of commuting costs and an inelastic supply of land ensure the existence of a unique equilibrium.
Wartime bombing reduces the supply of floor space through the destruction of buildings. But this reduction in the supply of floor space is only temporary, because these buildings can be rebuilt using the construction technology. Nevertheless, wartime destruction permanently affects the spatial distribution of economic activity through its persistent effects on productivity ($A_n$) and amenities ($B^n_n$). In particular, if reconstructed buildings are of lower quality than those destroyed, wartime destruction reduces amenities ($\eta_D^o < 0$). If higher-income workers care more about these reduced amenities than lower-income workers ($|\epsilon^H_D \eta^H_D| > |\epsilon^M_D \eta^M_D| > |\epsilon^L_D \eta^L_D|$), they will sort away from bombed locations, leading to an endogenous change in socioeconomic composition towards lower-income workers, as in our regressions above. In this benchmark case with no neighborhood effects ($\eta_R = 0$), wartime destruction in neighboring locations does not affect own amenities, and hence only affects the own location through general equilibrium effects from changes in the prices of residential floor space, and the resulting changes in location decisions.

Generalizing this benchmark case to introduce neighborhood effects ($\eta_R^o \neq 0$), wartime destruction in neighboring locations spills over to affect amenities in the own location. If higher-income workers care more about surrounding socioeconomic composition than lower-income workers ($|\epsilon^H_R \eta^H_R| > |\epsilon^M_R \eta^M_R| > |\epsilon^L_R \eta^L_R|$), the shift in socioeconomic composition towards lower-income workers from wartime destruction in neighboring locations makes the own location relative less attractive to higher-income workers, which leads to a further shift in socioeconomic composition towards lower-income workers in the own location.

In the presence of these neighborhood effects for residential decisions ($\eta_R^o \neq 0$) and agglomeration forces for production decisions ($\nu_E \neq 0$), there is the potential for multiple equilibria, if these agglomeration forces are sufficiently strong relative to exogenous differences across locations. An important feature of our empirical approach is that it explicitly addresses the potential for multiple equilibria, as discussed further in the next subsection.

6 Quantitative Analysis

In this section, we estimate the structural model’s parameters for the general case in which there are neighborhood effects and workers from different occupations are imperfect substitutes. Our quantitative analysis has a sequential structure, such that we undertake our analysis in a number of steps, where each step uses results from the previous one, and imposes the minimal set of additional assumptions relative to the previous step.

In a first step in Subsection 6.1, we parameterize the model, such that it rationalizes the observed pre-war data as an equilibrium outcomes. In a second step in Subsection 6.2, we use the observed pre-war and post-war data to solve for the implied changes in wages for each group of workers in each Output Area ($\omega_i^o$). In Subsection 6.3, we use these pre-war and post-war data to
solve for the implied changes in amenities for each group of workers in each Output Area ($B^o_n$). In Subsection 6.4, we separate out changes in amenities into the contributions of changes in fundamentals, the direct effect of wartime destruction and neighborhood effects. We estimate the strength and spatial decay of neighborhood effects using the exogenous variation from wartime destruction.

There are a number of advantages to our quantitative approach. First, we are not required to make any assumptions about the impact of wartime bombing on productivity or about the strength of functional form of agglomeration economies, because we condition on the employment of workers from each occupation in each Output Area in the data. Second, we are not required to make any assumptions about whether the model has a unique equilibrium or multiple equilibrium, because we again condition on the observed equilibrium in the data. Given this observed equilibrium in the data and the structure of the model, we are able to estimate the model’s parameters, regardless of whether or not there could have been another (unobserved) equilibrium for the same parameter values.

### 6.1 Step 1: Parameterization

In a first step, we calibrate the share of housing in expenditure for each group of workers using historical data for London before the Second World War. In particular, we use data from a survey by the Registrar General of 30,000 workers in different occupations in the LCC area in 1887 (Parliamentary Papers 1887). For low, medium and high-income workers, we set the housing expenditure share parameter ($1 - \alpha^o$) equal to the median housing expenditure share for workers in the bottom, middle and top terciles of the income distribution, respectively.

We assume that the labor cost index ($W^i_t$) in the production technology (8) is Cobb-Douglas in the inputs of low-income, medium-income, and high-income workers. We calibrate the cost shares of these three groups of workers using our historical data.

Given our pre-war data on residents by occupation in each output area ($R^o_n$), residential rateable values in each output area ($Q^o_n$), commercial rateable values in each output area ($q^o_n$), and a parameterization of bilateral commuting costs by occupation ($\kappa^o_{ni}$), we use the general equilibrium conditions to solve for other unobserved endogenous variables, such as employment by occupation in each output area ($L^o_n$), and wages by occupation in each output area ($w^o_n$).

### 6.2 Step 2: Wages

In a second step, we solve for changes in wages by occupation between the pre-war and post-war periods using the labor market clearing condition (14). We observe pre-war employment by occupation ($L^o_i$), pre-war residents by occupation ($R^o_n$) and pre-war conditional commuting
probabilities by occupation \((\lambda_{ni|n})\). We also observe changes in employment by occupation \((\hat{L}_i)\), changes in residents by occupation \((\hat{R}_n)\), and changes in travel times \((\hat{\tau}_{ni})\) between the pre-war and post-war periods. Given these pre-war values and observed changes, we can solve for the unique changes in wages by occupation \((\hat{w}_i)\) that satisfy this labor market clearing condition (up to a choice of units in which to measure changes in wages):

\[
L_i^{n} \hat{L}_i^{n} = \sum_{n \in N} \frac{\lambda_{n|n}^{o} (\hat{\tau}_{ni})^{\nu} (\hat{w}_i^{o})^{\varepsilon}}{\sum_{\ell \in N} \lambda_{\ell|n}^{o} (\hat{\tau}_{\ell n})^{\nu} (\hat{w}_\ell^{o})^{\varepsilon}} \hat{R}_n^{o} \hat{R}_n^{o},
\]

whererecall that commuting costs are a power function of travel time, such that \(\kappa_{ni}^{-\phi_o} = \tau_{ni}^{-\phi_o} = \tau_{ni}^{\nu/o},\) and \(\nu/o \equiv -\phi_o \varepsilon/o\). Therefore, we are able to recover changes in wages \((\hat{w}_i)\) without making about the impact of wartime bombing on productivity or about the strength of functional form of agglomeration economies, by using the structure of the commuting market clearing condition in the model and our data on employment \((L_i)\) and residents \((R_n)\) by occupation.

6.3 Step 3: Amenities

In a third step, we solve for changes in amenities by occupation \((\hat{B}_n)\) from the residential choice probabilities \((\lambda_{ni})\). We observe pre-war residential choice probabilities \((\lambda_{ni}^{R})\) and pre-war commuting probabilities \((\lambda_{ni}^{o})\). We observe changes in residential choice probabilities \((\hat{\lambda}_{ni}^{R})\), changes in the price of residential floor space \((\hat{Q}_i)\) and changes in travel times \((\hat{\tau}_{ni})\) between the pre-war and post-war periods. Given our solutions for changes in wages by occupation from the previous step \((\hat{w}_i)\), and our assumed values of the share of housing in expenditure \((1 - \alpha^o)\) and the Fréchet shape parameter \((\varepsilon/o)\) for each occupation, we can solve for the unique changes in amenities by occupation \((\hat{B}_n)\) that satisfy these residential choice probabilities (up to a choice of units in which to measure changes in amenities):

\[
\lambda_{Rn}^{o} \hat{\lambda}_{n}^{R} = \frac{\sum_{i \in N} \lambda_{ni}^{o} (\hat{B}_n^{o})^{\varepsilon/o} (\hat{w}_i^{o})^{\varepsilon/o} (\hat{\tau}_{ni})^{\nu/o} (\hat{Q}_n^{o})^{-(1-\alpha^o)\varepsilon/o}}{\sum_{k \in N} \sum_{\ell \in N} \lambda_{\ell k}^{o} (\hat{B}_k^{o})^{\varepsilon/o} (\hat{w}_\ell^{o})^{\varepsilon/o} (\hat{\tau}_{\ell k})^{\nu/o} (\hat{Q}_k^{o})^{-(1-\alpha^o)\varepsilon/o}}.
\]

Therefore, we are able to recover changes in overall amenities \((\hat{B}_n)\) without making functional form assumptions about their determinants, and without making assumptions about the determinants of productivity, using the structure of the residential choice probabilities in the model, our data on residents \((R_n)\) and our solutions for changes in wages \((\hat{w}_i)\) from the previous step.

6.4 Step 4: Neighborhood Effects

In a fourth step, we separate changes in amenities by occupation \((\hat{B}_n)\) into the contributions of wartime destruction, neighborhood effects and unobserved changes in location fundamentals.
Taking logarithms, and differencing in our specification of amenities (6), we obtain:

\[ \Delta \ln B_n^o = \eta_D^o D_n + \eta_R^o \Delta \ln B_n^o + \Delta \ln b_n^o. \]  

(25)

We assume the following functional form for neighborhood effects (\(B_n\)), such that they depend on the travel-time weighted sum of socioeconomic composition in surrounding locations:

\[ B_n = \sum_{i \in N} e^{-\rho \tau_{ni}} I_i, \]  

(26)

where we measure socioeconomic composition using our index (\(I_i\)) from equation (1).

We estimate the parameters \(\{\eta_D^o, \eta_R^o, \rho\}\) using the identifying assumption that changes in location fundamentals for each occupation are uncorrelated with a location’s own wartime destruction and with wartime in the surrounding buffers:

\[ \mathbb{E}[D_n \times \Delta \ln b_n^o] = 0, \]
\[ \mathbb{E}[D_n,0–100 \times \Delta \ln b_n^o] = 0, \]
\[ \mathbb{E}[D_n,100–200 \times \Delta \ln b_n^o] = 0, \]
\[ \mathbb{E}[D_n,200–300 \times \Delta \ln b_n^o] = 0, \]
\[ \mathbb{E}[D_n,300–400 \times \Delta \ln b_n^o] = 0. \]

Intuitively, this identifying assumption requires that the changes in amenities for each occupation implied by the changes in residents, wages and prices of residential floor space are driven by the direct effects of wartime destruction and indirect effects from changes in surrounding socioeconomic composition.

[XXX Estimation in Progress XXX]

7 Conclusions

An enduring source of debate in the economics and sociology literatures is the relevance of neighborhood effects, according to which individual behavior is influenced by socioeconomic composition. We use the German bombing of London during the Second World War as an exogenous source of variation to estimate the strength of these neighborhood effects.

We begin by providing reduced-form evidence on wartime bombing. We show that wartime destruction is uncorrelated with the pre-war characteristics of locations within narrow geographical grid cells in London, which is consistent with the primitive bomb-aiming technology at the time, and supports its use as an exogenous source of variation. We next show that wartime bombing has a long-run causal impact on building structures in bombed locations, which reduces property values and leads to a shift in socioeconomic composition towards lower-income
residents. Finally, we show that bombing in neighboring locations does not affect building structures in the own location, but does reduce property values and shift socioeconomic composition towards lower-income residents in the own location. We find that these spillover effects from neighboring locations are highly localized within 300 meters.

To rationalize these empirical findings, we develop a theoretical model in which workers from different socioeconomic groups (low, middle and high-income) endogenously sort across residences and workplaces. Residential choices for each group of workers depend on amenities, which are determined by location characteristics (including building quality) and neighborhood effects (the socioeconomic composition of the surrounding areas). We suppose that higher income workers value high-quality buildings and high-socioeconomic status more than lower-income workers. We interpret wartime bombing as an exogenous shock that permanently changes building quality, which affects patterns of spatial sorting, both directly (through preferences for building quality), and indirectly (though preferences over the resulting changes in socioeconomic composition).
References


