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 urban model, in which heterogeneous groups of individuals endogenously sort across locations in response to differences in natural advantages, wartime destruction and neighborhood effects. We find strong and localized neighborhood effects, which magnify the direct impact of wartime destruction, and make a substantial contribution to observed differences in socioeconomic outcomes across locations.

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1 Introduction

A key research question in economics is the explanation of the large observed differences in property prices and socioeconomic outcomes across locations. One class of explanations emphasizes differences in fundamentals, such as green areas and scenic views. According to this perspective, a location with attractive fundamentals, will see its house prices bid up, until only the rich can afford to live there. In contrast, another group of hypotheses stresses neighborhood effects, in which individual behavior is influenced by the surrounding neighborhood. The importance of these two mechanisms is not only fundamental to our understanding of cities but also has important policy implications. If location fundamentals are the dominant force, place-based interventions to revitalize a neighborhood will only succeed to the extent that they can change these fundamentals. If neighborhood effects are more influential, even small place-based interventions can be effective if they shift neighborhood composition.

We use the German bombing of London during the Second World War as a natural experiment to provide evidence on the relative importance of these explanations. First, we show that wartime destruction provides an exogenous shock, in the sense that it is uncorrelated with the pre-war characteristics of locations within geographical grid cells. Second, we show that wartime destruction has long-lasting direct effects on property values and socioeconomic composition in bombed locations, because reconstruction primarily occurred through the construction of council (social) housing. Third, we show that wartime destruction had long-lasting spillover effects on property values and socioeconomic composition in surrounding unbombed locations. Fourth, we develop a quantitative urban model, in which heterogeneous groups of individuals endogenously sort across locations in response to differences in natural advantages, wartime destruction and neighborhood effects. In the presence of these neighborhood effects, wartime destruction in bombed locations spills over to affect surrounding unbombed locations.

To undertake our analysis, 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 the 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 the 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 km 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 km 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.

We then establish that wartime destruction has spillover effects on neighboring locations. After again controlling for geographical location within London using our 1 km 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 7-8 percent, and our index of socioeconomic composition falls by 3 percentage points. These spillover effects decline rapidly with distance, with no 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 amenity-adjusted real income. There is a single final good that is costlessly traded across locations. We allow locations to differ from one another in terms of productivity, amenities, floor space and transport connections.

We interpret wartime destruction as an exogenous shock that changes the relative amenities of a location for low, middle and high-income workers, because the construction of council housing reduces the relative attractiveness of bombed locations for higher-income workers. Housing accounts for a smaller share of expenditure for higher-income workers, which implies that they are more willing to pay higher housing prices in locations that offer higher amenities. As a result, wartime destruction changes 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, such that amenities in one location depend on the characteristics of surrounding locations, this change in relative amenities in bombed locations spills over to affect socioeconomic composition in neighboring unbombed locations. We use our estimated model to undertake counterfactuals to evaluate the role of these neighborhood effects in magnifying the impact of wartime destruction and shaping observed differences in socioeconomic outcomes across locations more broadly.

Our paper is related to several strands of existing research. First, we contribute to research on the internal organization of economic activity within cities, including Fujita et al. (1999), Lucas and Rossi-Hansberg (2002), Ahlfeldt et al. (2015), Allen et al. (2016), Monte et al. (2018), Heblich et al. (2020) and Owens et al. (2020). One strand of this research has been concerned with the spatial sorting of heterogeneous agents, including Fajgelbaum and Gaubert (2020), Tsivanidis (2023) and Gaubert and Robert-Nicoud (2023). We incorporate neighborhood effects into a quantitative urban model of spatial sorting. We use the exogenous variation from wartime destruction to estimate the model's structural parameters. We use the estimated model to undertake counterfactuals to quantify the role of location fundamentals and neighborhood effects in shaping differences in socioeconomic outcomes across locations.

Second, our research contributes to empirical research on urban rebuilding in the wake of disasters, including fires (Siodla 2015, Hornbeck and Keniston 2017, Field et al. 2021), wartime destruction (Davis and Weinstein 2002, Brakman et al. 2004, Bosker et al. 2007, Dericks and Koster 2021, Harada et al. 2022, and Takeda and Yamagishi 2024) and hurricanes (Paxson and Rouse 2008, Fu and Gregory 2019). The effects of these disasters depend on whether the new buildings are upgrades or downgrades of those destroyed. In our empirical setting of post-war London, we show that downgrading dominated, largely because of the construction of council housing. We first use this downgrading of property characteristics in response to wartime destruction to estimate the strength of neighborhood effects. We next use our quantitative urban model to assess the contribution of these neighborhood effects to observed spatial differences in socioeconomic outcomes, even in counterfactual scenarios without wartime destruction.

Third, our work connects to the literature on neighborhood effects in economics and sociology, including Glaeser et al. (1996), Kling et al. (2007), Ellison et al. (2010), Rossi-Hansberg et al. (2010), Ioannides (2013), Galiani et al. (2015), Bayer et al. (2016), Chetty et al. (2016), Fogli and Guerrieri (2019), Ambrus et al. (2020) and Bayer et al. (2022). A relatively small number of these studies use quasi-experimental variation, such as "moving to opportunity" or neighborhood revitalization programs. We exploit a new source of large-scale exogenous variation from wartime destruction in London. We combine this exogenous shock with rich spatially-disaggregated data on socioeconomic outcomes over a long historical time period. We embed our estimates of neighborhood effects in a quantitative urban model that can be used to evaluate their general equilibrium implications for the spatial distribution of economic activity.

Fourth, our paper contributes to empirical research on social housing, including Currie and Yelowitz (2000), Diamond and McQuade (2019), van Dijk (2019), Davis et al. (2019), Blanco (2021), Almagro et al. (2023) and Staiger et al. (2024). One of the key challenges in evaluating the impact of social housing is that its placement is unlikely to be random. We exploit the quasi-experimental variation in the construction of social housing induced by wartime destruction. We combine our quasi-experimental estimates of neighborhood effects with a quantitative urban model to assess their general equilibrium implications.

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 wartime destruction. Section 5 develops our theoretical model. Section 6 estimates the model's parameters. Section 7 reports our counterfactuals. Section 8 summarizes our conclusions.

2 Historical Background

London has a long history of measuring socioeconomic status at a spatially-disaggregated level. In the late 19th-century, Booth (1902), recorded the socioeconomic status of the households in each street segment in London on a series of maps, by discrete categories of occupation and income, which ranged from extreme poverty to the wealthy. In the lead-up to the Second World War, one of Booth's assistants led a London School of Economics study that repeated this analysis as the *New Survey of London Life and Labor (NSOL)*, published in Smith (1930). Using the same methodology, street segments were again classified by discrete categories of socioeconomic status on a series of maps, as illustrated in Figure G.12 in Online Appendix G3.

During the Second World War, London experienced heavy aerial bombardment.[1] After the Fall of France in May 1940, initial attacks by the German air force sought to destroy the British Royal Air Force (RAF). But there was a shift over time to a strategic bombing campaign aimed at breaking the will of the British people to resist. The resulting intense bombardment of London (the "Blitz") lasted from 7 September 1940 to 21 May 1941. Destruction occurred from 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.[2]

After Germany's invasion of the Soviet Union in June 1941, conventional air attacks on London were substantially reduced. 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.[3] These missiles caused destruction in a dartboard pattern throughout the LCC area (and Southern England), reflecting the primitive targeting system, variation in atmospheric conditions, the challenges of developing this new technology, and problems of manufacturing quality.[4]

To keep a record of the destruction of the built-up area, the LCC Architects' Department used detailed pre-war Ordinance 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).[5] 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 1, we display part of one of these maps for an area around Regent's Park in Central London. We observe substantial 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.

As the Second World War progressed, three separate plans were commissioned for post-war

[1]By 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).

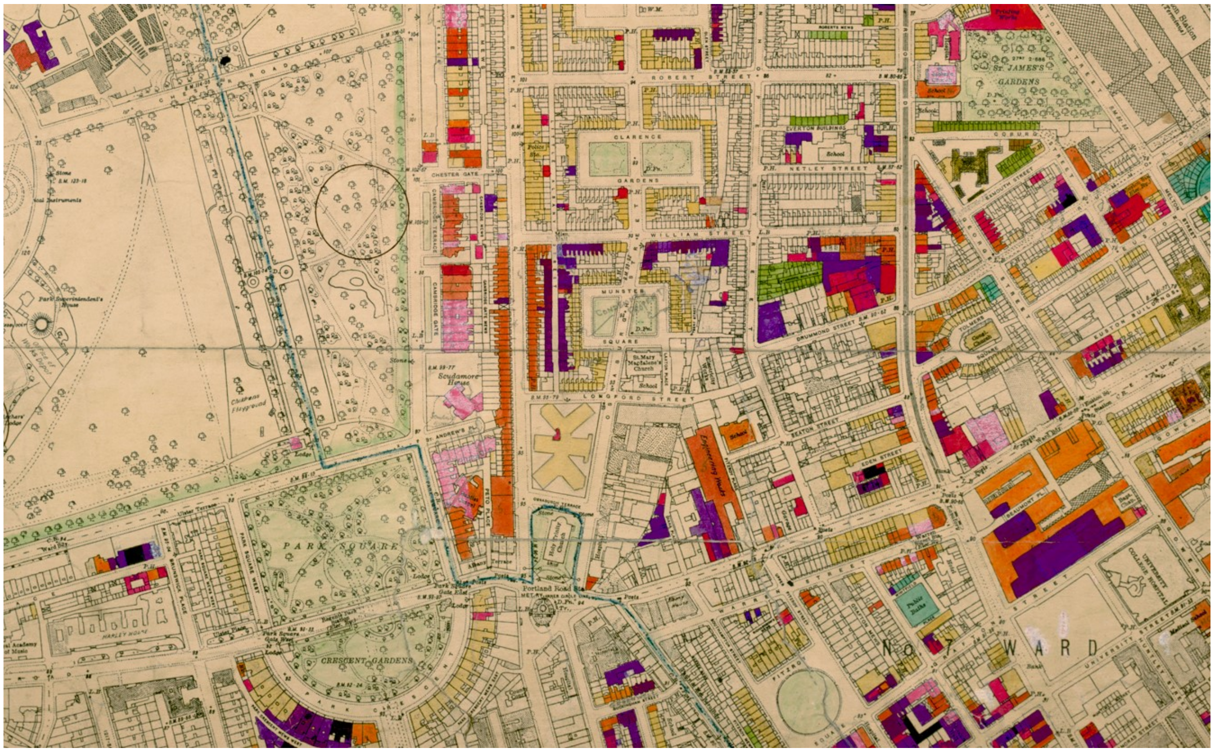
[2]For further discussion of the London Blitz, see for example Ray (2004) and White (2021).

[3]For the history of the development of the V-1 and V-2, see Johnson (1981) and Campbell (2012).

[4]V-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.

[5]The LCC bomb damage maps were recently re-published in Ward (2016).

Figure 1: Excerpt from a LCC Bomb Damage Map for an Area Around Regent's Park



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.

rebuilding for the historical City of London (the Square Mile or old Roman city), the LCC area (which included most of the built-up area), and the larger Greater London region.[6] 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.[7] Motivated in part by notions of shared national sacrifice during the war, and a belief that everyone should have access to decent housing, more than 80 percent of the new housing units constructed in the LCC area up until the end of the 1970s were government-owned council housing units.[8]

[6]See Holden and Holford (1951), Forshaw and Abercrombie (1943) and Abercrombie (1945), respectively. Urban planning in London began with the Barlow Commission of 1940, as discussed in Foley (1963).

[7]The rationing that was introduced in Britain during the war did not end until 1954 (see Kynaston 2008).

[8]See Online Appendix G8, which disaggregates new housing units in both the LCC area and England and Wales as a whole into units owned by local authorities and the private sector.

3 Data

We construct a new spatially-disaggregated dataset that combines property values and socioeconomic composition before and after the Second World War together with information on wartime destruction. A detailed exposition of the data sources and definitions is contained in Online Appendix G. Our data cover the administrative area of London County Council (LCC), which was the principal local government body for London from 1889-1965, with a geographical area of just over 300 kilometers squared, and a total population of 4.4 million in 1931.

Spatial Units We use Output Areas (OAs) from the 2001 population census as our main 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 LCC area. 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 LCC area, with hexagon diameters varying from 1 km (380 hexagons) to 4km (34 hexagons), as discussed further in Online Appendix G1.[9]

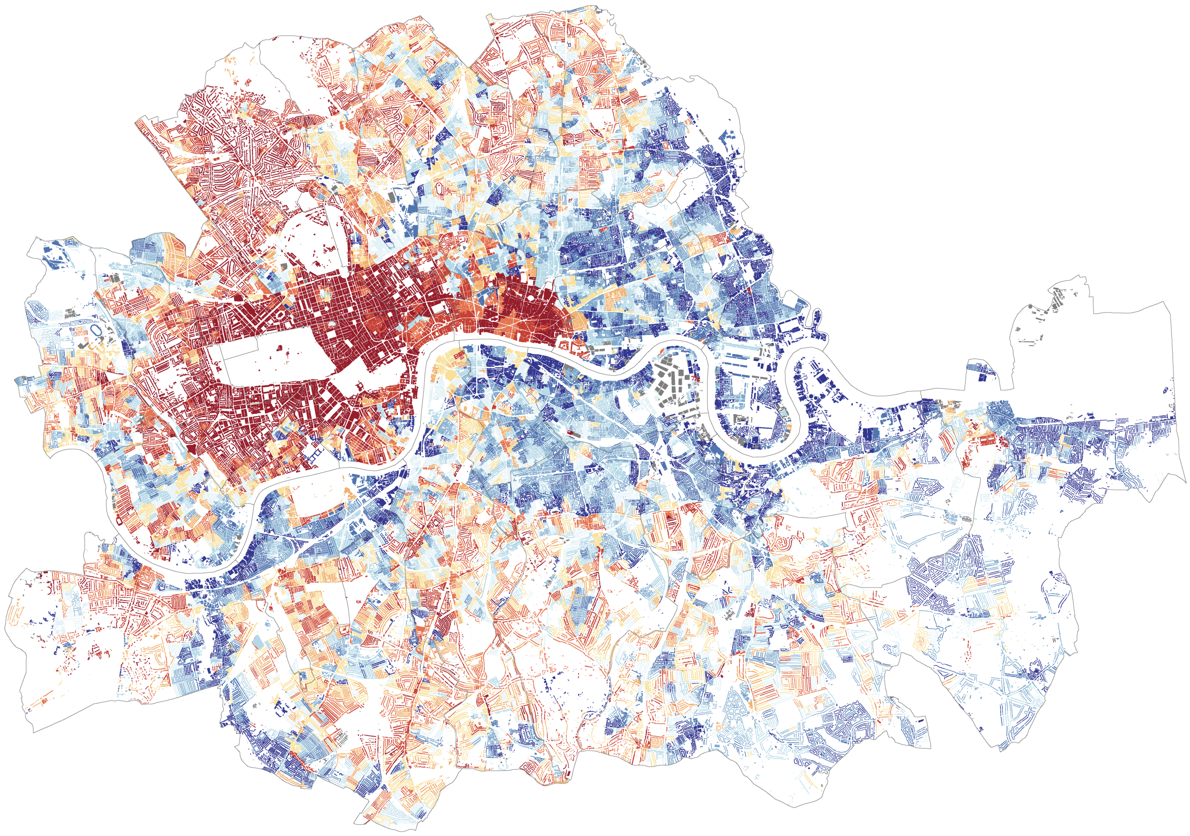
Property Values We measure residential and commercial property values before the Second World War using data on rateable values, which correspond to the market rental value of property for tax purposes. These rateable values have a long history in England and Wales, dating back to the 1601 Poor Relief 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 street 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 valuations 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 2, we show the distribution of pre-war residential property values in the LCC area. We find the highest property values in the most central parts of London and a clear East-West gradient, with higher property values in the West End than in the East End, but substantial variation even within narrow geographical areas.

[9]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).

Figure 2: Pre-War Residential 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 estimate 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 1931 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 Online Appendix G4.

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 socioeconomic categories into three groups of low, middle and high-income. The income thresholds separating these three groups in the NSOL data are weekly-family incomes of £3 and £5 per week, as summarized in Table G.7 in Online Appendix G3.

We also construct an index of socioeconomic status at the Output Area level following Orford et al. (2002). We first assign a score ($\$^o$) to each socioeconomic group $o \in \{L, M, H\}$, which equals the mid-point of the cumulative distribution of residents for the entire LCC area. We next calculate the socioeconomic status ($\$_i$) of each Output Area i as the weighted average of these scores, using the shares of residents in each group for each Output Area (R_i^o / R_i) as weights:

$$\$_i = \left(\frac{R_i^L}{R_i} \times \$^L \right) + \left(\frac{R_i^M}{R_i} \times \$^M \right) + \left(\frac{R_i^H}{R_i} \times \$^H \right). \tag{1}$$

Finally, we rescale this socioeconomic index such that it varies between zero (all residents are low income) to one (all residents are high income). As shown in Figure G.14 in Online Appendix G3, we find a strong pattern of spatial sorting, such that the areas with higher property values in Figure 2 have higher socioeconomic status in Figure G.14.

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.[10] We aggregate these disaggregated occupations into the same three categories of low, middle and high-income, as documented in Online Appendix G6. The low and high-income categories make up 24 and 28 percent of the population in the pre-war period, compared with 22 and 20 percent in the post-war period, respectively. In robustness checks, we also use data on socioeconomic status from the population census for 2011.

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

[10]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).

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.[11] As our baseline measure of war destruction, we use the fraction of 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 do not distinguish between repairable and unrepairable damage, because what is deemed repairable could be endogenous. Finally, as a robustness check, we construct an overall index of war destruction. We first score levels of damage to each building from 0 to 6 (from no to total destruction). We next compute our index of war destruction for each Output Area as the weighted average of these scores, using the shares of its pre-war built-up area with each level of destruction.

In Figure 3, 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 more than 40 percent of the pre-war built-up area experienced some damage (yellow or worse) and around 17 percent experienced serious damage according to our measure.[12] There is a clear East-West gradient, with Eastern areas experiencing more destruction. But the extent of idiosyncratic variation within narrow geographic areas is striking, with substantial destruction in the Western parts of London. This pattern of idiosyncratic variation is consistent with our identifying assumption that war destruction is exogenous within narrow geographic areas.

Other Data We use a variety of other data, including the height of buildings, the fraction of people of living in council housing, and travel time using the transport network.

4 Reduced-Form Evidence

We now present reduced-form evidence on the impact of wartime destruction that guides our theoretical model. Subsection 4.1 shows that wartime destruction is uncorrelated with pre-war characteristics within small geographical areas and hence provides an exogenous source of variation. Subsection 4.2 estimates the causal effect of wartime destruction on post-war outcomes.

[11] 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, Fetzer (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 the bomb damage maps differ substantially from the BombSight data used in Dericks and Koster (2021), which claims to record the locations where German bombs landed. The BombSight data does not record building damage. 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 shown in Online Appendix G2.5.

[12] Clearance areas (green) were areas assigned for post-war development (1.3 percent of the pre-war built-up area), 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.

Figure 3: Second World War Destruction by Building in the LCC Area

Notes: The map shows the bomb damage for each building in the LCC area using the color 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 (1.3 percent of the pre-war built-up area) are in green.

Subsection 4.3 shows that these causal effects spill over to neighboring locations. Subsection 4.4 provides further evidence on the mechanisms through which these causal effects occur.

4.1 Randomness of Second World War Destruction

We estimate the following regression specification between socioeconomic outcomes *before* the Second World War and *subsequent* wartime destruction:

$$Y_{i,\text{pre-war}} = \beta D_{i,\text{war}} + \varrho_k + u_i, \tag{2}$$

where i indexes Output Areas and k indexes hexagonal grid cells; $Y_{i,\text{pre-war}}$ is pre-war socioeconomic status or property values; $D_{i,\text{war}}$ is wartime destruction; ϱ_k are fixed effects for hexagonal grid cells; and u_i is a stochastic error. In our baseline specification, we report standard errors clustered by 1 km hexagons, which allows for spatial correlation across Output Areas within hexagons. As a robustness test, Table F.6 in Online Appendix F3 reports Heteroskedasticity and

Autocorrelation Consistent (HAC) standard errors following Conley (1999).[13]

Table 1 reports estimation results using our baseline measure of wartime destruction, the fraction of the built-up area seriously damaged. Online Appendix F2 documents a similar pattern of results using our damage index. 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 G5. The first row reports results with no fixed effects; the second row presents estimates using fixed effects for hexagons of 4 km diameter; and the third row gives results using fixed effects for hexagons of 1 km diameter.

Table 1: Randomness of Wartime Destruction

Fixed Effects	(1) Fraction High Status	(2) Fraction Middle Status	(3) Fraction Low Status	(4) Socio-Economic Index	(5) Log of Property Value	(6) Log of Property Value
None	−0.235***	0.039*	0.196***	−0.215***	−0.473***	−0.481***
	(0.031)	(0.023)	(0.025)	(0.026)	(0.057)	(0.066)
4 km Hexagons	−0.061***	0.020	0.042**	−0.051***	−0.094**	−0.094**
	(0.020)	(0.018)	(0.017)	(0.016)	(0.041)	(0.044)
1 km Hexagons	−0.007	−0.004	0.011	−0.009	−0.017	−0.024
	(0.014)	(0.013)	(0.012)	(0.012)	(0.033)	(0.033)

Notes: Each cell in the table 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) are pre-war measures of socioeconomic composition from the New Survey of London (fraction of population that has low, middle and high income and an index of socioeconomic status). In column (5) the dependent variable is the logarithm of the average 1936 assessed value of residential buildings without any hedonic controls, and we additionally control for a set of building characteristics in column (6). The explanatory variable is the fraction of the pre-war built-up area seriously damaged during the Second World War. All regressions include either no fixed effects, fixed effects for 4 km hexagons, or 1 km hexagons, as indicated in the first column. The number of observations is 8,720 observations in all regressions as 321 of the 9041 output areas do not have residential built-up area in 1936. * denotes significance at 10% level; ** denotes significance at 5% level; *** denotes significance at 1% level.

In the specification with no fixed effects in the top row, 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 wartime destruction. This pattern of results is consistent with the East-West gradients in Figures 2-3 above. Once we include fixed effects for 4 km hexagons in the middle row, much of this correlation goes away. Nevertheless, 4 km hexagons still cover a relatively large geographical area, and are still likely affected by these East-West gradients. Once we include fixed effects for 1 km hexagons in the bottom row, the coefficients fall close to zero and are

[13] Bertrand et al. (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.

statistically insignificant. Therefore, once we focus on variation within narrow geographical grid cells, wartime damage is entirely unrelated to pre-war socioeconomic status and property values. This pattern of results is consistent with the primitive bomb-aiming technology and night-time bombing, which precluded the precise targeting of locations.[14]

4.2 Direct Effects of Second World War Destruction

We estimate the following regression specification for the causal effect of wartime destruction on post-war outcomes:

$$Y_{i,\text{post-war}} = \beta D_{i,\text{war}} + \varrho_k + u_i \tag{3}$$

where $Y_{i,\text{post-war}}$ is post-war socioeconomic status or property values; the other variables are the same as for specification (2) above; and our baseline specification again reports standard errors clustered by 1 km hexagons.

Table 2 reports the estimation results for our main specification using fixed effects for 1 km hexagons. The columns report results for different post-war outcomes ($Y_{i,\text{post-war}}$). Even after including these fixed effects for 1 km hexagons, we find that Output Areas that experienced more wartime destruction have lower post-war shares of the population who are high and middle status (Columns (1) and (2)); higher post-war shares of the population who are low status (Column (3)); a lower post-war value for our index of socioeconomic status (Column (4)); and lower post-war 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 wartime destruction leading to a downgrading in property characteristics.

These estimates are not only statistically significant but also economically relevant. Comparing undamaged to completely destroyed output areas, the estimated coefficients in Panel A imply 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.

The estimated coefficient on wartime destruction (β) in equation (3) captures an average treatment effect. We also examined potential treatment heterogeneity, by augmenting this regression with interaction terms between wartime destruction and indicator variables for quintiles of pre-war socioeconomic status, where the first quintile is the excluded category. In this augmented specification, the main effect of wartime destruction (β) captures the treatment effect for the first

[14]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) later 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).

Table 2: The Direct Effect of Wartime Destruction

	(1) Fraction High Status	(2) Fraction Middle Status	(3) Fraction Low Status	(4) Socio-Economic Index	(5) Log of Property Value	(6) Log of Property Value
All Damage	-0.039^{***}	-0.023^{***}	0.062^{***}	-0.051^{***}	-0.175^{***}	-0.113^{***}
	(0.006)	(0.005)	(0.009)	(0.007)	(0.022)	(0.018)
Hexagon Fixed Effects	1 km	1 km	1 km	1 km	1 km	1 km
Observations	8912	8912	8912	8912	8112	8112
R-squared	0.505	0.280	0.439	0.483	0.658	0.799

Notes: The unit of observation for all regressions is an output area as defined in the 2001 UK Census. The dependent variables in columns (1) to (4) consist of measures of socioeconomic status from the 2001 UK Census (fraction of the population that has low, middle and high income and an index of socioeconomic status). In column (5) the dependent variable is the logarithm of the average 1995 to 2020 residential property value for output areas with at least 25 transactions over this period, and we additionally control for a set of building characteristics in column (6). The explanatory variable is the fraction of the pre-war built-up area seriously damaged during the Second World War. The unit of observation for all regressions is an output area as defined in the 2001 UK Census and all regressions include fixed effects for 1 km hexagons. Numbers of observations are less than 9041 due to the availability of modern housing transaction data and whether Output Areas had pre-war built-up area. Standard errors are clustered at the 1 km hexagon level. * denotes significance at 10% level; ** denotes significance at 5% level; *** denotes significance at 1% level.

quintile, while the sum of the main effect and the coefficient on the interaction term captures the treatment effect for the other quintiles. As reported in Online Appendix F1, we estimate coefficients on the interaction terms that are substantially smaller than the main effect and in most cases statistically insignificant, suggesting a relatively homogenous treatment effect across quintiles of pre-war socioeconomic status. This pattern of results is consistent with the idea that the negative effect of wartime destruction is mainly driven by the post-war construction of council housing, rather than by the characteristics of the pre-war houses that were destroyed.

We find that this pattern of results is robust across a wide range of specifications. In Online Appendix F2, we corroborate these findings using our index of wartime destruction. In Online Appendix F3, we demonstrate the robustness of our results to using Conley (1999) Heteroskedasticity and Autocorrelation Consistent (HAC) standard errors. In Online Appendix F4, 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 on steady-state outcomes. In Online Appendix F5, 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 long-run impacts. In Online Appendix F6, we establish the same pattern of results if we exclude the Cities of London and Westminster as the main commercial centers, consistent with our results capturing effects through residential activity.

4.3 Spillover Effects of Second World War Destruction

We measure the spillover effects of wartime destruction using buffers of 100-meter width around the built-up area of each Output Area. These buffers exclude the Output Area itself and the area of the next smallest buffer, such that they form a set of hollow concentric rings around each Output Area.[15] We estimate the following regression specification between a location's own post-war outcomes, its own wartime destruction, and the wartime destruction in these buffers:

$$Y_{i,\text{post-war}} = \beta D_{i,\text{war}} + \sum_{g=1}^{G} \gamma_g D_{ig,\text{war}} + \varrho_k + u_i \tag{4}$$

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 km meter hexagons.

Table 3: The Spillover Effect of Wartime Destruction

	Socio-Economic Index		Log of Property Value		Log of Property Value	
	(1)	(2)	(3)	(4)	(5)	(6)
Destruction in own area	−0.051***	−0.042***	−0.175***	−0.157***	−0.113***	−0.097***
	(0.007)	(0.007)	(0.022)	(0.022)	(0.018)	(0.017)
Destruction in 100m buffer		−0.030**		−0.080*		−0.070*
		(0.013)		(0.045)		(0.038)
Destruction in 200m buffer		−0.026		−0.130**		−0.110**
		(0.018)		(0.059)		(0.047)
Destruction in 300m buffer		−0.026		−0.094		−0.100*
		(0.019)		(0.064)		(0.054)
Destruction in 400m buffer		0.004		−0.085		−0.063
		(0.023)		(0.076)		(0.061)
Destruction in 500m buffer		0.001		−0.011		−0.024
		(0.023)		(0.077)		(0.070)
Hexagon Fixed Effects	1 km	1 km	1 km	1 km	1 km	1 km
Observations	8912	8909	8112	8109	8112	8109
R-squared	0.483	0.485	0.658	0.659	0.799	0.800

Notes: The unit of observation for all regressions 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 using 2001 UK Census data, in columns (3) and (4) it is the logarithm of the average residential property value for output areas with at least 25 transactions over the period 1995 to 2020, and we additionally control for a set of building characteristics in column (5) and (6). The explanatory variables are the fraction of the pre-war built-up area seriously damaged in each Output Area and five buffers of 100 meter width around each Output Area during the Second World War. All regressions include fixed effects for 1 km hexagons. Numbers of observations are less than 9041 due to the availability of modern housing transaction data and whether Output Areas and their buffers had pre-war built-up area. Standard errors are clustered at the 1 km hexagon level. * denotes significance at 10% level; ** denotes significance at 5% level; *** denotes significance at 1% level.

Consistent with our results for a location's own wartime destruction in Subsection 4.1, we find that destruction in neighboring locations is uncorrelated with own pre-war socioeconomic

[15] We provide an example of these 100-meter buffers in Figure G.2 in Online Appendix G1.

outcomes, further validating its use as an exogenous source of variation. In Table 3, we report the estimation results for our main specification using 1 km hexagon fixed effects. The columns report results for different post-war outcomes ($Y_{i,\text{post-war}}$); the first row reports the coefficient estimates for own destruction (β); the remaining rows report results for neighboring destruction (γ_g). Columns (1), (3) and (5) replicate our results for the direct effects of destruction from Table 2. Columns (2), (4) and (6) augment these specifications with neighboring destruction, including buffers up to 500 meters around the own location.

We find that the estimated coefficient on own destruction is smaller in absolute value once we control for neighboring destruction. We find statistically significant spillover effects from neighboring destruction. These spillover effects are large, with estimated coefficients for the 100-meter buffer that are substantial relative to the own effects. These spillover effects are also highly localized: by the 500-meter buffer, we find estimated coefficients for all three groups of workers that are close to zero and statistically insignificant. For our socioeconomic index, the estimated coefficient for the 500-meter buffer is around 30 times smaller than that for the 100-meter buffer, and lies outside the confidence interval around that coefficient. In Online Appendix F, we show that these estimates for spillovers in Table 3 are robust across the same set of specifications considered for the direct effect of wartime destruction in the previous subsection.

4.4 Mechanisms

In Online Appendix F7, we provide further evidence on the mechanisms underlying these findings. First, we show that the direct effects of wartime destruction operate through changes in the types of buildings, whereas the spillover effects do not (Columns (1)-(3) of Table F.17). We find that wartime destruction in the own location reduces the probability that buildings lie within the pre-war building footprint; increases the height of buildings; and reduces the share of the land area that is built up, which is in line with post-war architectural trends towards high-rise tower blocks surrounded by open areas.[16] In contrast, wartime destruction in neighboring locations has no effects on the type of buildings in the own location. These results suggest that the spillover effects are not capturing the demolition of undamaged buildings in neighboring areas in response to wartime destruction. Instead these results are consistent with the idea that the spillover effects reflect changes in surrounding neighborhood characteristics.

Second, we show that the direct effects of wartime destruction involve significant changes in the share of households living in council housing, whereas the spillover effects do not (Columns (4)-(5) of Table F.17). From 1945-80, more than 80 percent of all housing units constructed in the LCC area were council housing, as shown in Online Appendix G8. After Margaret Thatcher's 1980

[16]While we find negative effects of wartime destruction on socioeconomic composition in Table 2, we find little impact on population density. In part, this result reflects higher building height being offset by smaller built-up area.

Housing Act the construction of council housing sharply declined and existing council tenants gained the "right to buy" their properties at considerable discounts on the market price, which led to a large transfer to private ownership. We find economically large and statistically significant direct effects of wartime destruction on the share of households living in council housing in both 1981 and 2001, with larger coefficients for 1981 before this transfer to private ownership. In contrast, wartime destruction in neighboring locations has no effects on the share of households living in council housing in either year. Again these results are consistent with the idea that the spillover effects of destruction are not operating through the demolition of undamaged buildings but rather through changes in surrounding neighborhood characteristics.

Third, we provide additional evidence that the impact of wartime destruction is operating through residential rather than commercial activity. As a first approach, we re-estimate our spillovers specification using the log of employment density as the dependent variable. We find a negative and statistically significant direct effect of wartime destruction, with no evidence of statistically significant spillover effects (Column (6) of Table F.17). Therefore, if anything, we find that wartime destruction shifted economic activity towards residential use, which is consistent with our focus on residential activity.

As a second approach, we use residential and commercial destruction as separate sources of variation. In Online Appendix F7.3, we re-estimate our randomization, direct effects and spillover effects specifications using these two separate measures of destruction. We find that both residential and commercial destruction are uncorrelated with pre-war characteristics, validating their use as exogenous sources of variation (Table F.18). Both the direct and spillover effects of wartime destruction are driven by damage to residential buildings (Tables F.19 and F.20), with coefficients for commercial destruction that are close to zero and statistically insignificant. This pattern of results is again consistent with the mechanism of our model, in which wartime destruction operates through changes in residential activity.

Taken together, these empirical findings for spillovers rule out some possible explanations (such as the demolition of undamaged buildings), and are consistent with two potential mechanisms for neighborhood effects. First, residential amenities could depend on the surrounding socioeconomic composition of the population. The post-war construction of council housing in a bombed location shifts socioeconomic composition towards lower-income residents. If higher-income workers care more about surrounding socioeconomic composition than lower-income workers, because of concerns about crime or through the provision of local public goods, this reduces relative amenities for higher-income workers in neighboring unbombed locations.

Second, residential amenities could depend on surrounding buildings. The post-war construction of council housing in a bombed location shifts the composition of buildings towards post-war construction. If higher-income workers care more about surrounding buildings than lower-income residents, because of more refined architectural sensibilities, this reduces relative amenities for higher-income workers in neighboring unbombed locations.

Both these mechanisms feature neighborhood effects, but one stresses people whereas the other emphasizes buildings. Since buildings and people are closely linked through equilibrium spatial sorting, definitively telling these two explanations apart is challenging, but several pieces of evidence cast doubt on an explanation based purely on buildings. First, residents would need to care about residential buildings but not about commercial buildings, since we do not find either direct or spillover effects from commercial destruction. Second, given the distance over which we find spillover effects, residents would need to care about surrounding buildings that are typically not visible from their homes. Third, while people directly affect key components of local amenities, such as crime, the quality of schools and demand for non-traded services, buildings do not. Fourth, while people can walk around and influence the surrounding neighborhood, buildings have a fixed geographical location and easily can be avoided.

In our quantitative analysis, we consider a general specification of neighborhood effects that accommodates both mechanisms, as well as a parameterization of neighborhood effects in terms of the surrounding socioeconomic composition of the population.

5 Theoretical Framework

We next develop a quantitative urban model of spatial sorting to account for our reduced-form empirical findings and evaluate the general equilibrium impact of wartime destruction and neighborhood effects.[17] 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 locations is $N = |\mathbb{N}|$. Time is discrete and is indexed by t. There are two types of agents: workers and landlords. A continuum of workers belong to three occupations $o \in \mathbb{O} = \{L, M, H\}$: low-income ($L$), middle-income ($M$) and high-income ($H$). Workers are geographically mobile within the city and choose a residence and workplace to maximize utility. We consider both a closed-city (an exogenous supply of workers in each occupation ($\overline{E}_t^o$)) and an open-city (the supply of workers in each occupation ($\overline{E}_t^o$) is endogenously determined by population mobility with the wider economy that provides a reservation utility for each occupation ($\overline{U}_t^o$)). The floor space in each location is owned by a local landlord.

Locations differ in productivity, amenities, the supply of floor space, and transport connections, where each of these location characteristics can change over time. Firms produce a single final good under conditions of perfect competition and constant returns to scale. This final good is costlessly traded and chosen as the numeraire ($P_{nt}^Y = 1$). Workers from different occupations are

[17] See Online Appendix B for the derivation of all theoretical results in this section of the paper.

imperfect substitutes in production and receive different wages. They also have different preferences over amenities and housing expenditure shares. 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.

5.1 Preferences

The indirect utility for worker ψ from occupation o residing in location n and working in location i is assumed to depend on her wage (w_{it}^{o}), the price of the homogenous final consumption good (P_{nt}^{Y}), the price of residential floor space (Q_{nt}), bilateral commuting costs (κ_{nit}^{o}), amenities that are common for all workers from an occupation (B_{nt}^{o}), and an idiosyncratic amenity draw ($z_{nit}^{o}(\psi)$):

$$u_{nit}^{o}(\psi) = \frac{B_{nt}^{o} z_{nit}^{o}(\psi) w_{it}^{o}}{\kappa_{nit}^{o} \left(P_{nt}^{Y}\right)^{\alpha^{o}} \left(Q_{nt}\right)^{1-\alpha^{o}}}. \qquad 0 < \alpha^{o} < 1, \tag{5}$$

where we assume different Cobb-Douglas preferences for each worker group, which allows both preferences for amenities (B_{nt}^{o}) and housing expenditure shares (α^{o}) to differ across groups. In Online Appendix C1, we derive similar predictions from a common non-homothetic preference structure for the three worker groups following Bohr et al. (2023).

We begin with a general specification for neighborhood effects, in which residential amenities for workers from each occupation (B_{nt}^{o}) depend on both the characteristics of the own location and the characteristics of surrounding locations. These characteristics include residential fundamentals (b_{nt}), which capture features of physical geography that make a location a more or less attractive place to live independently of surrounding economic activity (e.g., green areas). They also include wartime destruction (D_{nt}), which can affect residential amenities through in particular the post-war construction of council housing on wartime bomb sites:[18]

$$B_{nt}^{o} = B^{o}\left(b_{nt}, D_{nt}, \{b_{-nt}\}, \{D_{-nt}\}\right), \tag{6}$$

where the subscript $-n$ denotes other locations $\{\mathbb{N} \setminus n\}$; the notation $\{b_{-nt}\}$ indicates the set of residential fundamentals in all other locations; the superscript o on the function $B^{o}(\cdot)$ allows residential fundamentals and wartime destruction to have different effects on the residential amenities of workers in different occupations.

This general specification does not take a stand on the mechanism why residential amenities (B_{nt}^{o}) in one location depend on the set of residential fundamentals and wartime destruction in other locations ($\{b_{-nt}\}$, $\{D_{-nt}\}$). We consider below a specific parameterization of neighborhood effects, in which the mechanism connecting residential amenities (B_{nt}^{o}) in one location to

[18]We assume in equation (6) that residential amenities depend directly on wartime destruction. In Online Appendix C2, we derive this relationship from a technology for the construction sector.

the characteristics of surrounding locations ($\{b_{-nt}\}$, $\{D_{-nt}\}$) is preferences over the surrounding socioeconomic composition of the population.

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

$$G^o_{nit}(z) = e^{-z^{-\epsilon^o}}, \qquad \epsilon^o > 1, \tag{7}$$

where we normalize the Fréchet scale parameter in equation (7) to one, because it enters worker choice probabilities isomorphically to common amenities (B^o_{nt}) from equation (5). A larger value for the Fréchet shape parameter ϵ^o implies less dispersion in idiosyncratic amenities, such that location decisions are more responsive to economic variables relative to idiosyncratic amenities. We allow this shape parameter to vary across occupations, such that low-income residents can be more sensitive to differences in real income than high-income residents.

We assume that floor space in each location is owned by a local landlord, who receives expenditure on floor space as income, and for simplicity consumes only the final good.

5.2 Production

Production occurs under conditions of perfect competition and constant returns to scale. We assume that the single 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 this tradable final good:

$$1 = \frac{1}{A_{it}} \mathbb{W}^{\beta}_{it} q^{1-\beta}_{it}, \qquad 0 < \beta < 1, \tag{8}$$

where A_{it} is productivity; q_{it} is the price of commercial floor space; and $\mathbb{W}_{it}$ is a constant elasticity of substitution (CES) labor cost index that depends on the wages for each occupation (w^o_{it}):

$$\mathbb{W}_{it} = \left[\left(\frac{w^L_{it}}{\gamma^L} \right)^{1-\sigma} + \left(\frac{w^M_{it}}{\gamma^M} \right)^{1-\sigma} + \left(\frac{w^H_{it}}{\gamma^H} \right)^{1-\sigma} \right]^{\frac{1}{1-\sigma}}, \tag{9}$$

where (γ^L, γ^M, γ^H) control the relative importance of each occupation in labor costs, with $\gamma^H = 1 - \gamma^M - \gamma^L$, and $\sigma > 1$ is the elasticity of substitution across the three worker groups. Applying Shephard's Lemma, the share of each occupation in labor costs is:

$$s^o_{it} = \frac{\left(w^o_{it} / \gamma^o \right)^{1-\sigma}}{\sum_{\ell \in \mathbb{O}} \left(w^\ell_{it} / \gamma^\ell \right)^{1-\sigma}}. \tag{10}$$

We begin with a general specification for productivity (A_{it}), in which productivity in each location depends on the characteristics of the own location and the characteristics of surrounding locations. These characteristics include production fundamentals (a_{it}), which capture features of physical geography that make a location a more or less attractive place to produce independently of surrounding economic activity (e.g., access to natural water). They also in principle could include wartime destruction (D_{it}):

$$A_{it} = A\left(a_{it}, D_{it}, \{a_{-it}\}, \{D_{-it}\}\right), \tag{11}$$

where this general specification again does not take a stand on the mechanism why productivity (A_{it}) in one location depends on the set of production fundamentals and wartime destruction in other locations ($\{a_{-it}\}$, $\{D_{-it}\}$).

One potential mechanism for these spillovers is agglomeration forces, where productivity depends on surrounding employment, which in turn depends on surrounding production fundamentals. An advantage of our econometric approach below is that we can estimate the effect of wartime destruction on residential amenities without taking a stand on agglomeration forces, because productivity only affects residential location decisions through wages and the price of floor space. Using the price of residential floor space, residents and wages in residential choice probabilities, we recover amenities and estimate the impact of wartime destruction on amenities. Only when we undertake counterfactuals do we need to make assumptions about agglomeration forces in production.

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:

$$\lambda_{nit}^{o} = \frac{E_{nit}^{o}}{\overline{E}_{t}^{o}} = \frac{\left(B_{nt}^{o} w_{it}^{o}\right)^{\epsilon^{o}} \left(\kappa_{nit}^{o} Q_{nt}^{1-\alpha^{o}}\right)^{-\epsilon^{o}}}{\sum_{k \in \mathbb{N}} \sum_{\ell \in \mathbb{N}} \left(B_{kt}^{o} w_{\ell t}^{o}\right)^{\epsilon^{o}} \left(\kappa_{k\ell t}^{o} Q_{kt}^{1-\alpha^{o}}\right)^{-\epsilon^{o}}}, \qquad n, i \in \mathbb{N}, \tag{12}$$

where E_{nit}^{o} is the measure of commuters from residence n to workplace i in occupation o; we have used our choice of numeraire ($P_{nt}^{Y} = 1$); and the term $\left(B_{nt}^{o} w_{it}^{o}\right) / \left(\kappa_{nit}^{o} Q_{nt}^{1-\alpha^{o}}\right)$ in the numerator and denominator captures amenity-adjusted real income.

From these commuting probabilities, bilateral commuting flows satisfy a gravity equation, consistent with empirical evidence.[19] This gravity equation holds by occupation, such that workers from different occupations sort endogenously across residence-workplace pairs, based on differences in amenities (B_{nt}^{o}), wages (w_{nt}^{o}), the price of residential floor space (Q_{nt}), commuting costs (κ_{ni}^{o}), expenditure shares ($1 - \alpha^{o}$), and the preference dispersion parameter (ϵ^{o}).

[19] See for example McFadden (1974), Fortheringham and O'Kelly (1989), and McDonald and McMillen (2010).

Summing across workplaces i in equation (12), we obtain the share of workers from occupation o who live in residence n ($\lambda_{nt}^{Ro} = R_{nt}^{o}/\bar{E}_{t}^{o}$), where R_{nt}^{o} is the measure of residents from occupation o in location n. Summing across residences n in equation (12), we obtain the share of workers from occupation o who are employed in each workplace i ($\lambda_{it}^{Eo} = E_{it}^{o}/\bar{E}_{t}$), where E_{it}^{o} is the measure of employment from occupation o in location i. With a continuous measure of workers, there is no uncertainty in the supply of either residents or workers for each location.

Finally, expected utility conditional on choosing a residence-workplace pair for each occupation (U_{t}^{o}) is equalized across all residence-workplace pairs:

$$U_{t}^{o} = \mathbb{E}_{t}\left[u_{t}^{o}\right] = \vartheta^{o}\left[\sum_{k\in\mathbb{N}}\sum_{\ell\in\mathbb{N}}\left(B_{kt}^{o}w_{\ell t}^{o}\right)^{\epsilon^{o}}\left(\kappa_{k\ell t}^{o}Q_{kt}^{1-\alpha^{o}}\right)^{-\epsilon^{o}}\right]^{\frac{1}{\epsilon^{o}}}, \tag{13}$$

where $\mathbb{E}_{t}$ is the expectation operator with respect to the distribution of idiosyncratic amenities; $\vartheta^{o} \equiv \Gamma\left(\frac{\epsilon^{o}-1}{\epsilon^{o}}\right)$; and $\Gamma(\cdot)$ is the Gamma function. Intuitively, bilateral pairs with more desirable economic characteristics (e.g., low commuting costs) attract commuters with lower realizations for idiosyncratic amenities, until expected utility (including idiosyncratic amenities) is the same across all bilateral residence-workplace pairs.

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

$$E_{it}^{o} = \sum_{n\in\mathbb{N}}\lambda_{nit|n}^{Ro}R_{nt}^{o}, \qquad \lambda_{nit|n}^{Ro} \equiv \frac{\lambda_{nit}^{o}}{\lambda_{nt}^{Ro}} = \frac{\left(w_{it}^{o}/\kappa_{nit}^{o}\right)^{\epsilon^{o}}}{\sum_{\ell\in\mathbb{N}}\left(w_{\ell t}^{o}/\kappa_{n\ell t}^{o}\right)^{\epsilon^{o}}}, \tag{14}$$

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

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

$$v_{nt}^{o} = \sum_{i\in\mathbb{N}}\lambda_{nit|n}^{Ro}w_{it}^{o}. \tag{15}$$

We assume that commuting costs are a power function of travel times (τ_{nit}) using the transport network ($(\kappa_{nit}^{o})^{-\epsilon^{o}} = \tau_{nit}^{-\epsilon^{o}\kappa} = \tau_{nit}^{-\phi^{o}}$); $\phi^{o} \equiv \epsilon^{o}\kappa$ is the product of the elasticity of commuting flows to commuting costs (ϵ^{o}) and the elasticity of commuting costs to travel time (κ).

5.4 Floor Space Market Clearing

Given the supplies of floor space allocated to residential (H_{it}^{R}) and commercial use (H_{it}^{E}), the prices of residential (Q_{it}) and commercial (q_{it}) floor space are determined by the equalities between the demands and supplies for each use of floor space:

$$Q_{it} = \frac{\sum_{o \in \mathbb{O}} (1-\alpha^o) v_{it}^o R_{it}^o}{H_{it}^R}, \tag{16}$$

$$q_{it} = \frac{1-\beta}{\beta} \frac{\left[\sum_{o \in \mathbb{O}} w_{it}^o E_{it}^o\right]}{H_{it}^E}. \tag{17}$$

In our estimation of the model's parameters, we do not need to take a stand on how the supplies of residential and commercial floor space (H_{it}^R, H_{it}^E) are determined. Instead, we use the model's equilibrium conditions and the observed endogenous variables to solve for the implied supplies of floor space. When we undertake counterfactuals, our baseline specification holds these supplies of floor space fixed, which is motivated by our empirical setting, in which the reallocation of land between residential and commercial use was heavily restricted following the Town and Country Planning Act of 1942. In robustness checks, we undertake counterfactuals allowing for endogenous responses in the supply of floor space.

5.5 General Equilibrium

We now characterize the general equilibrium of the model. The spatial distribution of economic activity is determined by the model parameters ($\alpha^o, \beta, \gamma^o, \sigma, \epsilon^o, \kappa$); functions for amenities ($B^o(\cdot)$) and productivity ($A(\cdot)$); and location characteristics: residential fundamentals (b_{nt}), production fundamentals (a_{nt}), wartime destruction (D_{nt}), land area (K_n), travel times (τ_{nit}), and the supplies of residential (H_{nt}^R) and commercial (H_{nt}^E) floor space.

The open-city general equilibrium is referenced by the residence and workplace choice probabilities for each occupation ($\lambda_{nt}^{Ro}, \lambda_{nt}^{Eo}$), wages for each occupation (w_{nt}^o), the prices for residential and commercial floor space (Q_{nt}, q_{nt}), and the total city population for each occupation ($\overline{E}_t^o$). Given these equilibrium variables, all other endogenous variables can be recovered. We now provide a sufficient condition for the existence of a unique equilibrium in the special case of neither neighborhood effects nor agglomeration forces, in which amenities and productivity in each location only depend on its own exogenous characteristics: $\overline{B}_{nt}^o = B^o(b_{nt}, D_{nt})$ and $\overline{A}_{nt} = A(a_{nt}, D_{nt})$. We show that the system of general equilibrium conditions in the model can be written in the form required to apply Theorem 1 from Allen et al. (2024).

Proposition 1 *Assume exogenous productivity ($\overline{A}_{nt}$) and amenities ($\overline{B}_{nt}^o$). Given the location characteristics ($\overline{B}_{nt}^o, \overline{A}_{nt}, D_{nt}, K_n, \tau_{nit}, H_{nt}^R, H_{nt}^E$), a sufficient condition for the existence of a unique general equilibrium ($\lambda_{nt}^{Ro}, \lambda_{nt}^{Eo}, w_{nt}^o, Q_{nt}, q_{nt}, \bar{E}_t^o$) (up to scale) is that the spectral radius of a coefficient matrix of model parameters ($\alpha^o, \beta, \gamma^o, \sigma, \epsilon^o, \kappa$) is less than or equal to one.*

Proof. See Online Appendix B5.1. ■

In general, with sufficiently strong neighborhood effects and agglomeration forces, there is the potential for multiple equilibria in the model. An important feature of our estimation approach is that it is robust to the presence of multiple equilibria, because we condition on the observed equilibrium in the data. Given this observed equilibrium and the structure of the model, we are able to estimate the neighborhood effects parameters, regardless of whether there could have been another (unobserved) equilibrium for the same parameter values.

If $0 < \alpha^L < \alpha^M < \alpha^H < 1$, housing accounts for a larger share of expenditure for lower-income workers. If $\epsilon^L > \epsilon^M > \epsilon^H$, lower-income workers are more sensitive to differences in amenity-adjusted real income across residence-workplace pairs. When both of these conditions are satisfied, locations with higher equilibrium prices for residential floor space tend to have lower equilibrium shares of low-income workers, other things equal. Nevertheless, this spatial sorting is imperfect because of the idiosyncratic preference shocks.

Wartime destruction affects the spatial distribution of economic activity in the model through four mechanisms. First, wartime destruction leads to a temporary reduction in the supply of residential and commercial floor space, until reconstruction occurs. In our baseline specification, we assume that the supply of residential and commercial floor space is rebuilt to its pre-war values, such that there is no permanent impact through this channel. In robustness specifications, we allow for endogenous changes in the supply of floor space.

Second, wartime destruction affects residential amenities for each occupation in bombed locations through the construction of council housing. As this construction of council housing reduces amenities for higher-income workers relative to lower-income, it leads higher-income workers to sort out of bombed locations, and lower-income workers to sort into these locations.

Third, if residential amenities in one location depend on the characteristics of surrounding locations through neighborhood effects, the direct effects of wartime destruction in bombed locations can spill over to surrounding unbombed locations. In this case, the reduction in relative amenities for higher-income workers in bombed locations makes their unbombed neighbors less attractive to higher-income workers.

These direct and spillover effects of wartime destruction on residential amenities change patterns of spatial sorting. The mechanisms that restore equilibrium are changes in wages and the prices of residential and commercial floor space, until firms make zero profits in each location with positive production, and expected utility for workers from a given occupation is the same across all residence-workplace with positive commuters from that occupation.

Finally, wartime destruction in principle can affect productivity. We use the separability of our econometric approach to estimate the effects of wartime destruction on residential amenities without taking a stand on its effects on productivity.

6 Quantitative Analysis

In this section, we quantify the model using the observed data and estimate its parameters. Our quantitative analysis has a sequential structure, such that we proceed in a number of steps, where we provide further details on each step in Online Appendix D.

6.1 Preference and Production Parameters (Step 1)

We calibrate the housing expenditure shares $(1-\alpha^o)$ for each group of workers using a British Ministry of Labor household expenditure survey from 1937-8. We distinguish low, middle and high-income households using the £3 and £5 thresholds for weekly-family income that separate these three groups in our NSOL data. We set the household expenditure share for each group equal to the mean across households within that group, which yields $(1-\alpha^L) = 0.26$, $(1-\alpha^M) = 0.22$, and $(1-\alpha^H) = 0.16$. Therefore, we find an intuitive pattern, in which housing expenditure accounts for a lower share of expenditure for higher-income workers.[20]

We assume a value for the share of labor in production costs of $\beta = 0.55$, which lies in the middle of the range of 0.43-0.63 reported in Antràs and Voth (2003), and is close to the labor share reported for Britain in 1913 in Matthews et al. (1982). The remaining share of production costs of $(1-\beta) = 0.45$ is attributed to commercial floor space, including capital (machinery, equipment, buildings and structures) and land.

6.2 Commuting Parameters (Step 2)

We estimate the model's commuting parameters using data on bilateral commuting flows. Pre-war commuting data are not disaggregated by worker group and are only available for the relatively aggregated spatial units of the 29 LCC boroughs. Therefore, we use post-war data on bilateral commuting flows by worker group, which are available for 356 Middle Super Output Areas in the LCC area from the 2011 Population Census. Re-writing equation (12), we estimate the following gravity equation for each worker group separately:

$$\lambda^o_{nit} = \eta^{Ro}_{nt}\eta^{Lo}_{it}\tau^{-\phi^o}_{nit}\zeta^o_{nit}, \tag{18}$$

where recall $((\kappa^o_{nit})^{-\epsilon^o} = \tau^{-\epsilon^o\kappa}_{nit} = \tau^{-\phi^o}_{nit})$; η^{Ro}_{nt} are residence fixed effects that capture amenities (B^o_{nt}) and the cost of living $(Q^{-(1-\alpha^o)}_{nt})$ and vary by occupation; η^{Lo}_{it} are workplace fixed effects that capture wages (w^o_{nt}) and again vary by occupation; we use the property that the denominator in equation (12) equals expected utility (U^o_t) from equation (13) to absorb this denominator into

[20] We find a similar pattern using a later British Ministry of Labor household expenditure survey from 1953-4 and an earlier survey of 30,000 workers in the LCC area in 1887, as discussed further in Online Appendix D1.

the fixed effects; and ζ^o_{nit} is a stochastic error. We cluster the standard errors by residence and workplace to allow for correlated error components by residence and workplace.

In our baseline specification, we estimate this gravity equation (18) in levels using the Poisson pseudo maximum likelihood (PPML) estimator to allow for zero bilateral flows and granularity at small spatial scales following Santos Silva and Tenreyro (2006) and Dingel and Tintelnot (2023). An empirical challenge in this estimation is that travel time depends on the transport network, which is likely to be endogenous, because railway lines in London were constructed by profit-seeking private-sector companies. To address this concern, we follow Heblich et al. (2020) in instrumenting bilateral travel times (τ_{nit}) with straight-line distance, and use a control function approach for the PPML estimator following Wooldridge (2014).

In Columns (1)-(3) of Panel B of Table D.1 in Online Appendix D2, we report these control function estimates using the PPML estimator. We find that lower-income workers have commuting elasticities that are larger in absolute magnitude, which reflects the net effect of several forces. On the one hand, lower-income workers could have lower opportunity costs of time, which implies commuting elasticities that are smaller in absolute magnitude. On the other hand, lower-income workers' commuting decisions are plausibly more sensitive to differences in real income relative to idiosyncratic preferences, which implies commuting elasticities that are larger in absolute magnitude. We find that the second of these forces dominates, which is consistent with the findings in Kreindler and Miyauchi (2023) and Tsivanidis (2023). We use these estimates as our baseline parameter values: $\phi^L = 2.92$, $\phi^M = 2.41$, and $\phi^H = 1.87$.[21]

Finally, we separate the composite elasticity of commuting flows to travel times ($\phi^o = \epsilon^o \kappa$) into its two components. We allow the commuting decisions of high, middle and low-income workers to respond differentially to commuting costs (through variation in ϵ^o). But we assume that travel time affects commuting costs in the same way for all three groups of workers (common κ). Given these assumptions, we calibrate the preference dispersion parameter for middle-income workers as $\epsilon^M = 5.25$, based on the estimate using the construction of London's 19th-century railway network in Heblich et al. (2020). We then recover the implied preference dispersion parameters for low and high-income workers from our estimated commuting elasticities above, using our assumption of a common κ: $\epsilon^L = (\phi^L/\phi^M)\epsilon^M = 6.36$ and $\epsilon^H = (\phi^H/\phi^M)\epsilon^M = 4.07$.[22]

[21]In Online Appendix D2, we show that we find similar results if we re-estimate the gravity equation (18) in logs using the linear fixed effects estimator, and instrument bilateral travel times (τ_{nit}) with straight-line distance using two-stage least squares. We show that bilateral straight-line distance is a strong predictor of bilateral travel times in the first-stage regression, with a first-stage F-statistic well above the conventional threshold of ten.

[22]These values for the preference dispersion parameters lie within the range of existing empirical estimates from 2.18 to 8.3 in Ahlfeldt et al. (2015), Dingel and Tintelnot (2023), Severen (2023) and Kreindler and Miyauchi (2023).

6.3 Wages, Commuting and Employment (Step 3)

We next solve for wages (w_{it}^{o}), commuting flows (E_{nit}^{o}) and employment (E_{it}^{o}) for each occupation, which we use as inputs in our counterfactuals below. Cost minimization and zero profits imply that labor payments by workplace for each occupation ($w_{it}^{o}E_{it}^{o}$) are a multiple of payments for commercial floor space ($\mathbb{V}_{it}^{E}$), which depends on the labor share (β) and the share of each occupation in labor costs (s_{it}^{o}). Using equation (10) and our estimates of commuting costs ($(\kappa_{nit}^{o})^{-\epsilon^{o}} = \tau_{nit}^{-\phi^{o}}$), we can re-write the commuter market clearing condition (14) for each occupation as:

$$\frac{\beta}{1-\beta}\frac{\left(w_{it}^{o}/\gamma^{o}\right)^{1-\sigma}}{\sum_{\ell\in\mathbb{O}}\left(w_{it}^{\ell}/\gamma^{\ell}\right)^{1-\sigma}}\mathbb{V}_{it}^{E} = \sum_{n\in\mathbb{N}}\frac{\left(w_{it}^{o}\right)^{\epsilon^{o}}\tau_{nit}^{-\phi^{o}}}{\sum_{\ell\in\mathbb{N}}\left(w_{\ell t}^{o}\right)^{\epsilon^{o}}\tau_{n\ell t}^{-\phi^{o}}}w_{it}^{o}R_{nt}^{o}. \tag{19}$$

We set the elasticity of substitution across occupations equal to the conventional value of $\sigma = 1.41$ from Katz and Murphy (1992). We calibrate the labor cost weights (γ^{o}) such that the shares of the three occupations in the total wage bill are consistent with their aggregate shares in total residential rateable values. Under our assumption of Cobb-Douglas preferences, residential rateable values are a constant multiple of residential income, which implies that the shares of the occupations in total residential income can be recovered from their shares in total residential rateable values. Given the observed commercial rateable values ($\mathbb{V}_{it}^{E}$), residents (R_{it}^{o}) and travel times (τ_{nit}), equation (19) determines pre-war wages (w_{it}^{o}) by occupation and location.[23]

Using these solutions for pre-war wages (w_{it}^{o}) and our estimates of commuting costs ($(\kappa_{nit}^{o})^{-\epsilon^{o}} = \tau_{nit}^{-\phi^{o}}$), we compute pre-war conditional commuting probabilities for each occupation ($\lambda_{nit|n}^{Ro}$) using equation (14). Finally, using these solutions for pre-war conditional commuting probabilities ($\lambda_{nit|n}^{Ro}$), together with observed residents (R_{nt}^{o}) and total city population by occupation ($\bar{E}_{t}^{o}$), we calculate pre-war unconditional commuting probabilities ($\lambda_{nit}^{o} = \lambda_{nit|n}^{Ro}R_{nt}^{o}/\overline{E}_{t}^{o}$) and employment ($E_{it}^{o} = \sum_{n\in\mathbb{N}}\lambda_{nit|n}^{Ro}R_{nt}^{o}$) for each occupation and location.

In Online Appendix D3, we report two model specification checks, in which we compare our model's predictions to the available pre-war data on employment by workplace and commuting. We aggregate across the three occupations and report results for boroughs, because our pre-war bilateral commuting data are not disaggregated by occupation and are only available for the 29 LCC boroughs. Our model predictions are based on the commuter market clearing condition (19) using our data on residents and commercial rateable values during the 1930s. Therefore, there is no necessary reason why these model predictions should exactly equal the observed data on

[23]Residential income on the right-hand side of equation (19) equals the sum of the income of workers from occupation o employed in workplace i and living in any residence n within the LCC area. In contrast, commercial rateable values ($\mathbb{V}_{it}^{E}$) on the left-hand side are a multiple of workplace income ($w_{it}^{o}E_{it}^{o}$), including the income of all workers from occupation o employed in workplace i, regardless of where they live. To ensure that both variables are measured for workers living within the LCC area, we scale down the commercial rateable values by the share of workers that in-commute from outside the LCC area to each borough in our pre-war commuting data.

employment and bilateral commuting, in part because our pre-war data are for the earlier year of 1921. Nonetheless, we find a strong and approximately log linear relationship between our model's predictions and the observed data, with a correlation coefficient of 0.94 for employment by workplace, and 0.87 for bilateral commuting flows.

For the post-war period, we solve for wages using a similar a procedure. We use our observed data on employment (E^o_{it}) and residents (R^o_{nt}) by Output Area and occupation and the commuter market clearing condition (14) to solve for for wages (w^o_{it}) by occupation and location.

6.4 Amenities (Step 4)

We next use the structure of the model to solve for residential amenities (B^o_{nt}) by location and occupation. Summing across workplaces in the commuting probabilities (12) and using expected utility (13), we obtain the following closed-form expression for residential amenities for each occupation (B^o_{nt}) in terms of the observed shares of residents (λ^{Ro}_{n}), observed residential floor space prices (Q_n) and a measure of residents' commuting market access (RMA^o_{nt}):

$$\ln B^o_{nt} = \ln\left(\frac{U^o_t}{\delta^o}\right) + \frac{1}{\epsilon^o}\ln\left(\lambda^{Ro}_{nt}\right) + (1-\alpha^o)\ln Q_{nt} - \ln RMA^o_{nt}. \tag{20}$$

Residents' commuting market access (RMA^o_{nt}) for each occupation is a travel-time weighted average of wages in each workplace for that occupation:

$$RMA^o_{nt} = \left[\sum_{\ell\in\mathbb{N}} \left(w^o_{\ell t}\right)^{\epsilon^o} \tau^{-\phi^o}_{n\ell t}\right]^{\frac{1}{\epsilon^o}}, \tag{21}$$

where we have again used our estimates of commuting costs ($(\kappa^o_{nit})^{-\epsilon^o} = \tau^{-\phi^o}_{nit}$).

Intuitively, locations with high shares of residents (λ^{Ro}_{nt}), high prices for residential floor space (Q_{nt}) and low residents' market access (RMA^o_{nt}) in equation (20), must have high amenities (B^o_{nt}) in order for so many residents to be willing to live there. We solve for amenities (B^o_{nt}) from these residential choice probabilities without taking a stand on the determinants of productivity (A_{nt}) or the relative importance of the components of amenities (B^o_{nt}): wartime destruction (D_{nt}), neighborhood effects ($\mathbb{B}^o_{nt}$) and residential fundamentals (b^o_{nt}).

6.5 Wartime Destruction and Neighborhood Effects (Step 5)

In our fifth and final step, we estimate the impact of wartime destruction on residential amenities and the strength of neighborhood effects.

6.5.1 General Specification of Neighborhood Effects

We begin by considering our general specification of neighborhood effects, in which we estimate the direct and spillover effects of wartime destruction on residential amenities using equation (4), without taking a stand on whether these spillover effects occur through the surrounding composition of either people or buildings.

We start with a Placebo specification, in which we regress pre-war amenities on subsequent wartime destruction, including fixed effects for 1 km hexagons. As reported in Table D.2 in Online Appendix D5, we find no evidence that pre-war amenities are correlated with future wartime destruction, which again provides further validation for our use of wartime destruction as an exogenous source of variation.

We next turn to our main causal regression, in which we regress post-war amenities on wartime destruction. As reported in Table 4, we find that the direct effects of wartime destruction are negative and statistically significant for high-income workers. In contrast, these direct effects are positive and weakly significant for low-income workers. This pattern of estimated coefficients is consistent with the idea that the construction of council housing in bombed locations reduces relative amenities in these locations for high-income workers.

We find that the spillover effects of wartime destruction are also negative and statistically significant for high-income workers, whereas these spillover effects are insignificant and small in absolute magnitude for low-income workers. These results are in line with the idea that the construction of council housing on bomb sites in neighboring locations reduces relative amenities in the own location for high-income workers. As in our earlier regressions for property values and socioeconomic composition, we find that these spillover effects are localized, with the spillover coefficient for high-income workers losing significance by the 300 meter buffer and falling by a factor of five between the 100 and 500 meter buffers.

Taken together, these empirical results are consistent with the mechanism in our model, in which wartime destruction changes relative amenities for the three groups of workers, which affects equilibrium patterns of spatial sorting, and hence post-war property prices and socioeconomic status. Our finding that bombing in neighboring locations affects amenities in the own location provides evidence of neighborhood effects, without taking a stand on the mechanism through which these neighborhood effects occur.

6.5.2 Neighborhood Effects and Socioeconomic Composition

Motivated by our mechanisms findings in Section 4.4, we next parameterize neighborhood effects as depending on the surrounding socioeconomic status of the population:

$$\ln B^{o}_{nt} = \eta^{o}_{D} D_{nt} + \eta^{o}_{R} \ln \mathbb{B}_{nt} + \eta^{o}_{X} X_{nt} + \varrho^{o}_{kt} + b^{o}_{nt}, \tag{22}$$

Table 4: The Direct and Spillover Effects of Wartime Destruction on Post-War Amenities

	(1) $\ln B^{H}_{n,\text{Post}}$	(2) $\ln B^{H}_{n,\text{Post}}$	(3) $\ln B^{M}_{n,\text{Post}}$	(4) $\ln B^{M}_{n,\text{Post}}$	(5) $\ln B^{L}_{n,\text{Post}}$	(6) $\ln B^{L}_{n,\text{Post}}$
Destruction in own area	-0.102***	-0.088***	-0.046***	-0.041***	0.014*	0.013*
	(0.014)	(0.013)	(0.007)	(0.006)	(0.008)	(0.007)
Destruction in 100m buffer		-0.056**		-0.024*		0.002
		(0.027)		(0.014)		(0.015)
Destruction in 200m buffer		-0.072**		-0.036*		-0.034
		(0.036)		(0.019)		(0.021)
Destruction in 300m buffer		-0.044		-0.049**		-0.005
		(0.037)		(0.020)		(0.025)
Destruction in 400m buffer		-0.030		0.008		-0.025
		(0.045)		(0.022)		(0.026)
Destruction in 500m buffer		-0.012		-0.030		-0.027
		(0.045)		(0.025)		(0.031)
Hexagon Fixed Effects	1 km	1 km	1 km	1 km	1 km	1 km
R Squared	0.56	0.56	0.61	0.62	0.46	0.46
Observations	8,779	8,776	8,794	8,791	8,775	8,772

Note: The unit of observation for all regressions is an Output Area as defined in the 2001 UK Census. The dependent variable in columns (1) and (2) is post-war log amenities for high-income workers ($\ln B^{H}_{n,\text{Post}}$), in columns (3) and (4) it is post-war log amenities for middle-income workers ($\ln B^{M}_{n,\text{Post}}$), and in columns (5) and (6) it is post-war log amenities for low-income workers ($\ln B^{L}_{n,\text{Post}}$). The explanatory variable is the fraction of the pre-war built-up area in each Output Area and five buffers of 100 meter width around each Output Area seriously damaged during the Second World War. All regressions include fixed effects for 1 km hexagons. Numbers of observations are less than 9,041 due to whether Output Areas and their buffers had pre-war built-up area and positive post-war residents for each group of workers. Standard errors are clustered at the 1 km hexagon level. * denotes significance at 10% level; ** denotes significance at 5% level; *** denotes significance at 1% level.

where $\mathbb{B}_{nt}$ is the surrounding socioeconomic status of the population, as defined below; ϱ^{o}_{kt} are our 1 km hexagon fixed effects; X_{nt} are controls; and b^{o}_{nt} is a stochastic error, which captures residential fundamentals (e.g., scenic views).

We allow for a direct effect of wartime destruction on amenities in bombed locations (η^{o}_{D}), because the destruction and reconstruction of buildings can change the amenities that residents derive from living in those buildings. But we assume that the impact of destruction in neighboring locations on residential amenities in the own location is fully summarized by the surrounding socioeconomic status of the population (η^{o}_{R}).[24] The inclusion of the 1 km hexagon fixed effects

[24]Therefore, we assume either that there is no independent effect of neighboring buildings from neighboring people, or that the effect of neighboring buildings is fully summarized by the effect of neighboring people, because people and buildings are closely linked in spatial equilibrium.

ensures that the parameters are estimated from the exogenous variation in wartime destruction within these geographical grid cells, where these fixed effects also control for other determinants of amenities that vary across these geographical grid cells.

In our general specification of amenities above, and in our earlier regressions for property values and socioeconomic status, we find that the spillover effects from wartime destruction are small and statistically insignificant by the 500-meter buffer. Therefore, we model neighborhood effects as depending on the distance-weighted average of socioeconomic status in the own location and the 100-500 meter buffers:

$$\mathbb{B}_{nt} = \sum_{\{i\,:\,\text{dist}_{ni}<500\}} \frac{e^{-\delta \text{dist}_{ni}}}{\sum_{\{k\,:\,\text{dist}_{nk}<500\}} e^{-\delta \text{dist}_{nk}}} \mathbb{S}_{it}, \tag{23}$$

where dist_{ni} is the distance from the outer boundary of each Output Area to the inner boundary of the buffer; and $\mathbb{S}_{it}$ is our index of socioeconomic status.

In our baseline specification in equation (23), we assume exponential distance decay, and calibrate the rate of decay (δ) such that the weight is close to zero by 500 meters (equal to 0.01). But we find a similar pattern of results across a range of assumptions for the rate of distance decay, including a simple step function, where either the first three or four buffers receive a weight of one and areas further away receive a weight of zero.

The main challenge in estimating neighborhood effects is that the surrounding socioeconomic composition of the population is endogenous, because workers sort endogenously across locations in response to differences in amenities, which induces a positive correlation between surrounding socioeconomic status ($\mathbb{B}_{nt}$) and the error term (b^o_{nt}). We use the exogenous variation in wartime destruction within 1 km hexagons to address this challenge. We instrument surrounding socioeconomic status ($\mathbb{B}_{nt}$) with the distance-weighted average of the share of the built-up area seriously damaged in the 100-500 meter buffers excluding the own location itself (D^{Neigh}_{nt}):

$$\ln \mathbb{B}_{nt} = \varkappa^o_D D_{nt} + \varkappa^o_N D^{\text{Neigh}}_{nt} + \varkappa^o_X X_{nt} + \varpi^o_{kt} + u^o_{nt}, \tag{24}$$

where the instrument (D^{Neigh}_{nt}) is defined analogously to neighborhood effects ($\mathbb{B}_{nt}$) in equation (23), but replacing our socioeconomic index ($\mathbb{S}_{it}$) with wartime destruction (D_{it}), including only the 100-500 meter buffers, and excluding the own location itself.

Table 5 reports the results of estimating our second-stage regression (22) for post-war amenities. The top, middle and bottom panels display results for high, middle and low-income workers, respectively. Column (1) estimates this relationship using OLS, including a location's own wartime destruction (D_{nt}) and the fixed effects for 1 kilometer hexagons (ϱ^o_{kt}), replicating the specifications from Columns (1), (3) and (5) of Table 4.

Column (2) augments this specification with our measure of post-war neighborhood effects based on the distance-weighted average of socioeconomic status in the own location and the 100-

Table 5: Post-war Amenities, Wartime Destruction and Neighborhood Effects

	(1)	(2)	(3)	(4)	(5)	(6)
(A) High-income	$\ln B_n^H$	$\ln B_n^H$	$\ln B_n^H$	$\ln B_n^H$	$\ln B_n^H$	$\ln B_n^H$
Destruction in own area	-0.102***	-0.020**	-0.043***	-0.054***	-0.055***	-0.085***
	(0.014)	(0.008)	(0.011)	(0.010)	(0.010)	(0.010)
Post-war neighborhood effects		1.347***	0.970***	0.892***	0.861***	0.776***
		(0.020)	(0.169)	(0.149)	(0.158)	(0.179)
Pre-war neighborhood effects					0.070***	0.092***
					(0.024)	(0.028)
Observations	8779	8773	8771	8587	8587	8587
R-squared	0.556	0.845	–	–	–	–
First-stage F-statistic	–	–	11.56	19.19	18.72	28.08
(B) Middle-income	$\ln B_n^M$	$\ln B_n^M$	$\ln B_n^M$	$\ln B_n^M$	$\ln B_n^M$	$\ln B_n^M$
Destruction in own area	-0.046***	-0.014***	-0.018**	-0.023***	-0.024***	-0.042***
	(0.007)	(0.005)	(0.008)	(0.007)	(0.007)	(0.006)
Post-war neighborhood effects		0.533***	0.465***	0.529***	0.515***	0.463***
		(0.016)	(0.135)	(0.119)	(0.125)	(0.115)
Pre-war neighborhood effects					0.034*	0.048***
					(0.019)	(0.018)
Observations	8794	8788	8786	8602	8602	8602
R-squared	0.615	0.737	–	–	–	–
First-stage F-statistic	–	–	11.60	19.15	18.69	28.00
(C) Low-income	$\ln B_n^L$	$\ln B_n^L$	$\ln B_n^L$	$\ln B_n^L$	$\ln B_n^L$	$\ln B_n^L$
Destruction in own area	0.014*	-0.000	0.022**	0.021*	0.021*	0.009
	(0.008)	(0.007)	(0.011)	(0.011)	(0.011)	(0.007)
Post-war neighborhood effects		-0.233***	0.138	0.320	0.329	0.293
		(0.021)	(0.207)	(0.199)	(0.214)	(0.181)
Pre-war neighborhood effects					-0.021	-0.012
					(0.034)	(0.030)
Observations	8775	8769	8767	8584	8584	8584
R-squared	0.464	0.486	–	–	–	–
First-stage F-statistic	–	–	11.42	18.84	18.43	27.81
Estimation	OLS	OLS	IV	IV	IV	IV

Notes: The dependent variables ($\ln B_n^H$, $\ln B_n^M$, $\ln B_n^L$) are log post-war amenities for high, middle and low-income workers, respectively; in Columns (1)-(3), wartime destruction is measured using the fraction of the pre-war overall built-up area seriously damaged during the Second World War; in Columns (4)-(6), wartime destruction is measured using the fraction of the pre-war residential built-up area seriously damaged during the Second World War; in Columns (2)-(5), post-war and pre-war neighborhood effects are measured as the distance-weighted average of our index of socioeconomic status in the own location and the 100-500 meter buffers; in Column (6), post-war and pre-war neighborhood effects are measured as the distance-weighted average of our index of socioeconomic status in the 100-500 meter buffers, excluding the own location; the instrument in Column (3) is the distance-weighted average of wartime destruction in the 100-500 meter buffers, excluding the own location; in Columns (4)-(6), the instrument is the distance-weighted average of residential wartime destruction in the 100-500 meter buffers, excluding the own location; all specifications include fixed effects for 1 kilometer hexagons; First-stage F is first-stage F-statistic; R-squared not reported for the IV specifications, because it does not have a meaningful interpretation; standard errors in parentheses clustered by 1 kilometer hexagons; *, ** and *** denote significance at the 10, 5 and 1 percent levels, respectively.

500 meter buffers. After controlling for neighborhood effects, we find direct effects of wartime destruction (η_D^o) that are smaller in absolute magnitude but display the same pattern as in the previous column. Additionally, we find evidence of neighborhood effects, which are positive and statistically significant for high and middle-income workers, with a coefficient that is larger in ab-

solute magnitude for high-income workers. In contrast, the estimated coefficient for low-income workers is negative and statistically significant. Although this pattern of results is suggestive of stronger neighborhood effects for higher-income workers, this OLS specification is subject to the concern discussed above that surrounding socioeconomic status is endogenous, because workers sort spatially in response to unobserved differences in amenities.

Column (3) addresses this concern by reporting our instrumental variables (IV) estimates, in which we instrument post-war neighborhood effects using the distance-weighted average of wartime destruction in the 100-500 meter buffers, excluding the own location. Even when we focus on exogenous variation in surrounding socioeconomic status from wartime destruction in neighboring locations, we continue to find evidence of neighborhood effects that are stronger for higher-income workers. We find that wartime destruction in neighboring locations is a powerful instrument for surrounding socioeconomic status, with a first-stage F-statistic of over ten.[25] Comparing Columns (2)-(3), our IV estimates of the neighborhood effects parameters for high-income workers are smaller than those using OLS. This is the expected pattern of results with spatial sorting, if attractive residential fundamentals both directly raise amenities and induce high-income workers to sort into a location, thereby raising surrounding socioeconomic status, and imparting an upward bias to the OLS coefficient for high-income workers.

In our analysis of mechanisms in Section 4 above, we find that the effects of wartime destruction are driven by residential destruction rather than by commercial destruction. Therefore, in Column (4), we re-estimate our IV specification, using the distance-weighted average of residential destruction in the 100-500 meter buffers, again excluding the own location itself. Neighboring residential destruction is a more powerful instrument for post-war socioeconomic status than neighboring overall destruction, with the first-stage F-statistic increasing by more than 50 percent. We continue to find the same pattern of estimated coefficients for both wartime destruction and neighborhood effects. This pattern of results provides further evidence in support of the mechanism in our model, in which wartime destruction of buildings changes the amenities from living in those buildings and hence patterns of spatial sorting, which spills over to neighboring locations through surrounding socioeconomic composition.

In Column (5), we report a robustness check, in which we include pre-war neighborhood effects as an additional control variable (again as defined in equation (23)). We find a pattern of estimated coefficients for post-war neighborhood effects that is virtually unchanged. This finding provides further support for the idea that wartime destruction within 1 km hexagons is an exogenous source of variation that is uncorrelated with the pre-war characteristics of locations. We find that the estimated coefficients on pre-war neighborhood effects are small in absolute magnitude for all three groups of workers, which is consistent with our post-war neighborhood

[25] In Table D.3 of Online Appendix D5, we report the full first-stage regressions for each specification in Table 5.

effects measure successfully capturing surrounding socioeconomic status.[26] In Column (6), we present a further robustness check, in which we exclude the own location from our measure of neighborhood effects (as well as from neighboring destruction). Again we find a similar pattern of estimated coefficients, which provides further evidence that wartime destruction is uncorrelated with unobserved characteristics of the own location.

In Table D.4 of Online Appendix D5, we estimate the reduced-form specification implied by the second-stage (22) and first-stage (24). Consistent with the second-stage results above, we find that the effects of own and neighboring destruction are more negative for higher-income workers. As a final placebo specification check, in Table D.5 of Online Appendix D5, we re-estimate this reduced-form regression for *pre-war* amenities and *subsequent* war-time destruction. Again we find no evidence of a relationship between pre-war amenities and subsequent wartime destruction, providing further support for the idea that wartime destruction provides an exogenous source of variation within 1 km geographical grid cells.

7 Counterfactuals

We next use our estimates to undertake counterfactuals to assess the general equilibrium implications of neighborhood effects. We first examine the role of neighborhood effects in determining the impact of wartime destruction across locations. We next examine the role of these neighborhood effects in shaping observed differences in socioeconomic outcomes across locations even in counterfactual scenarios without wartime destruction. We report results for both our general specification, in which we do not take a stand on the mechanism through which neighborhood effects occur, and for our specific parametrization, in which we assume that neighborhood effects arise from preferences over the socioeconomic composition of the population.

We report the results of these counterfactuals for both closed and open-city specifications. In the closed-city specification, we hold the total population of each occupation in the LCC area constant, such that wartime destruction affects the expected utility of workers in each occupation. In the open-city specification, we hold the reservation level of utility for workers in each occupation constant, which implies that wartime destruction affects the total population of each occupation, but leaves expected utility for each occupation unchanged (after integrating across the distribution of idiosyncratic preferences). In both specifications, wartime destruction has distributional consequences for the amenity-adjusted real income of workers (without taking into

[26] We also find similar results if we include an additional control for post-war log population density instrumented by pre-war log population density. We find positive estimated coefficients on log population density of 0.01 (high-income), 0.04 (middle-income) and 0.05 (low-income), which are statistically significant at conventional critical values for middle and low-income workers. This pattern of results is consistent with the idea that higher-income workers derive higher relative amenities from lower population density locations.

account idiosyncratic preferences) and the real income of landlords across locations.

In our baseline specification, we report results for the case of exogenous productivity and perfectly inelastic supplies of commercial and residential floor space. In robustness specifications, we report results allowing for agglomeration forces (such that productivity responds to changes in employment) and an imperfectly elastic supply of residential floor space (such that the supply of residential floor space responds to changes in its price). In Online Appendix E, we provide further details on our baseline and robustness counterfactuals.

7.1 Wartime Destruction

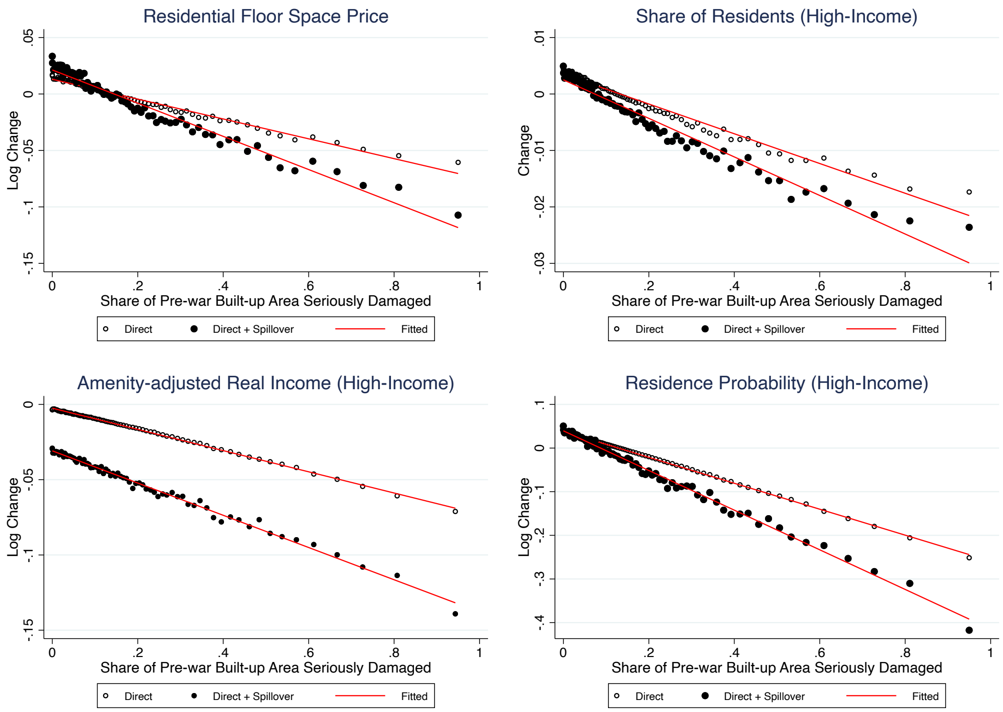
We undertake counterfactuals for wartime destruction starting at the observed pre-war equilibrium in the data. Whereas in reality many things can change between the pre and post-war periods, these counterfactuals evaluate the impact of wartime destruction holding all else constant. Although our reduced-form regressions control for many changes between these two periods by estimating separate fixed effects for 1 km hexagons for each time period, the inclusion of these fixed effects implies that these reduced-form regressions cannot capture general equilibrium effects (which are absorbed into the fixed effects). In contrast, our counterfactuals use the structure of our model to evaluate these general equilibrium effects. Although starting at the observed pre-war equilibrium is the natural choice to evaluate the general equilibrium impact of wartime destruction, we find a similar pattern of results if we instead start at the observed post-war equilibrium and remove the effects of wartime destruction.

We first undertake counterfactuals for wartime destruction using our general specification for neighborhood effects. We use the estimated direct and spillover effects of wartime destruction from Columns (2), (4) and (6) of Table 4. We multiply these estimated coefficients for each occupation (η_D^o) by the share of the pre-war built-up area seriously damaged during the Second World War for each Output Area (D_n), and compute the implied exogenous changes in amenities ($\widehat{B}_n^o$). Given these exogenous changes in amenities, we solve the model's system of general equilibrium conditions for a counterfactual equilibrium. We undertake separate counterfactuals for the direct effects of wartime destruction (setting the spillover coefficients equal to zero) and the full effects of wartime destruction (allowing for both direct and spillover effects).

In Figure 4, we display the results of these counterfactuals for the direct and full effects of wartime destruction. Each panel shows a binscatter across Output Areas of the counterfactual change in a variable against the share of the pre-war built-up area seriously damaged during the Second World War. The circles correspond to percentiles of the distribution of wartime destruction and the red line represents the linear fit.

We find substantial distributional consequences of wartime destruction for landlord income. As shown in Panel A, the price of residential floor space declines by over 10 percent in locations

Figure 4: Counterfactuals for Wartime Destruction



Notes: Counterfactuals using our general specification of neighborhood effects and the estimated direct and spillover effects of wartime destruction from Columns (2), (4) and (6) of Table 4; circles show values by percentile of the share of the pre-war built-up area seriously damaged during the Second World War; around 40 percent of locations experience zero destruction, such that the circle for zero destruction captures the first 40 percentiles; hollow circles show counterfactuals using the estimated direct coefficients alone (setting the spillover coefficients to zero); solid circles show counterfactuals using the estimated direct and spillover coefficients; red lines show the linear fit; Panel A shows the log change in the price of residential floor space; Panel B shows the change (not in logs) in the share of a location's residents who are high-income ($R_n^H / \left(R_n^L + R_n^M + R_n^H\right)$); Panel C shows the log change in amenity-adjusted real income for high-income residents ($\log(B_n^H w_i^H Q_n^{-(1-\alpha^H)})$); Panel D shows the log change in the share of all high-income residents in the LCC area who live in a location ($\lambda_n^H = R_n^H / \sum_{i\in\mathbb{N}} R_i^H$).

that were completely destroyed. In locations with no destruction, we find a small increase in the price of residential floor space of 3 percent, which reflects general equilibrium effects. As higher-income workers move way from bombed locations, this bids up the price of residential floor space in unbombed locations. We find that the full effects of wartime destruction (solid circles) are notably larger than the direct effects (hollow circles), highlighting the quantitative relevance of neighborhood effects. The magnitude of the full relative change in property prices is comparable to that implied by our reduced-form regressions in Section 4 and shows that our model is able to account quantitatively for the observed changes in the data. Whereas these earlier reduced-form regressions only capture relative changes in outcomes across bombed and unbombed locations, these general equilibrium counterfactuals capture absolute levels (as illustrated by the rise in the price of residential floor space in unbombed locations).

We find that wartime destruction changes equilibrium patterns of spatial sorting by workers from each occupation. As shown in Panel B, the share of high-income workers declines by around 2 percentage points in locations that were completely destroyed and rises by around 0.5

percentage points in areas with no destruction. These results in Panel B illustrate the role of spatial sorting in shaping the changes in property prices in Panel A. Again the full effects of wartime destruction (solid circles) are notably larger than the direct effects (hollow circles), highlighting the role of the surrounding neighborhood in shaping residential choices.

We find that the distributional consequences of wartime destruction for the amenity-adjusted real income of workers are of a similar size to those for landlord income. As shown in Panel C, the amenity-adjusted real income of high-income workers declines by around 14 percentage points in locations that were completely destroyed, compared with a decline of about 3 percentage points in locations that experienced no destruction. These patterns reflect both the direct effects of wartime destruction on amenities (more negative for high-income workers) and general equilibrium effects (as some high-income workers move away from bombed locations, this reduces the price of residential floor space for those remaining). Again neighborhood effects magnify the impact of wartime destruction, with the full effects (solid circles) markedly larger than the direct effects (hollow circles).

Despite these substantial impacts of wartime destruction on amenity-adjusted real income and socioeconomic composition, we find smaller impacts on expected utility of less than 4 percent for all three worker groups, which reflects the net effect of four forces. First, our counterfactuals evaluate the long-run effects of wartime destruction on residential amenities after reconstruction has occurred. Second, some of the decline in residential amenities in response to wartime destruction is capitalized in lower prices for residential floor space, thereby dampening its impact on the expected utility of workers. Third, many Output Areas experience little or no destruction, which allows workers to relocate away from bombed locations. Fourth, our estimated preference dispersion parameters (ϵ^o from $4.23-6.90$) and those commonly-used in existing empirical research, Output Areas are relatively good substitutes for one another.[27]

Whereas Panel B displays the share of high-income workers in a given location in the total residents of that location ($R_n^H/\left(R_n^L+R_n^M+R_n^H\right)$), Panel D shows the log change in the share of high-income workers in a given location in the total number of high-income workers in the LCC area (the residential choice probability, $\lambda_n^H = R_n^H/\sum_{i\in\mathbb{N}} R_i^H$). The parts of London that experienced heavier wartime destruction and a decline in the share of high-income workers (often in the East) had lower initial shares of high-income workers, which results in a large percentage decline of around 30 percent in the share of high-income workers in completely-destroyed locations. In contrast, since these locations had higher initial shares of low-income workers, they experience a smaller percentage rise in the share of low-income workers of around 10 percent (not shown).

[27] As a result, we find a relatively small impact of wartime destruction on total city population in our open-city specification in Online Appendix E5.3 of less than 5 percent. Therefore, our findings suggest that wartime destruction can lead to substantial changes in local outcomes at the neighborhood level, with a smaller impact on total city population, which is consistent with existing evidence on the aggregate city-wide impact of wartime destruction.

For both these groups of workers, wartime destruction results in a substantial change in the distribution of workers from that group across locations within the LCC area.

In Online Appendix E3, we show that the counterfactual predictions of our model are successful in replicating the results of our reduced-form regressions for property values in Section 4 above. We re-estimate these regressions using our model's counterfactual predictions for post-war property values instead of the observed data on post-war property values. When we assume no neighborhood effects, we find no evidence of spillover effects of wartime destruction on counterfactual property values in surrounding unbombed locations. In contrast, when we allow for neighborhood effects, we find negative and statistically significant spillover effects of wartime destruction on counterfactual property values in surrounding unbombed locations.

In Online Appendix E2.2, we show that we find a similar pattern of counterfactual predictions using our parameterization of neighborhood effects in terms of preferences over the surrounding socioeconomic composition of the population. Therefore, this interpretation of neighborhood effects of operating through people is empirically successful in replicating the predictions of our general specification that does not take a stand on the underlying mechanims. Both specifications suggest that neighborhood effects are quantitatively relevant for evaluating the impact of interventions in any one place on surrounding economic activity.

7.2 Neighborhood Effects

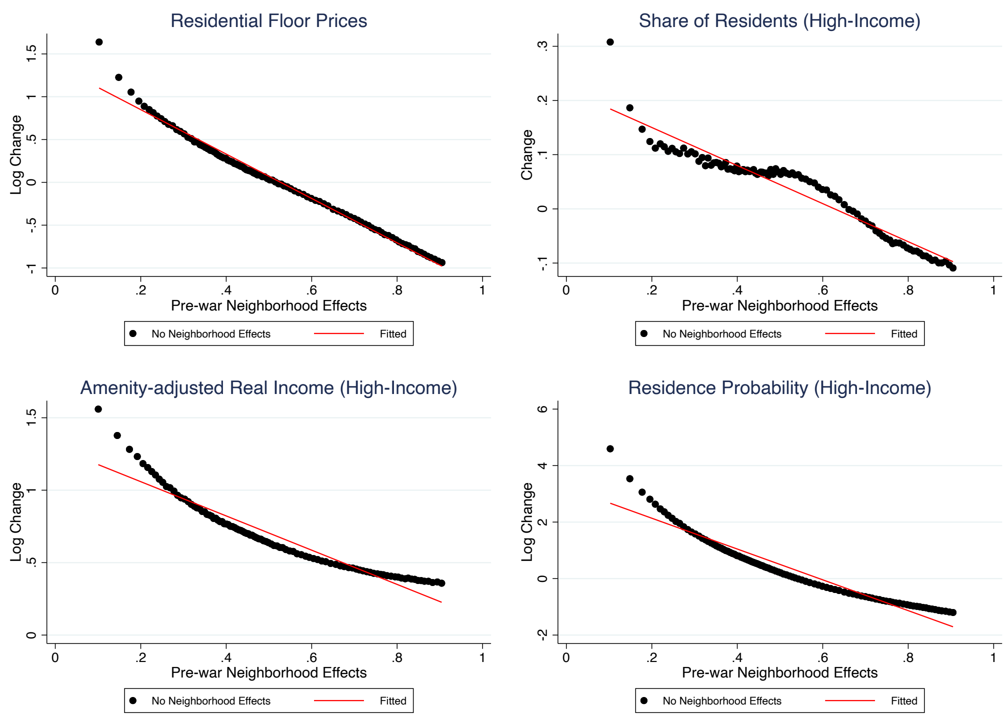
We next undertake counterfactuals to evaluate the importance of neighborhood effects in shaping observed differences in socioeconomic outcomes across locations, even in counterfactual scenarios without wartime destruction. We use our parameterization of neighborhood effects in terms of the surrounding socioeconomic composition of the population. We start from the observed pre-war equilibrium in the data and set the preference parameter for socioeconomic composition in the counterfactual equilibrium equal to zero, which implies that residential fundamentals become the sole determinant of residential amenities in the counterfactual equilibrium:

$$\widehat{B}_n^o = \frac{B_n^{o\prime}}{B_n^o} = \frac{b_n^o \left(\mathbb{B}_{n,\text{pre-war}}\right)^0}{b_n^o \left(\mathbb{B}_{n,\text{pre-war}}\right)^{\eta_R^o}} = \frac{1}{\left(\mathbb{B}_{n,\text{pre-war}}\right)^{\eta_R^o}}, \tag{25}$$

where $\mathbb{B}_n$ is the distance-weighted average of our socioeconomic index ($\mathbb{S}_n$) in the own location and the 100-500 meter buffers (from equation (23)) and we set η_R^o in the pre-war equilibrium in the denominator equal to our estimate from Column (5) of Table 5. Since $\mathbb{S}_n$ takes values from zero to one, $\mathbb{B}_{n,\text{pre-war}}$ also lies within this interval.

In Figure 5, we display the results of these counterfactuals. Each panel shows a binscatter across Output Areas of the counterfactual change in a variable against pre-war neighborhood effects ($\mathbb{B}_{n,\text{pre-war}}$). The circles correspond to percentiles of the distribution of pre-war neighborhood effects and the red line represents the linear fit.

Figure 5: Counterfactuals Removing Neighborhood Effects



Notes: solid circles show values by percentile of pre-war neighborhood effects ($\mathbb{B}_{n,\text{pre-war}}$); red line shows the linear fit; Panel A shows the log change in the price of residential floor space; Panel B shows the change (not in logs) in the share of a location's residents who are high-income $(R_n^H / (R_n^L + R_n^M + R_n^H))$; Panel C shows the log change in amenity-adjusted real income for high-income residents $(\log(B_n^H w_i^H Q_n^{-(1-\alpha^H)}))$; Panel D shows the log change in the share of all high-income residents in the LCC area who live in a location $(\lambda_n^H = R_n^H / \sum_{i \in \mathbb{N}} R_i^H)$.

We find that neighborhood effects make a substantial contribution to the observed differences in socioeconomic outcomes across locations. As shown in Panel A, prices of residential floor space fall by more than one half in locations with the highest pre-war neighborhood effects, and more than double in locations with the lowest pre-war neighborhood effects. Intuitively, high-income workers have the strongest preferences for socioeconomic status in the initial equilibrium (largest η_R^o). When high-income workers no longer value surrounding socioeconomic status, they are no longer willing to pay the high prices of residential floor space to live in initially-more-exclusive neighborhoods, and instead find it attractive to move to initially-less-exclusive neighborhoods. As high-income workers reallocate across neighborhoods, this bids down the price of residential floor space in initially-more-exclusive neighborhoods, and bids up the price of residential floor space in initially-less-exclusive neighborhoods.

As shown in Panel B, these changes in the price of residential floor space involve substantial changes in socioeconomic composition across locations. The share of residents who are high-income $(R_n^H / (R_n^L + R_n^M + R_n^H))$ falls by 10 percentage points in the initially-most-exclusive locations and rises by more than 20 percentage points in the initially-least-exclusive locations. Although these counterfactual changes in the share of high-income residents tend to decline with pre-war neighborhood effects (the black solid circles tend to be downward sloping), this relationship need not always be downward-sloping, in part because pre-war neighborhood effects depend not only on the share of high-income residents, but also on the shares of low and middle-income residents. Again these results in Panel B highlight the importance of spatial sorting and neighborhood effects for property prices.

As shown in Panel C, neighborhood effects also make a substantial contribution towards variation in amenity-adjusted real income ($\log(B_n^o w_i^o Q_n^{-(1-\alpha^o)})$). For positive values of the preference parameters over socioeconomic composition (η_R^o), the direct effect of removing neighborhood effects on amenities is positive for all locations, because pre-war neighborhood effects ($\mathbb{B}_{n,\text{pre-war}}$) lie in between zero and one, which implies that $\log\left(1/\left(\mathbb{B}_{n,\text{pre-war}}\right)^{\eta_R^o}\right)$ is greater than zero for positive η_R^o. The resulting counterfactual change in amenity-adjusted real income depends on both this direct effect and general equilibrium effects from changes in wages and prices of residential floor space. As high-income workers move away from initially-more-exclusive neighborhoods, this bids down the price of residential floor space in these locations. In contrast, as high-income workers move into initially-less-exclusive neighborhoods, this bids up the price of residential floor space in these locations. However, these general equilibrium effects are dominated by the direct effects on amenities, such that removing neighborhood effects reduces relative amenity-adjusted real income in initially-more-exclusive neighborhoods compared to initially-less-exclusive neighborhoods.

In Panel D, we show the log change in the share of high-income workers in a given location in the total number of high-income workers in the LCC area (the residential choice probability, $\lambda_n^H = R_n^H / \sum_{i \in \mathbb{N}} R_i^H$). We find that removing neighborhood effects leads to a substantial change in the distribution of residents from a given worker group across locations, again confirming the importance of neighborhood effects in shaping patterns of spatial sorting.

Therefore, using our parameterization of neighborhood effects in terms of the surrounding composition of the population, we find that these neighborhood effects make a substantial contribution to observed differences in socioeconomic outcomes across locations. These findings suggest that the construction of council housing in a location is likely to have an important impact on the residential composition and prices of surrounding buildings. More generally, these findings suggest that the success of policies to revitalize a location is likely to depend on the extent to which they also change surrounding socioeconomic composition.

7.3 Robustness

Our counterfactual findings for the general equilibrium impact of wartime destruction and neighborhood effects are robust across a wide range of specifications, as shown in Online Appendix E5. We report results for the following robustness specifications: (i) Agglomeration forces in production, using standard estimates for the elasticity of productivity with respect to employment density; (ii) Endogenous responses in the supply of residential floor space, using standard estimates for the elasticity of the supply of floor space with respect to changes in its price; (iii) An open-city specification, in which the supply of workers from each group is endogenously determined by a constant reservation level utility in the wider economy; (iv) Starting from the post-war equilibrium and removing wartime destruction instead of starting from the pre-war equilibrium and introducing wartime destruction. Across all of these specifications, we find that neighborhood effects play a quantitatively relevant role in magnifying the impact of wartime destruction and explaining observed differences in socioeconomic outcomes across locations.

8 Conclusions

A key area of economic debate is whether differences in socioeconomic outcomes across locations within urban areas are driven by fundamentals (e.g., green areas and scenic views) versus neighborhood effects (in which individual behavior is influenced by the surrounding characteristics of the neighborhood). The importance of these two mechanisms is fundamental to our understanding of cities and the impact of place-based interventions.

We use the German bombing of London during the Second World War as a large-scale source of exogenous variation to estimate the strength of neighborhood effects. We first show that wartime destruction is uncorrelated with the pre-war characteristics of locations within narrow geographical grid cells, 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 destruction has long-lasting direct effects on property values and socioeconomic composition in bombed locations, because reconstruction primarily occurred through the construction of council housing. Finally, we show that wartime destruction had long-lasting spillover effects on property values and socioeconomic composition in surrounding unbombed locations. These effects are both statistically significant and economically relevant: as we move from zero to complete destruction, 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.

To rationalize these empirical findings, we develop a quantitative urban model in which workers from different socioeconomic groups (low, middle and high-income) choose a residence and workplace within London, taking into account wages, residential amenities, the cost of living and commuting costs. We interpret wartime destruction as an exogenous shock that changes the relative amenities of a location for low, middle and high-income workers, because the construction of council housing reduces the relative attractiveness of bombed locations to higher-income workers. As a result, wartime destruction changes 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, this change in relative amenities in bombed locations spills over to affect surrounding unbombed locations.

We first consider a general specification of neighborhood effects, in which we allow amenities in each location to depend on the characteristics of surrounding locations, but do not take a stand on the underlying mechanisms. We next parameterize neighborhood effects in terms of preferences over the surrounding socioeconomic composition of the population. Undertaking counterfactuals for wartime destruction in both specifications, we show that neighborhood effects substantially magnify the impact of wartime destruction. Undertaking counterfactuals to remove preferences over the surrounding socioeconomic status of the population, we show that neighborhood effects drive an important part of the observed differences in socioeconomic outcomes across locations. Both sets of counterfactuals suggest that neighborhood effects play a quantitatively relevant role in shaping the impact of place-based interventions.

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