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THE SPATIAL IMPACTS OF A MASSIVE RAIL DISINVESTMENT PROGRAM: THE BEECHING AXE

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Working Paper 32800
http://www.nber.org/papers/w32800

NATIONAL BUREAU OF ECONOMIC RESEARCH
1050 Massachusetts Avenue
Cambridge, MA 02138
August 2024

We are deeply indebted to Jordi Marti-Henneberg and his colleagues for providing us with the rail GIS data, and to Humphrey Southall and Paula Aucott from the Vision of Britain project for helping us with queries over the historical census data. This work is based on data provided through www.VisionofBritain.org.uk and uses historical material which is copyright of the Great Britain Historical GIS Project and the University of Portsmouth. We thank Cong Peng for excellent GIS work with the road network. The work was supported by ESRC grant number ES/M010341/1. Heblich acknowledges support by the Institute for New Economic Thinking (INET), Grant No. INO15-00025. The views expressed herein are those of the authors and do not necessarily reflect the views of the National Bureau of Economic Research.

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NBER Working Paper No. 32800
August 2024
JEL No. H5,N74,R1,R40

ABSTRACT

This paper investigates the reversibility of the effects of transport infrastructure investments, based on a programme that removed much of the rail network in Britain during the mid-20th Century. We find that a 10% loss in rail access between 1950 and 1980 caused a persistent 3% decline in local population relative to unaffected areas, implying that the 1 in 5 places most exposed to the cuts saw 24 percentage points less population growth than the 1 in 5 places that were least exposed. The cuts reduced local jobs and shares of skilled workers and young people.

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1 Introduction

Transport infrastructure is durable, but its costs and benefits can shift over time. Consequently, decision-makers may need to remove or repurpose historical infrastructure investments. For example, the second half of the 20^{th} century saw widespread reductions in railway infrastructure, while more recently, cities are reallocating road space to walking or cycling or removing highways to create public spaces.[1] Interestingly, we know relatively little about the economic impacts of dismantling a transport network, aside from the fact that it is not guaranteed to simply reverse the effects of its construction. This follows from existing research on the construction of transport infrastructure, which generally concludes that building such infrastructure induces path dependencies through its positive effects on agglomeration economies, durable housing and local infrastructure (see Redding and Turner (2015) for a review and Jedwab and Moradi (2016) or Brooks and Lutz (2019) for specific examples).

This paper investigates the economic impacts of large-scale infrastructure removal by examining a policy of rail decommissioning in Britain during the third quarter of the 20^{th} century. This policy became known as the 'Beeching Axe', after a 1963 report, *The Reshaping of British Railways* authored by a Dr Beeching. This report led to the elimination of over two-fifths of all railway lines and nearly three-fifths of all stations. Despite major rail cuts being commonplace in other countries in the period we study, to our knowledge, this is the first paper to characterize their long-term impacts. Our analysis shows that the cuts caused a spatial redistribution of population that persists through to 2001, as well as localized losses of productive individuals and jobs. These results suggests that the effects of rail infrastructure construction are at least partially reversible, which stands in contrast to the evidence on natural advantages, even when those advantages have dissipated (Davis and Weinstein, 2002; Bleakley and Lin, 2012). Crucially however, we also go on to show that the effects of the rail cuts were offset by new freeways created by the contemporaneous construction of the UK motorway network. A central message of our work is therefore that continued access to viable transportation systems may be necessary to sustain previous concentrations of economic activity in cases where natural advantages do not dominate.

To conduct our analysis, we collect small scale aggregated historical decennial census

[1] Between 1916 and 1987, around 35 percent of the US rail network was abandoned (Frye, 2018). Other countries that implemented major rail cut policies include France (1930s), Ireland (1958–66), Argentina (from the 1960s), Spain (1980s), South Africa (1980s), and Canada (1980s/1990s). Regarding roads, many European cities have recently designated car free areas (Nieuwenhuijsen and Khreis, 2016). Los Angeles, San Fransisco, and New York are currently experimenting with similar policies. while these and other cities are also debating the removal of specific urban highways, see e.g. https://www.nytimes.com/interactive/2021/05/27/climate/us-cities-highway-removal.html.

data from 1901 through to 2001 and then link this data to a historical GIS of Britain's railway network that contains details of the rail lines and stations that were opened and closed in each decade.[2] During the 1950s–1970s, around 13,000 km of rail lines (42%) and 3,700 stations (58%) were closed. To estimate how changes in accessibility due to these cuts drive changes in population and other demographic and socioeconomic area characteristics, we have to face the following fundamental challenges.

Firstly, we need a measure of the local intensity of rail network changes. As traditional metrics like the proximity of local lines or stations miss network-wide diffusion of local changes in a network, recent papers have adopted more sophisticated measures of accessibility, centrality or market access that consider the entire network structure (e.g. (e.g. Ahlfeldt and Feddersen, 2017; Donaldson and Hornbeck, 2016) for rail, or Gibbons et al. (2019) and Herzog (2021) for roads). We follow this approach by using a network centrality/market access metric that is based on travel time changes between all origin-destination pairs of stations in the network to capture rail accessibility changes.[3]

Secondly, we must address the natural concern that the rail cuts may have targeted places that were already declining, or that were expected to decline to in the future. The rail cuts were driven by the need to reduce severe operating losses on the rail network. The reasons for these losses were complex but include the shift to buses and roads, failed investment, poor management, and oversupply from 19^{th} century private development. British Railways, the state-owned company formed when railways were nationalized in 1948, explicitly targeted cuts to currently unprofitable lines and stations. This raises identification concerns as current profitability is likely to be strongly driven by local population trends or other factors that determine future outcomes. Critically however, unprofitable lines and stations were identified by a series of statistical studies which were hastily constructed and incomplete. Memos between the architects of the cuts and reports by contemporary and subsequent commentators strongly suggest that closure decisions at the margins were often based as much on guesswork and arbitrary factors as on hard evidence. Bearing this context in mind, our identification strategy compares future outcomes between matched locations with different rail accessibility changes but effectively identical pre-existing population trends. This strategy reflects that controlling for these trends will account for the bulk of the variation in current profitability, and that conditional on these trends decisions about whether to retain or close local stations and lines were arbitrary and exogenous.

[2]The spatial units in our analysis are either *Civil Parishes* or *Local Government Districts*, which are historical administrative units. Parishes represent the smallest geographical units available for the period of our analysis and are used in the majority of our estimations.

[3]We calculate a network centrality index that closely resembles standard measures of market access. Therefore, we use the terms 'market access' and 'network centrality' interchangeably.

A third and remaining concern is that the cuts, and the changes in accessibility they generated, might be correlated with other shocks which had a direct influence on local populations and changed the spatial structure of the economy in ways that favored central and urban areas. Specific concerns in our context are centers of planned population growth that were developed over the middle of the 20^{th} century (so-called New Towns) and the contemporaneous construction of a national motorway network.[4] To mitigate potential biases, we introduce three novel instruments in our regression analysis. The first two use features of British railway history and network geometry respectively to predict local accessibility changes that arise due to rail cuts. The third uses Britain's north-south orientation to predict accessibility changes based on east-west line lengths in parishes. As an alternative strategy, we directly control for contemporaneous shocks from changes in centrality, the development of the motorway network, and New Towns. Estimations using these instruments or controls produce similar results to our baseline estimates, suggesting changes in accessibility from the rail cuts were effectively random, conditional on pre-trends in population.[5]

Our findings suggest that areas with significant reductions in rail centrality experienced relative declines in population. The elasticity of population with respect to network centrality we estimate is around 0.3.[6] These population results indicate that, as theory would suggest, transport has a major role to play in changing patterns of land use, and that removal reverses some of the effects of construction. As the national population grew during the period of rail cuts, it was redistributed towards areas with preserved rail access and new motorway access. However, this reversal was not complete. There was considerable persistence in the spatial population distribution, as expected in the presence of agglomeration economies and durable housing and other infrastruc-

[4]Concerns that some local political leaders were successful at lobbying against closures and determining the future economic development would also be covered by this strategy. However, the historical record suggests that there was little political influence behind Beeching's proposals. The lack of political considerations is consistent with Quiroz Flores and Whiteley (2018) who show that the location of the 2,000 stations listed for closure in the 1963 Reshaping report were not related to political marginality in the 1959 election. We will specifically look at the performance of regions with proposed but not closed stations in the robustness tests section.

[5]As noted on pages 55-57 of the 1963 report, the authors of the cuts explicitly chose not to take account of anticipated future population movements when determining the cuts. For example, the section entitled Long-Term Trends in the Location of Industry and Population begins. "No novel assumptions have been made about the future distribution of population and industry in the country as a whole. Implicitly, it has been assumed that the pattern will continue to be basically similar to that which exists at present and that, while there may be a continuation or a reversal of existing trends, there is not likely to be any change so radical as to affect the desirability of [the proposals]." The similarity of the IV and OLS estimates provides reassurance that this was indeed the case. Nevertheless, we control for past population trends throughout as these are strongly correlated with the local changes in accessibility.

[6]A more easily interpretable ancillary regression we use indicates that in that places in the top quintile of accessibility cuts saw 24 percentage points less growth in population than the places that were in the least exposed quintile.

ture. Population loss was linked to a decline in high skilled and working age individuals, an increase in retirees, and fewer local jobs per resident. At the same time, commuting patterns remained unchanged, suggesting that population movements were driven by job-relocations to better-connected areas.[7]

This paper contributes to our understanding of the role of infrastructure in two important ways. Firstly, it complements the literature on the economic effects of transport infrastructure investments by explicitly considering the effects of infrastructure removal. Secondly, it contributes to the literature on the geography of path dependence and assesses the relative importance of agglomeration economies and durable locational investments versus market access. To further illustrate the asymmetry between transport infrastructure construction and deconstruction, we can compare our estimates to findings from the construction of the railway system. Our back-of-the-envelope calculations suggest that the population loss in parishes where the nearest station closed between 1951 and 1981 was less than half of the population gain upon the station's opening (see Appendix Table A5).

Specific examples of work on the impacts of rail infrastructure construction include Ahlfeldt and Feddersen (2017), who examine the long-term effects of railway access on urban growth in Germany; Baum-Snow et al. (2017), who analyse the impact of railroads on city populations in China; Bogart et al. (2018b), who study the economic effects of early railways in England; Donaldson (2018), who investigates the impact of railways on market integration and welfare in colonial India; Donaldson and Hornbeck (2016), who explore the broader economic impacts of railroads in the United States; Heblich et al. (2020), who assess the role of historical railroads in shaping modern economic geography in Germany; Garcia-López et al. (2016), who look at the effects of rail infrastructure on urban form in Spain; Gonzalez-Navarro and Turner (2018), who analyze how rail transit investments influence city development in the US; Hornung (2015), who examines the impact of Prussian railroads on economic development; and Qin (2016), who studies the effects of high-speed rail in China on local economies. Of particular relevance is Bogart et al. (2022), who investigate the effects on local growth from of the construction of the rail network in Britain, the dismantling of which is the topic of our research. While all the papers above focus on the effects of large-scale railway infrastructure investments, we are looking at an equally large disinvestment. This is a worthwhile exercise because large

[7]Note that we are investigating the impact of infrastructure changes on population distribution across space. Studies focused on aggregate productivity or employment face the challenge to distinguish between casual effects on growth from reorganization. Our study explicitly examines displacement and sorting. We ask whether transport cuts in one location relative to another lead to population shifts, thus identifying relative effects of infrastructure losses. We do not claim effects on national aggregate population, age, or skills, but discuss potential changes to agglomeration economies in the conclusion.

scale railway cuts were common throughout the last 100 years, and because decision-makers are currently considering restoring previous services in several settings.

More generally, studying large scale infrastructure reductions allows us to address questions of path dependence. Important contributions to the path-dependence literature include Davis and Weinstein (2002), who investigate the impact of World War II bombings on the economic recovery and growth of Japanese cities; Bleakley and Lin (2012), who analyze the long-term effects of historical portage sites on modern economic activity in the United States; Michaels and Rauch (2018), who study the persistent impacts of historical events on current economic outcomes using the example of the US slave trade; and Allen and Donaldson (2023), who examine how historical trade routes have influenced present-day economic geography and development patterns. Closest to our topic is a small set of papers that study persistent effects of rail infrastructure investments. Jedwab and Moradi (2016) and Jedwab et al. (2017) study colonial railroads in Africa and find evidence for path dependence of cities along the railway transport corridors. Brooks and Lutz (2019) zoom into one city, L.A., and find evidence of agglomeration in neighborhoods along streetcar lines, leading to subsequent 1922 zoning designations which, in turn, become a force of persistence once the streetcar lines were removed. These papers look at relatively simple rail networks and do not explicitly measure changes in accessibility caused by their removal or disuse. In contrast, we examine major cuts to a large and complex national rail network and show that these cuts generated changes in rail accessibility across the country. These changes in accessibility shifted populations towards more accessible places, a corollary of which was a move towards large urban centers.

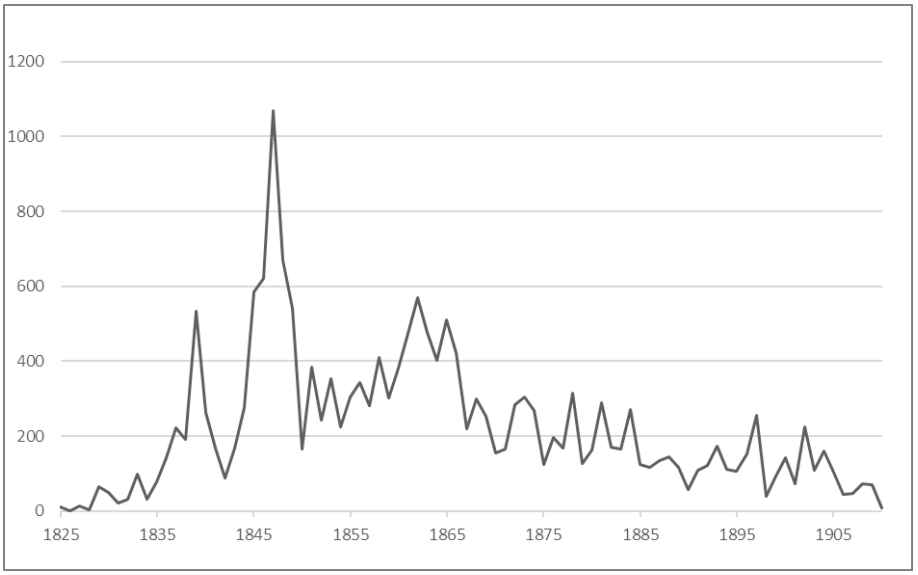
We organize our analysis around three core themes: how does rail infrastructure removal affect local populations, jobs, and skills?; to what degree are community-wide impacts driven or mitigated by local circumstances such as car ownership, proximity to new highways, or the retention of a local station?; and what are the implications for long-run economic geography, agglomeration and aggregate productivity? In the next section we provide more details on the political background of the Beeching cuts. After that, we outline our methods, present our key results, assess their robustness and finally conclude.

2 Historical Background

This section provides a brief history of the British railway network and introduces the political context of the cuts before, during and after the 'Beeching' era (a more detailed discussion is available in Appendix D). In contrast to other countries, the development

of the railways in Britain prior to 1900 was led by private enterprise with an emphasis on market forces. As is illustrated in Figure 1, this led to 'Railway Mania' periods in the 1840s, 1850s and 1860s (see Bogart et al., 2018a). After that, further development came at a much slower pace. Around 1914, the network consisted of some 20,000 route miles of track that included a dense network of rural branch lines, suburban lines with irregular demand, and duplicated lines between many locations.

Figure 1. Annual change in railway mileage in Britain, 1825–1911.



Notes: The figure is taken from Bogart et al. (2018a).

During the First World War the railways came under national control. A 1921 Act reorganized the then 120 railway companies into four large regional groups and subjected them to wage and price controls. The associated consolidation led to the closure of around 1,200 miles of lines (Loft, 2006). In 1948 the railways were nationalized. The newly formed British Railways (later British Rail) launched a modernization program and authorized the closure of 3,000 miles of highly unprofitable lines between 1950–1962 (See Gourvish (1986), p. 119 and Waller (2013)). Despite these cuts, continuing deficits led the government to create the *British Railway Board* (BRB) in 1962. Dr Richard Beeching was appointed as the BRB's first Chairman and tasked with restructuring the railways.

Under Beeching, the BRB proposed to withdraw a third of the tracks and 2,363 stations (British Railways Board, 1963, 1965).[8] The proposals were based, in part, on in-

[8]The reports contain explicit proposals for line and station closures but make no mention of what should but done with the associated land and infrastructure thereafter. Many former stations and lines have subsequently been redeveloped as housing or for other private purposes, which suggests the general policy of British Rail was to dispose of these assets where possible.

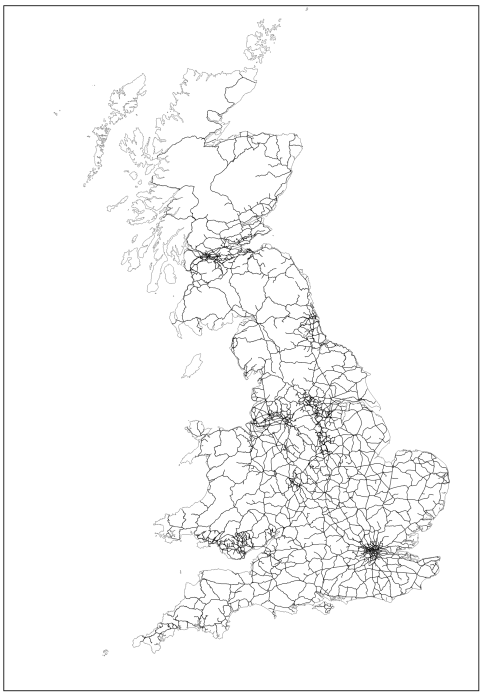
formation gathered in a series of statistical studies which collected data on rail usage, including passenger density and receipts. However, the proposed closures did not rely on any single source of evidence but rather on a combination of factors, suggesting the decision rules were fuzzy and subjective. The rules on which the decisions were based were not set out precisely in any public information, and the information on historical ticket sales and service frequencies or freight traffic is now unavailable. Close inspection of the historical records reveals considerable uncertainties, inconsistencies, and faults in the data that were available to the BRB.[9] The pressure to make closures quickly to reduce deficits means that the report was based on hastily constructed figures obtained using guesswork rather than actual data.[10] The subjective nature of these judgments adds a quasi-random element to the procedures used to determine the closure proposals. The implication of these historical factors is that there were a lot of spurious cuts and retentions, meaning it is potentially possible to identify the causal impacts of the cuts.

The Beeching-era cuts were part of an ongoing and wider program of network rationalization and cost savings, so the closures taking place in the period we study between 1950 and 1980 do not perfectly coincide with those proposed in the 1963 report: some closures occurred before the publication of the report, some closures proposed in 1963 were reprieved, and other subsequent closures were never listed in the Beeching reports. A sketch map of the proposed closures is shown in panel a) of the Appendix Figure A1. Figure 2 shows the railway line network as it was in 1950 (Panel a) and as it became by 1980 (Panel b). Evidently, the cuts to lines were severe. As the lower two panels of Figure 2 illustrate, the changes in the distribution of stations were even more dramatic, so looking at the effects of cuts based on line length alone—as is common in many studies of rail and road infrastructure—is inadequate. Many areas retained lines but lost all their stations. Instead, our analysis will make full use of both the cuts in lines and the cuts in stations, through the network centrality index defined in following section.

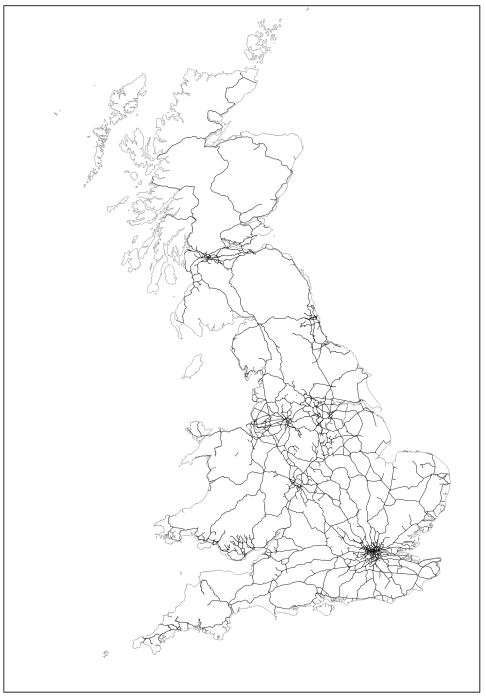
[9] For example, (Munby, 1963, p.162) writes "One hoped that the Beeching Report would provide a more solid foundation of facts and argument to substantiate this policy [of closures] than was available before. Unfortunately, it must be stated that the Plan is disappointing, not so much in what it recommends, as in the inadequacy of the facts, the thinness of the arguments in several places, and in the extent to which it accepts official railway viewpoints without critical scrutiny."

[10] A Confidential Memorandum of Meeting held at BTS Headquarters Friday 21st July 1961 kept in the National Archives reports "The General Managers had given an undertaking that the Traffic Studies could be completed within the suggested timetable. It was essential that as many hard facts as possible should be incorporated: to the extent to which this was not possible there must be reliable managerial assessments and estimates... . As to accuracy of traffic flows, it was thought better to estimate a full year's figures by a combination of facts and managerial assessment than simply to multiply, with all the attendant risks, one week's figures to produce yearly totals... . In regard to passenger traffics, the Costings Divisions passenger traffic analyses might be used, test weeks in March and October probably giving the most balanced results. Some Regions had conducted tests in recent months: others had not had one for many years."

Figure 2. Rail network and stations in Britain in 1950 and 1980.



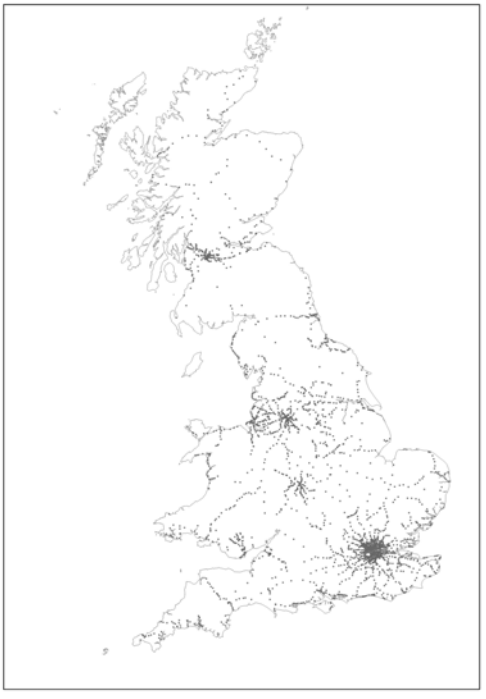
(a) Rail Network in 1950



(b) Rail Network in 1980



(c) Rail Stations in 1950



(d) Rail Stations in 1980

3 Methods and Data

3.1 Outline empirical strategy and identification concerns

Our goal is to estimate how changes in accessibility across the rail network in Britain, caused by cuts to rail lines and stations, affected population and employment outcomes in small areal units in Britain. We estimate these effects using regressions of changes in population (or other outcomes) on changes in accessibility over the period between 1951 and 1981. Our index of rail accessibility is an index of network closeness centrality, based on imputed travel times between stations on the network and between these stations and residential locations. We define this index in more detail in Section 3.3. There are two fundamental challenges to estimation. First, places affected by cuts might have already been on varying population trends, not due to deliberate targeting of declining areas, but because cuts targeted unprofitable lines with low traffic. Second, contemporaneous shocks might have influenced both the likelihood of experiencing cuts and future prosperity. Notable changes in our context include the development of a national motorway network and the strategic planning of centers for population growth.

To address the concern about differential pre-trends, we carefully control for (or match on) pre-existing population trends in our regressions. Specifically, we either: i) include lags of historical census population variables back to 1901; ii) control directly for population pre-trends using dummies for quantiles of the distribution of these trends; or iii) use pairwise differences in a semi-parametric estimator to difference out population pre-trends.

More formally, we estimate flexible time-differences specifications for geographical units i, with the following form:

$$\ln y_{i81} = \beta(\ln cent_{i81} - \ln cent_{i51}) + \gamma \ln cent_{i51} + \delta \ln y_{i51} + \mathbf{x}_i'\lambda + \epsilon_i \tag{1}$$

The dependent variable, sourced from the Census, represents growth or changes in population composition. The variable *cent* is the centrality/accessibility of place i via the rail network in a given year, as described in Section 3.3. It is important to note that the estimate of β in equation (1) matches the result from regressing the 1951–1981 change in log y on the change in log centrality during the same period, conditional on log rail centrality and log y in 1951. The vector of control variables x_i includes: i) log population in 1921, 1931, 1911 and 1901 and squares of these log populations; or ii) sets of dummies for 5 percentile intervals in the distribution of the pre-1951 population trends, for 1901–51, 1911–51, 1921–51 and 1931–51. The geographical units i are parishes for our main population analysis, or Local Government Districts for other socioeconomic variables.

These units are described in Section 3.4.

To construct the pairwise-difference estimator, we rank observations by an index of the population pre-trends and then transform equation (1) into differences between adjacent ranked observations. This ensures that we are comparing places which are on nearly identical pre-trends. The index used for this ranking is either: i) the 1901-1951, 1911-1951, 1921-51 or 1931-51 log population change; or ii) the linear prediction of a regression of the 1951 to 1981 parish rail centrality changes on a flexible polynomial in the population growth in preceding decades:

$$(\ln cent_{i81} - \ln cent_{i51}) = \pi_1 \ln pop_{i01} + \pi_2 (\ln pop_{i01})^2 + \sum_{t=11}^{51} \left(\sigma_{1t} \Delta \ln pop_{it} + \sigma_{2t} (\Delta \ln pop_{it})^2 \right) + v_i \quad (2)$$

In equation (2), Δ represents the difference between census period t and the preceding census year. The advantage of pairwise differencing is that it controls flexibly for non-linearities in the relationship between the outcome variables and the pre-trends. This approach has been proposed for partially linear models (Yatchew, 1997; Honore and Powell, 2005; Aradillas-Lopez et al., 2007). However, our focus is not on estimating the non-linear part, but merely controlling for it.

To mitigate the remaining concern that policy shocks correlated with the cuts may determine future local economic development and therefore bias our estimates, we employ several strategies. First, we use instrumental variables derived from historical network developments and geometry to predict cuts that are independent of contemporary local shocks. Second, we control directly for contemporaneous shocks from changes in centrality, the development of the motorway network, and New Towns. Third, we add geographical grid-square unit fixed effects to equation (1) to partial out simultaneous shocks at the local geographical level.

In additional analysis, we conduct a 'placebo' test with stations proposed for closure but not closed, to ensure that our results are not influenced by targeted cuts to places where adverse economic shocks were expected. We describe the instrumental variables strategy next and other strategies along with the results in Section 4.

3.2 Instrumental variables

Our first two instruments build on insights from the history of the railways that is presented in Section 2. The key insight is that laissez-faire policies led to an oversupply of lines due to private railway companies' wasteful competition for local monopolies.

After the trunk network's completion, speculation often resulted in line duplication and investments in less optimal routes that were cutting though difficult terrain. Over time, as national rail demand declined, these sub-optimal lines became unprofitable and more likely to be closed.

To exploit this insight, our first instrument calculates the distance to redundant lines predicted in 1950. To implement this approach, we first use the 1950 network to predict trunk routes between major cities with populations over 80,000 and between the same major cities and London. These trunk routes are calculated using least cost 'traveling salesman' paths. Appendix Figure A2, Panel (a) shows the predicted trunk lines. Next, we remove these trunk routes from the network, and re-predict connections between the same major cities using the remaining routes.[11] These second-best trunk routes shown in Appendix Figure A2, Panel (b) are our predictions of potentially redundant and unprofitable routes which were more likely to be closed.

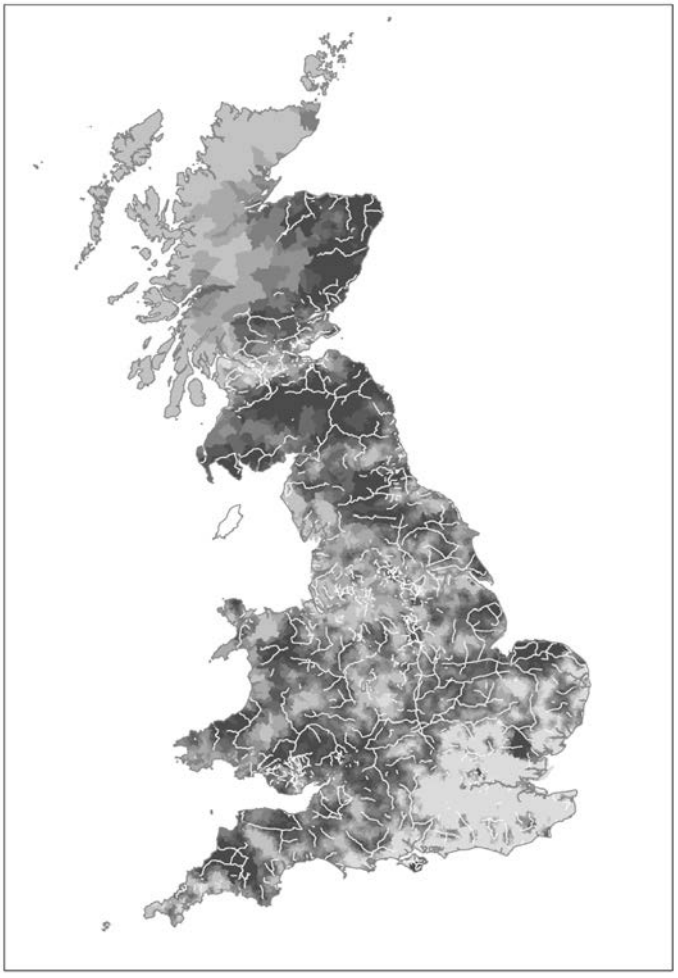
Our second instrument follows a similar logic and splits the distribution of opening years into quintiles. Lines in the third to the fifth quintile were built after 1860. Appendix Figure A2, Panel (c) shows these lines. At this time, the trunk network was established and they are more likely wasteful line additions. To address concerns about recent line additions being endogenous to local policy shocks, we can control for these more recent openings, and exclude only the 3^{rd} and 4^{th} quintiles (the years between 1860–84) in our second-stage regression. The identifying assumption is that, conditional on pre-trends and 1951 network centrality, a parish's future development is unaffected by past competition for local monopolies, except through the higher likelihood of line cuts post 1950.

Our third instrument exploits a by-product of the decision rules outlined above. Travelers in Britain today will recognize that cross country journeys are challenging without going through London as many central and northern lines were cut between 1950 and 1980, a pattern confirmed by Figure 3. This east-west pattern is a by-product of cutting less profitable cross-country lines, rather than the more profitable lines on the north-south axis. Based on this empirical observation, we devise another instrument which predicts rail centrality loss based on the length of local lines running in an east-west orientation, as shown in Appendix Figure A2, Panel (d).[12] Specifically, we aggregate the length of line segments with less than 10km difference between their south and north endpoints across each parish and use this east-west parish line length, conditional on total line length, as our instrument. The identifying assumption is that, conditional on

[11] Instead of fully removing the predicted trunk routes, which would render the network incomplete, we make them virtually inaccessible by setting their cost at ten times their length.

[12] Michaels (2008) uses a similar instrument that exploits the orientation of US highways.

Figure 3. Rail lines cut 1950 to 1980 and changes in centrality/accessibility at parish level.



Notes: The figure shows sections of rail line in white that were removed between 1950 and 1980. Shading illustrates changes in Parish rail centrality, with darker shading indicating bigger reductions.

total line length, 1951 population, rail centrality, and pre-1951 population trends, future population growth in a parish is unaffected by it having east-west running train lines in 1951, except through the fact that these lines were likely to be cut after 1950.

3.3 Measuring centrality and market access

This section describes the construction of the network centrality indices. The main index we use is an unweighted network closeness centrality index. We also show results using a node population weighted centrality index, which is also known as a population accessibility index in the transport literature, or more recently as market access in the trade and spatial economics literature. Centrality indices of this type have long been used in the transport literature to measure accessibility, and recent applications in ana-

lyzing the impact of transport on the economy include Gibbons et al. (2019); Donaldson and Hornbeck (2016); Gibbons and Wu (2020) and Baum-Snow et al. (2020). In this application, we first construct these indices at the rail station level, before we aggregate them to the geographical units of analysis (parishes or Local Government Districts (LGDs)) using inverse distance weighting. Formally, the indices have the structure:

$$cent_{it} = \sum_{j \in J_{it}} \left(\sum_{k \in K_t} m_k \times railtime_{jk}^{-0.5} \right)_j \times roadtime_{ij}^{-0.5} \tag{3}$$

In this expression, i represents a geographical unit, j represents an origin station amongst a set J of stations local to place i, k represents other stations on the network amongst the set K of stations currently open on the network. For our main estimates, we set $J = 3$ so that parish centrality is a weighted average of the rail network centrality of the three nearest stations.

The cost variable $railtime_{jk}$ is an imputed shortest path rail time between station j and station k, derived by network analysis of a historical GIS of the rail network.[13] The cost variable $roadtime_{ij}$ is an imputed shortest path road journey time between a point chosen at random within zone i, and the local station j. Road times are based on 'Manhattan' distances, i.e. 1.4 times the straight-line distance between zone i and station j. To estimate a zone's distance to station j, we average distances from a random set of points within the zone to the station. Weights m_k are station node weights. They are set to 1 for our preferred unweighted centrality indices, or to the 1951 parish population for a market or population access index. Distance decay exponents are set to -0.5, making the index a standard centrality/market access index if only one station is nearby, with travel cost between two parishes as the geometric mean of rail and road journey stages. A doubling of road and rail speeds implies a doubling of accessibility.[14] We are not able to construct full multimodal measures of accessibility incorporating road and rail, because neither the road network nor maps of sufficient quality to construct it are available. However, in Section 4.3 we investigate the interaction between rail accessibility changes and road accessibility changes from the growth of the motorway network, which was the only significant driver of any change in road accessibility over our study period.

The index in equation (3) conceptualizes a parish's rail network centrality as a weighted average of the rail network centrality of the stations near to that parish. While other methods exist, like assigning parishes to the nearest station, our less restrictive structure

[13] We do not adjust road or rail times for topography. This is unlikely to be a major source of error, given the relatively flat topography of most of populated Britain.

[14] We also tried exponents of -1. The results we report later are not highly sensitive to this parameter, within the range typically found in the literature.

avoids singular assignments in cases of multiple equidistant stations, assigning higher weights to closer ones. Another advantage of this index structure is that it can be easily decomposed into (i) components due to changes in the network (the set of stations K and associated rail links), holding the set of local stations constant, and (ii) changes in the set of local stations J, holding the global set K constant. This decomposition allows us to estimate impacts on local economies from local station removals or network-wide changes.

Figure 3 shows the lines that were cut over the 1950 to 1980 period, and the resulting changes in rail centrality, computed as described in equation (3) without population destination node weights. The picture with parish population weights in the numerator is broadly similar, and as the descriptive statistics in Appendix A Table A1 show, the standard deviation in the two variant indices is similar, although their means differ. The correlation between the changes in the 'market access' indicator using population weights and a pure, unweighted closeness centrality index (with numerator weights of one) is 0.99, so the results we present later are nearly identical whichever index we use. In the following section, we will focus on the unweighted centrality index. As expected, there is a strong link between the locations of cut lines and the magnitude of the cut in centrality. Most, but not all places experiencing the least decline in centrality (the darkest areas) are central and urban. However, some places, such as the north of Scotland, experienced little decline in centrality because they were already poorly connected and peripheral.[15]

3.4 Data sources and construction

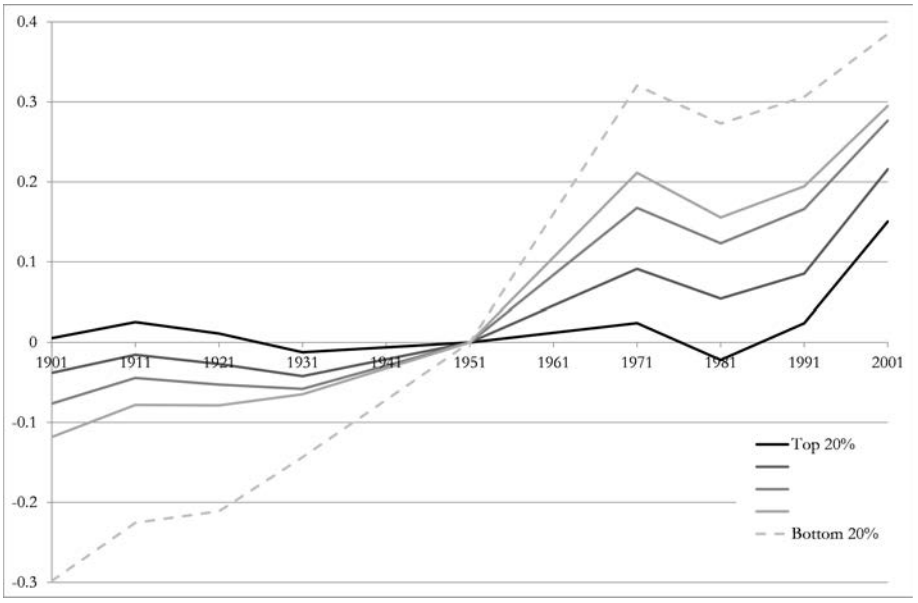
The outcome variables we use in our analysis are taken from historical population censuses that were collected every 10 years between 1901 and 1931 and again between 1951 and 2001; there was no census in 1941 for obvious reasons. At the parish level, we observe population for the whole of Great Britain; at the coarser Local Government District (LGD) level, we observe additional variables that capture changes in the composition of the population but only for England and Wales.[16] We focus on variables that we observe consistently over time: population; the number of 'qualified' workers, which means educated to at least age 20 in earlier censuses, or educated to degree or higher in later years;

[15] We retain the outlying islands of Scotland in our main estimation samples, but the following results are robust to dropping them and also to dropping Scotland as a whole.

[16] Data prior to 1971 have been digitized from paper records by the Vision of Britain project (http://www.visionofbritain.org.uk/) and we are limited to the records that have been published. At the present time, it is not possible to recover any more comprehensive data from the historical census micro data during the 20^{th} century because these are subject to 100-year confidentiality rules. From 1971 onward, more detailed small-area census data is readily available in electronic form, though for different geographical units so we re-weight this data to parish and LGD units as defined for 1951 using land area.

social class groups; broad age categories; total employment of residents; and the number of out-commuters. Our final estimation datasets contain around 1,470 LGDs in England and Wales, and 13,250 parishes in Britain.

Figure 4. Trends in log population, by depth of rail cuts 1950–1980.



Notes: Figure reports mean log populations for Parishes, in groups corresponding to quintiles of the reductions in rail centrality between 1950 and 1980.

Figure 4 shows the general patterns in parish population over the 20^{th} century, split by quintiles for the strength of the rail cuts that occurred over the 1950-1980 period. The darkest lines indicate the deepest cut areas; the light dotted line represents least affected areas. Populations are in natural logs normalized to zero in 1951. This figure illustrates the fundamental empirical challenge we are facing: the 20% of parishes facing the least cuts (the dotted line) were already on stronger population growth trends than the remainder, because they were predominantly core city areas. The pre-1950s population trends in the remaining 80% of parishes vary less with cut severity, and our empirical strategy aims to distinguish rail cut impacts from correlated effects of the pre-trends.

Our rail network was digitized from a historical atlas of British railways (Cobb, 2003). The data comprises lists of stations and lines closed by decade from 1900 to 2000.[17] We then calculate minimum distances for all station origin-destination pairs. Since the network does not distinguish between goods and passenger lines, and both types of services typically ran on the same lines, we cannot distinguish the effects of rail cuts on passen-

[17]We made a few corrections, added in the London underground network and cleaned the data to make it usable for a GIS Network Analysis

ger travel from freight transport. To simulate station access, we calculate straight-line distances from random points within parishes or LGDs to stations, with the number of points proportional to parish land area and a minimum of six points.[18]

Converting rail network and parish-station distances into travel times comes with some assumptions. In the absence of data on service frequencies or complete timetables, we omit these features in our journey time estimations. We assume that people would have timed their journeys in accordance with timetables to minimize delays. This implies that our empirical results should be interpreted as 'intent to treat' estimates relating to the provision of rail infrastructure. Since it is hard to find data on road and rail journey times for Britain in the 1950s, we infer appropriate speeds from samples of historical rail and bus timetables. Our baseline assumptions for rail speeds are 65 km per hour for journeys above 75km and 40km per hour for journeys below 75km, plus 6 minutes on all journeys for transfers and waits. Road travel speeds—which are for our purpose short journeys to local stations—are set to 20km per hour, plus 12 minutes for transfers and waits on all journeys.[19] Since private car use was relatively rare in Britain in the 1950s, this is a good approximation. We use these station-to-station rail travel times and parish-to-station road travel times to compute station-level centrality indices as described in Section 3.3. Although speeds will have changed over the decades of the analysis, we fix them at the 1950s speeds to ensure that all changes in centrality reflect network structure alterations and not arbitrary changes in the assumed travel speeds. That said, the estimates are not particularly sensitive to these assumptions because they are primarily driven by changes in physical network structure. For part of the analysis, we also use a centrality index based on the motorway network which is described alongside corresponding results. Descriptive statistics of all variables are presented in Appendix Table A1.

[18]Setting the number of points in proportion to land area reduces noise in the distance estimates. Using parish populations instead of area would make little sense given that some large parishes may have small populations and vice-versa. The use of six points as an arbitrary minimum is to prevent there being parishes with zero points.

[19]One additional data point other than bus timetables—though from an earlier period—is the figure of 12 miles per hour (19.2 km per hour) reported for average off-peak speeds of a 'motor driven cab' in 1904 (Hicks and Allen, 1999).

4 Results

4.1 Baseline regression results for 1981 populations, controlling for population pre-trends

Table 1 shows results from our base specifications for residential populations in parishes in Britain in 1981. The table shows regression coefficients and robust standard errors, corresponding to equation (1), estimated as discussed in Section 3.1 We experimented with clustering standard errors at higher levels of geographical aggregation (LGDs) but the results are broadly similar. We look at alternative clustering schemes based on grid squares when we discuss estimates with controls for geographical grid-square trends in Section 4.4.

Table 1. Changes in rail network centrality and 1981 populations in parishes, Great Britain

	(1) OLS no pre-trend	(2) OLS lagged pop	(3) OLS pre-trend all	(4) Pairwise diff 1901
Δ log centrality 51-81	0.367***	0.324***	0.270***	0.296***
	(0.023)	(0.022)	(0.021)	(0.021)
Observations	13,253	13,254	13,254	13,253
R-squared	0.032	0.899	0.901	0.853
	(5) Pairwise diff 1911	(6) Pairwise diff 1921	(7) Pairwise diff 1931	(8) Pairwise diff matched
Δ log centrality 51-81	0.302***	0.313***	0.297***	0.318***
	(0.021)	(0.021)	(0.020)	(0.021)
Observations	13,253	13,253	13,253	13,253
R-squared	0.854	0.863	0.871	0.691

Notes: Robust standard errors in parentheses, *** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$. Dependent variable: parish population in 1981 (based on 1951 parish geographical definitions). All regressions include log centrality in 1951, mean distance to stations 1951, and parish land area. All regressions except column 1 include log population in 1951. Column 1 has no other controls; column 2 includes log population in 1931, 1921, 1911, 1901. Column 3 includes dummies for 5 percentile bins in the distribution of changes in log population between 1901–1951, 1911–1951, 1911–1951, 1931–1951. Columns 4–7 estimated on pairwise differences between observations ranked on changes in log population between the given year and 1951. Column 9 estimated on pairwise differences between matched observations ranked on linear predictions from regression of 1951–1981 change in centrality on quadratic in log population in 1901 and quadratics in change in log population 1901–1951, 1911–1951, 1911–1951, 1931–1951. Sample size in columns 4–7 depends on having population variables in both 1951 and the respective base year (1901, 1911, 1921, 1931). Sample size in column 8 drops one observation relative to 1–3 due to differencing in the ranked sample.

Column 1 is a simple regression of the change in log population on the change in centrality with no control variables other than initial log centrality in 1951 and parish land area. Column 2 adds controls for log population and log population squared in 1901, 1911, 1921 and 1931. Column 3 controls instead for dummies for 5 percentile bins in the distribution of the changes in log populations in previous decades and columns 4-8 implement the pairwise difference approach to eliminating these pre-trends. In the latter, standard errors are robust to the autocorrelation induced by the pairwise differencing, using a Bartlett kernel with lag length 2. All coefficients show the effect of an implied increase in centrality: a positive sign indicates that the rail cuts reduced the outcome

variable under investigation.

The most striking feature of Table 1, is that—although controlling for population pre-trends makes some difference, between column 1 and 2—the exact method of control hardly changes the estimated coefficients. The elasticity of population with respect to centrality remains around 0.3 in all cases, suggesting that a 10 percent decrease in a parish's centrality is associated with a 3 percent decrease in population relative to a parish where centrality is unchanged. It is worth emphasizing at the outset that the centrality measure is simply an index of transport accessibility. Therefore, the scale of this elasticity—though not its qualitative implications—varies based on assumptions about its structure. We revisit this when we discuss alternative measures of exposure to rail cuts in Section 4.4.

To assess the effectiveness of our pairwise difference strategy in Table 1, columns 4–8, we estimated placebo pre-trend regressions of the specification in column 8 where we replace the dependent variable in equation (1) with either (i) 1951 population, controlling for 1921 population; or (ii) 1931 population, controlling for 1901 population; or simply (iii) the 1951 population. As expected, the coefficient on the 1981-1951 centrality change variable is zero in all cases. Evidently, matching on pre-trends does reliably eliminate the differences in trends exhibited in Figure 4. This result is a somewhat mechanical outcome of the estimation method, but demonstrates its effectiveness. We would ideally have other pre-1951 variables on which to base this test, but unfortunately none are available from the census records.

4.2 Instrumental variable estimates

We now turn to the results of our IV estimates where we use the three instruments discussed in Section 3.2. Conditional on the extensive controls for pre-trends, this will help us understand whether there are any other unobserved local shocks that affected both the probability to experience line cuts and prospects for future development. The results are presented in Table 2. Column 1 uses distance to the predicted redundant trunk network in 1950 as an instrument for changes in the network centrality index between 1951 and 1981. Column 2 reports results for the construction-year instrument where the excluded instruments are the 3^{rd} to 5^{th} quintiles of the line opening years (which are tabulated in Appendix Table A2). Column 3 presents results for the east-west instrument and column 4 uses all three instruments jointly. All estimations are conditional on controls for pre-policy centrality, population and population trends (we use pairwise differences between matched observations ranked on linear predictions from equation 2). In column 1, we additionally condition the instrument on straight line distance (and

its square) from each parish to the network in general and in column 3, we condition the instrument on the overall length of lines passing through the parish.

Table 2. IV estimates based on network geometry and history

	(1)	(2)	(3)	(4)
Δ log centrality 51–81	0.341*	0.469+	0.730**	0.348**
	(0.139)	(0.269)	(0.272)	(0.118)
Opening period 1^{st} quintile	-	0.031	-	-0.005
		(0.023)		(0.016)
Distance to predicted trunk	-0.056***	-	-	-0.053***
lines 1950 (10 km)	(0.005)			(0.005)
Distance to predicted trunk	0.005***	-	-	0.004***
lines 1950 squared (10km)	(0.000)			(0.000)
Length lines passing through	-	-	0.002***	0.001***
Parish 1950 (km)			(0.000)	(0.000)
First stage				
Excluded instruments	Distance to pred. redundant lines	3^{rd} and 4^{th} quintile opening date	E-W running line length	All
Opening period 1^{st} quintile	-	0.035***	-	0.025***
		(0.008)		(0.008)
Opening period 3^{rd} quintile	-	-0.031***	-	-0.024***
		(0.008)		(0.008)
Opening period 4^{th} quintile	-	-0.066***	-	-0.063***
		(0.008)		(0.008)
Opening period 5^{th} quintile	-	-0.036***	-	-0.037***
		(0.008)		(0.008)
Distance to predicted	0.038***	-	-	0.036***
redundant lines (10km)	(0.003)			(0.003)
Length E-W lines passing	-	-	-1.900***	-1.567***
through Parish (km)			(0.240)	(0.236)
First stage F-Stat.	234.78	31.19	62.52	81.75
p-value	0.000	0.000	0.000	0.000
Sargan chi-squared	-	-	-	3.296
Overidentification p-value				0.348
Observations	13,160	13,160	13,160	13,160

Notes: Estimated on pairwise differences between matched observations ranked on linear predictions from regression of 1951–1981 change in centrality on quadratic in log population in 1901 and quadratics in change in log population 1901–1951, 1911–1951, 1911–1951; 1931–1951. HAC Robust standard errors in parentheses *** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$, +0.10. Instrument in columns 1 is distance to predicted redundant trunk network based on least cost 'traveling salesman' routes between LGDs of populations > 80k and least cost routes between LGDs of population > 80k and London, after eliminating routes that are predicted trunk routes on the full network. See text for details. Instruments in column 2 are dummies for quintiles of line opening dates, as set out in the table. Instrument in column 3 is length of lines passing through Parish in an E-W direction (based on less than 10k north to south between line end points). Regressions include controls for log population in 1901-1951, log centrality in 1951, parish land area and distance to 1950 rail network. Sample smaller than main estimates due to missing opening date instrument data.

The first stages of all three IV regressions have strong F-statistics, implying the instruments work well in predicting which places lost rail connections. In column 1, the IV coefficient of 0.34 is around 10% larger than our preferred estimate from Table 1, column 8. In column 2, the line opening dates instrument gives a somewhat larger coefficient of 0.47.[20] In column 3, the east-west lines instrument gives an even higher coefficient of 0.73, though in both cases the standard errors are large. When we use all three

[20]If we use only quintiles 3 and 4 as excluded instruments and include quintile 5 in the second stage to control for potential direct effects from newer openings on subsequent population changes, the results are largely unchanged with a coefficient of 0.499, and standard error of 0.270.

instruments jointly, we find an elasticity of 0.35 which is very similar to the coefficient in column 1 and to Table 1, column 8. None of the IV estimates is statistically significantly different from our preferred estimate from Table 1, column 8. At the same time, the Sargan test suggests that we cannot reject the null that the overidentifying restrictions are valid (p-value 0.35). As apparent from the specifications in columns 1–3, this indicates that our IV parameter estimates are statistically insensitive to the instrument set used, and treatment heterogeneity is not a first order concern (Windmeijer, 2019).

A possible explanation for the higher IV coefficients is that we are smoothing out a lot of the idiosyncratic variation in rail centrality change, and population responds more to these broader spatial patterns of accessibility than to the localized patterns. In other words, our raw centrality index change is a noisy measure of the underlying changes in accessibility which affect population patterns, suggesting our main estimates are downward biased. Given this interpretation and the fact that the OLS and IV estimates on the pairwise-differenced regressions are not significantly different and in a similar range, we conclude that additional biases from shocks after controlling for pretrends are of second order importance. In the following sections, we will therefore focus on the pairwise-differenced OLS specification of Table 1, column 8.

4.3 Interaction of cuts with existing transport

In the next part of the analysis, we examine interactions with existing transport, first rail and then roads, to assess how prior transport access mitigated the effects of the rail cuts.[21] The results are presented in Table 3. Column 1 extends the base specification by including a dummy for above/below median rail centrality in 1951 and its interaction with the 1951–1981 change in rail centrality. Evidently, initial rail centrality matters (3^{rd} row column 1), with parishes above median rail centrality experiencing 22 percentage points higher population growth than those below the median. However, the coefficient on the interaction between initial centrality and the 1951–1981 changes in centrality is small and insignificant and the coefficient on the change in centrality is unchanged at 0.3. Column 2 takes this further by controlling for an indicator that a parish does not have station access within 10km in both the 1951 and 1981 periods, and its interaction with the rail centrality change index. The idea is to distinguish the effects of the cuts in peripheral parishes which were not targeted by the cuts—they were remote from rail both before and after the cuts—but nevertheless experienced centrality changes. Panel b) of the figure in Appendix Figure A1 illustrates the geographical distribution of these areas: they are rural and peripheral. The results in column 2 show that the effects of the

[21] Remember that the main specifications already controlled linearly for rail centrality in 1951.

cuts were quite general within both remote-from-rail and less remote areas.

Table 3. Effects on 1981 population of changes in rail centrality; interactions with other transport

	(1) Above median 1951 rail centrality	(2) Parish > 10km from stations, 1981 and 1951	(3) Dist. pre-motorway main roads
Δ log rail centrality 51–81	0.293***	0.329***	0.323***
	(0.026)	(0.022)	(0.029)
× Column heading variable	0.072	0.130	-0.004
	(0.041)	(0.069)	(0.017)
Column heading variable	0.201***	-0.063	-0.048*
	(0.053)	(0.084)	(0.021)
Observations	13,253	13,253	13,253
R-squared	0.693	0.695	0.693
	(4) Above median cars 1951	(5) Δ 1951–1981 motorway cent. (pop weighted)	(6) Δ 1951–1981 motorway cent. (pop weighted)
Δ log rail centrality 51–81	0.415***	0.326***	0.454***
	(0.031)	(0.021)	(0.134)
× Column heading variable	-0.147***		-0.187
	(0.041)		(0.194)
Column heading variable	-0.148**	0.304***	0.074
	(0.051)	(0.063)	(0.246)
Observations	13,229	13,245	13,245
R-squared	0.692	0.691	0.691

Notes: HAC robust standard errors in parentheses *** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$. parish level regressions based on matched pairwise differences, as in Table 1, column 8. First row shows baseline effect of change in centrality in parishes in low access group. Second row shows interaction with high access indicator. High/Low access defined in column headings. Distance to pre-motorway main roads is distance to A or B classified roads Change in road centrality 1951–81 is the change in a population weighed centrality index due to construction of the motorways and general road speed increases, 1951–1981. Sample smaller in columns 4–6 due to missing motorway centrality values for islands and missing car data.

Next, we turn to roads. The specification in column 3 includes the distance between the parish and the nearest A or B road, the major roads before the construction of motorways from the 1960s onward. Population growth falls with distance to the nearest main road, but the coefficient on the interaction between main roads and the rail cuts is insignificant and the main effect of the rail cuts is similar to that in our baseline specifications. In other words, there is no evidence that our main estimates are biased by pre-existing trends related to road infrastructure. In column 4 we consider an indicator for car ownership in 1951 instead.[22] The results are interesting: car ownership itself is associated with lower population growth, but the interaction implies that the cuts had less impact in places with high car ownership. Nevertheless, the implied effect of the railway cuts in high-car-ownership parishes is still large, with an elasticity of 0.268.

The final part of this analysis looks at the interaction of the changes in the rail network with changes in the road network, primarily the growth of the motorway network. In the UK, motorways are dual carriageway highways, typically with 3 lanes per carriageway and a 70mph speed limit. Notably, there were no motorways in 1950 although

[22]We only observe this measure at the Licensing Authority, a higher geographical level than parishes.

the basic road network was already highly developed. As a result, the construction of motorways over the 1960s, 70s and beyond mainly increased speeds while distance reductions were rare. We construct the index of motorway closeness centrality/market access using a standard inverse travel time-weighted population centrality index. Unfortunately, we do not have a road network for 1950 or for 1980. Instead, we construct the road network for 1980 by deleting motorways constructed after 1980.[23] We assume vehicle speeds of 60 miles per hour on motorways (97km per hour), 30 miles per hour (48km per hour) on A-roads (the highest category road in Britain at the time), and 18.6 miles per hour (30km per hour) on the imputed links between parishes and their nearest A-road network connections in 1980. These figures are approximations based on the Department for Transport's current average speed data, which have been stable over the past decades. For 1950, we use the same road network but limited travel times to 18.6 miles per hour (30 km per hour). This approach may overestimate journey time reductions and road-based centrality, but our aim is to give roads the best shot at explaining changes in population. The map in panel c) of Appendix Figure A1 shows these imputed market access/centrality changes in relation to the motorway network at the end of the 1970s.

Columns 5 and 6 show results where we consider the impact of motorways and their interaction with rail. In column 5 we include a measure of the change in accessibility induced by the construction of motorways over the 1950–1980 period. Introducing this control for the improvement in road transport and the growth of the motorway network makes no difference to our estimate of the effects of the change in the rail network. The reason for this is that, conditional on 1951 rail centrality, 1951 population, and the population pre-trends, there is almost no correlation between the motorway and rail-based centrality changes. To illustrate this, we regress our log motorway centrality change variable on the log rail centrality change variable and find a coefficient of only 0.01 (although statistically significant, not tabulated). Interestingly, the coefficient on the change in motorway centrality in the population regression in column 5 is itself very similar to that on rail. Given that there is no reason to expect the impacts of access by one mode to be markedly different according to mode of travel, this result provides some degree of confidence that our results have an economically meaningful interpretation.

The final specification in column 6 adds in an interaction between the changes in road centrality and changes in rail centrality. This accounts more flexible way for road and rail accessibility than a single multi-modal index because it permits distinct and comple-

[23]This method overlooks improvements on A-roads and new non-motorway links. However, it is important to note that (i) non-motorway road accessibility improvements mostly stemmed from speed increases, not distance reductions; and (ii) compared to motorway construction, these minor physical network changes are of second-order importance for our estimates.

mentary effects on population change, rather than assuming perfect substitutability for given travel times.[24] The main effect of rail centrality in row 1, corresponding to parishes that experienced little growth in motorway centrality, is twice as large as in previous columns. The coefficient on the interaction term (row 2) is also large albeit imprecise. This suggests that the rail cuts had a much bigger impact on population decline in places which did not benefit from the growth of the motorway network and improvements in road speed. Put differently, the effects of the rail cuts were mitigated by motorway centrality. Conversely, motorways had a much more limited effect on population change in areas that were unaffected by the rail cuts (row 3), but their effects were enhanced by the decline of railways.

4.4 Robustness Checks

This section summarizes a battery of checks that assess the robustness of our main estimates, described in more detail in Appendix C. We first consider potential biases that may arise from general changes in the spatial structure and the contemporaneous, policy-led development of 'New Towns' throughout our study period. Results, reported in Appendix Table A3, indicate little support for the idea that our results are biased by spatial centrality, rurality, or the New Town policy. Furthermore, we find the impact of the cuts is not strongly heterogeneous in more or less spatially peripheral places, or in distance from large cities, although the results do highlight that New Towns that were affected by rail cuts experienced much less population growth than they would have done otherwise.

As an alternative way to control for possible local confounders, in a second set of robustness checks reported in Appendix Table A4, we allow for arbitrary spatial trends by introducing fixed effects for grid squares of different magnitudes (20km, 50km, 100km). To assess possible concerns about inference, we cluster standard errors at the level of the grid squares. It is reassuring that parameter estimates are almost identical to the baseline estimates reported in Table 1 and while standard errors are larger, they still imply t-statistics of at least 9, so Type I errors seem unlikely.

In a third exercise reported in Appendix Table A5, we experiment with different definitions of rail access. We obtain results that are qualitatively similar to our baseline estimates if we use simpler measures of rail accessibility such as the change in the distance to the nearest station, or an indicator for the closure of the nearest station. Next, we revert to using the accessibility index from our base specification (equation 3) but modify the assumptions. First, applying destination node parish population weights yields parameter estimates that are highly similar to the unweighted index of column 8, Table 1.

[24] Additionally, constructing multi-modal network is infeasible due to data limitations.

Clearly, changes in network structure and station loss are more pivotal than specific weights on destinations in the centrality index. Second, we show that computing accessibility over larger and smaller sets of nearest stations rescales the accessibility index and hence coefficients but this does not affect interpretation, as is readily apparent by the similar patterns we obtain for quintiles of centrality index changes across variants.

Lastly, to further support our claim of not capturing effects from targeted cuts, Appendix Table A6 presents results using 474 stations proposed for closure but never actually closed. However, we note that these proposed closures are not an ideal 'placebo' test, as they often remained open for specific reasons, like social necessity in remote areas with limited roads. As a result, parishes near proposed closures are not necessarily comparable to those where closures went ahead. With this caveat in mind, we find that there are population changes associated with the proposed but unenacted closures, but they are 50-75% smaller than those linked to actual closures.

5 Mechanisms and longer-run effects

5.1 Global versus local centrality effects

As outlined in Section 3.3, we can decompose an area's overall rail centrality index change into two separate centrality indices, a local centrality index measuring the effect of local station removals, holding the network constant, and a global centrality index assessing the effect of network changes, holding the set of local stations constant (see Gibbons and Wu, 2020) Doing so helps us understand whether it is the additional road travel time to the nearest local station that matters, or changes in the preserved stations' global network centrality, e.g. because some links to cities nearby have been removed. The results are shown in Table 4. The average reduction in the global centrality index is much greater (-63%) than the reduction in the local centrality index (-21%). This reflects the massive changes to the national railway network (see Appendix Table A1). However, there is more variance across parishes in the local centrality index than the global centrality index (standard deviations of 23% and 15% respectively). The specifications in Table 4 are otherwise as for Table 1, column 8. The estimates show that local and global centrality matter, although the elasticity on local changes is much larger than that on global changes. The larger variance and effect size of local centrality changes suggests that costs from changes in the distance to a local station are key in shaping the spatial population distribution, more so than overall accessibility losses. This explains why Beeching era cuts are seen as primarily affecting rural communities with station closures, rather than areas retaining their stations, but still impacted by broader rail network removals.

Table 4. Local versus global centrality changes

	(1)
Δ log centrality 51–81 due to removal of local stations	0.423***
	(0.029)
Δ log centrality 51–81 due to global network changes	0.144***
	(0.041)
Observations	13,253
R-squared	0.691

Notes: HAC Standard errors in parentheses *** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$. Parish level regressions based on matched pairwise differences, as in Table 1, column 8.

5.2 Longer run and broader geographical population impacts

So far, we have looked at 1981 outcomes, and localized population redistribution at parish level. One might wonder whether these effects were only temporary. Perhaps the subsequent growth of car transportation meant that people gradually moved back to these areas that were disconnected from the rail network. A second question is how the population redistribution at parish level affected the more general pattern of populations across cities and regions: were the movements highly localized or are there implications for broader geographical patterns of population change?

Table 5. Long run effects on parish populations in 1991 and 2001

	(1) 1991	(2) 1991, conditional on 1981	(3) 2001	(4) 2001, conditional on 1991 & 1981
Δ log centrality 51–81	0.296***	-0.003	0.299***	0.047***
	(0.024)	(0.014)	(0.021)	(0.013)
Observations	13,249	13,249	13,253	13,249
R-squared	0.635	0.872	0.643	0.871

Notes: HAC Standard errors in parentheses *** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$. Parish level regressions based on matched pairwise differences, as in Table 1, column 8. Sample smaller in columns 1, 2 and 4 due to missing 1991 and 1981 population data.

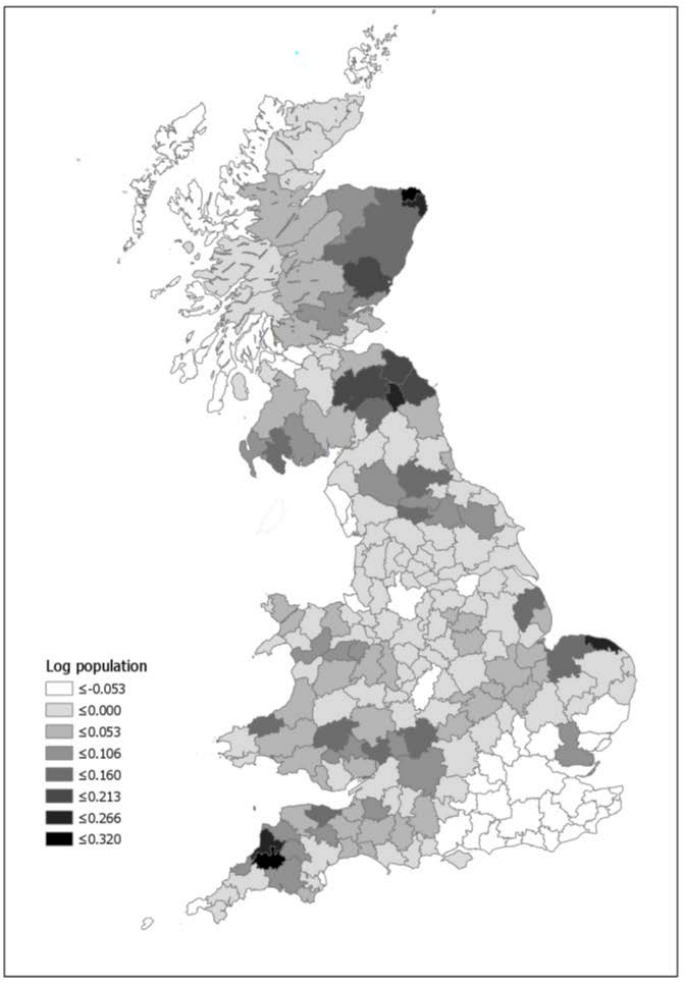
Table 5 explores the first question by repeating the specification of Table 1, column 8 but with parish populations from the 1991 and 2001 censuses. Columns 1 and 3 clearly show that the effects were not temporary. The elasticity of 1991 and 2001 populations with respect to changes in centrality is much the same as for 1981 populations, implying that the effects of the rail cuts were permanent. In columns 2 and 4, we look at the effects conditional on previous census years. Controlling for 1981 populations in the 1991 population regression wipes out the effects of centrality: evidently the 1950–1980 rail cuts affected 1981 populations but had no additional impacts after that. The story for 2001 is slightly different. Now, conditional on 1981 and 1991 populations, we find that the 1950–1980 rail cuts had an additional impact on population growth up to 2001.

The coefficient implies that a 10% cut in rail access in the 1950s, 60s or 70s led to further declines in population of around 0.5% after 1991. We have no data that can shed light on the reasons for this additional impact post-1991, but potential explanations are increased congestion on roads, or the shift from manufacturing to services in the UK economy, both of which may have favored places that remained better connected by rail in recent years. An alternative possibility is that the gradual depreciation of houses and other durable capital built before the cuts means the benefits of these places naturally erode over longer horizons.

We looked deeper into the way these long run population changes related to use of housing, given its durability (Glaeser and Gyourko, 2005). Did the fall in local demand in places affected by the rail cuts just mean fewer houses were built, or did houses fall vacant in the long run, or did the use of housing change towards other uses like second homes or holiday-let accommodation? Our analysis using data from 1981, 1991 and 2001 on parish housing occupancy suggests that the number of houses occupied as a main residence grew in line with the population changes, but there was an increase in housing not used as a main residence in places most affected by the cuts (with no change in vacant housing). The results are reported in Appendix Table A7. Although the exact mechanisms at work here cannot be uncovered by these data, an obvious explanation is that reduction in demand for housing in places affected by the cuts led to re-use of housing in these areas as second homes. This is consistent with the observed rise in ownership of rural and village second homes by urban residents in the UK during the second half of the 20^{th} century.

By construction, the patterns of population redistribution at the parish level mechanically follow the patterns of change in centrality shown in Figure 3. To investigate what these patterns imply for the city-size distribution, we first predicted the counterfactual 2001 population distribution across parishes, by subtracting the component attributable to the centrality cuts based on our estimates in Table 5. We then aggregated the actual and predicted parish populations to 2001 Travel to Work Area (TTWA) level (commuting areas). The results are mapped in Figure 5, which shows the difference in logs between the counterfactual and actual 2001 TTWA population distributions. The figures are adjusted such that the total population is the same under the actual and counterfactual scenarios and a negative number implies the TTWA population would have been lower without the rail cuts. The most obvious feature is that populations throughout London and the South East of Britain would have been at least 5% lower. The population of London itself comes out as 8.9% lower. Other major cities—Birmingham, Manchester, Glasgow—also show up as having lower counterfactual populations in the absence of

Figure 5. Predicted counterfactual log population changes, without rail cuts, at TTWA, 2001.



Notes: Figure shows Travel to Work Areas and shading indicates predicted change in 2001 log population under the counterfactual scenario in which the rail network in 1950 is preserved.

the rail cuts.[25] Overall, without the cuts, population would have been more evenly distributed across TTWAs. This is a result of shrinking the larger TTWAs: the standard deviation of populations in the actual distribution is 580,000 compared to 550,000 in the counterfactual. London's population shrinks from 8.2 million to 7.8 million in the absence of the rail cuts. In the Conclusion, we provide some remarks about what this might mean for productivity, given the well-established links between city size and productivity in the urban literature (Combes and Gobillon, 2015).

[25]There are also remote low population areas in Scotland that show up as having relative population losses in the absence of the cuts: as noted earlier, this is because their rail centrality change was small given that they were already poorly connected.

5.3 Age, education, occupational structure and jobs

In a last exercise, we use census data for a range of socioeconomic outcomes at the Local Government District Level (LGD) covering England and Wales. Looking at changes in the composition of the local population will give us a better understanding of the longer-run effects. Table 6 presents results from regressions with a specification similar to Table 1, column 8, but with different dependent variables relating to 1981 male education (educated to age 20+), occupation-based social class (class 1 is professional, class 2 is intermediate, class 3 is skilled, class 4 is partly skilled, class 5 is unskilled), population age structure, jobs per resident, or commuting patterns in 1971.

Table 6. Changes in rail network centrality and 1971/81 outcomes in Local Government Districts in England and Wales

	(1) Education	(2) Soc 1	(3) Soc 2	(4) Soc 3	(5) Soc 4	(6) Soc 5
Δ log cent. 1951–81	0.132***	0.175**	0.102***	-0.037*	-0.107***	-0.015
	(0.037)	(0.059)	(0.029)	(0.018)	(0.031)	(0.085)
Observations	1,465	1,465	1,465	1,465	1,465	1,465
R-squared	0.782	0.659	0.849	0.920	0.795	0.401
	(7) Age 0–15	(8) Age 15–64	(9) Age 65+	(10) Jobs p.c.	(11) Work Out LA	(12) Work in LA
Δ log cent. 1951–81	-0.008	0.021***	-0.102***	0.128**	0.170**	0.151***
	(0.012)	(0.005)	(0.018)	(0.046)	(0.057)	(0.043)
Observations	1,465	1,465	1,465	1,465	1,465	1,465
R-squared	0.958	0.992	0.880	0.376	0.605	0.618

Notes: Robust standard errors in parentheses *** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$. Dependent variables are: (1) 1981 log higher educated males; (2)–(6) 1981 log males in social class 1–5, (7)–(9) 1981 population in age groups, (10) 1981 jobs per resident, (11) 1971 residents working outside the Local Authority area, (12) 1971 residents working inside the Local Authority area. Class 1 is professional, class 2 is intermediate, class 3 is skilled, class 4 is partly skilled, class 5 is unskilled. All regressions include log centrality in 1951, log population in 1951, log denominator for dependent variable in 1981 and 1951, log dependent variable in 1951 Estimated on pairwise differences between matched observations ranked on linear predictions from regression of 1951–1981 change in LGD centrality on quadratic in LGD log population in 1901 and quadratics in change in log population 1901–1951, 1911–1951, 1911–1951; 1931–1951 (as Table 1, column 8).

In column 1 we see that reductions in centrality reduced the proportions of high-qualified (defined as education to age 20+) in the district. Similarly, in columns 2 and 3, we observe relative reductions in professional and managerial male workers, offset by a relative increase in workers in lower skill occupations in columns 4–6. Note these regressions are conditional on the log total numbers in all social class groups, so should be interpreted as changes in the share of one group holding the total constant. Looking at the age structure in columns 7–9, there is clear evidence of a negative association between centrality and the share of workers over 65 (i.e. a decline in centrality implies an older population) and a positive association with working age populations. These LGD results suggest that changes in rail centrality had non-negligible impacts on local population composition. For example, places that were one standard deviation above

the mean in the distribution of cuts (the standard deviation is around 0.27 in the LGD data) would have seen 4% less growth in the number of educated males in the population relative to the mean, and 3% more growth in the number of males over retirement age (holding total population constant). Column 10 further shows that this reduction in working age population went in hand with a loss of local jobs per person, where we calculate employment in LGDs in 1951 using the Census Report on Usual Residence and Workplace, and in 1981 by reweighting the ward level Census flows available from the UK Data Service. Using the same data sources, columns 11 and 12 show equal sized effects on the log number of residents working inside and outside the local area, suggesting no change in net commuting.[26] We interpret this as evidence that it was a loss of local jobs in response to the rail cuts that led to population movements, rather than a loss of commuting opportunities.

6 Conclusions

We examined the impact of a controversial rail disinvestment program that occurred in Britain in the mid-20^{th} century. Unlike other work focusing on the spatial economic impacts of transport network expansions, ours is the first to investigate large-scale transport infrastructure removal. Our results offer general lessons for the role of transport infrastructure in shaping the spatial economy, and they address the longstanding debate over the 'Beeching Axe' in Britain: did the cuts cause relative decline in affected areas, or were these places already on a downward trajectory?

The broad finding is that the cuts in rail infrastructure caused falls in population in affected areas relative to less affected areas, loss of educated and skilled workers, a loss of jobs, and an aging population. Housing in affected areas saw an increase in use for second homes. A 10% reduction in rail from 1950 to 1980 was associated with a 3% fall in population by 1981, relative to unaffected areas. Put another way, the 1 in 5 places in Britain that were most exposed to the rail network cuts saw 24 percentage points less growth in population than the 1 in 5 places that were least exposed. Populations did not recover in subsequent decades. A key lesson is that rail infrastructure affects the spatial distribution of population—a relevant finding for those interested in the role of transport in land use and the spatial structure of the economy. A second key lesson is that some of the effects of rail infrastructure development on the population are impermanent, as population readjusts once the infrastructure is removed. To compare the population effects of station closures with construction, we turn to (Bogart et al., 2018b) who studied

[26] Note that we report regressions for 1971 here because the local areas in 1971 are comparable to 1951. The same cannot be said for 1981 because major administrative reorganizations in 1974 reduced the number of districts by a factor of five.

population changes during the evolution of the railways in 19^{th} century Britain. Their results suggest that parishes receiving a new station between 1831 and 1841 experienced on average a 30 percentage point increase in population compared to parishes with a station opening in the 30 years from 1831 to 1861.

Our roughly-corresponding estimates (presented in Appendix Table A5) suggest that the population loss in parishes where the nearest station closed between 1951 and 1981 was less than half what was gained upon opening. This translates into a 13 percentage point fall compared to other parishes.[27] Although we have no data that would allow us to empirically analyses the precise reasons for this asymmetry, standard theories of the persistence of the effects of infrastructure are likely to apply. Transport connections trigger the development of other forms of infrastructure, growth in population and firms. The consequent local agglomeration economies encourage population to stay long after the transport infrastructure is removed or relocated.

An important additional finding, though not our main focus, is that growth in road network accessibility due to the construction of motorways also affected the distribution of population, interacting with changes in rail centrality. Places that experienced improvements in accessibility through the motorway network were less affected by the rail cuts. In general, though, the places losing rail access were not those targeted by improvements in road access—the changes in rail and road centrality are uncorrelated—so the motorway network in Britain did little to compensate the places worst affected by loss of rail.

All these estimates relate to population movements and sorting. Unfortunately, we do not have the data to directly answer the question of whether there were aggregate, national gains and losses in terms of productivity, employment and welfare. However, by extrapolating from previous estimates of the relationship between access to economic mass and firm productivity or wages—Combes and Gobillon (2015) suggest 'agglomeration elasticities' around 0.05 at most—we can cautiously conclude that the effects from cutting the railways were probably not that large. There are two channels through which aggregate productivity changes might emerge. Firstly, by cutting connectivity between places, the rail cuts had a direct effect on the centrality and access to economic mass. This is part of the so called 'wider benefits' of transport accessibility. The mean reduction in centrality in Britain was around 40%, implying a direct reduction in productivity of

[27] Unfortunately, their approach is not the same as ours. The nearest comparable figures are for 10-year population changes related to new stations in a parish, and appear in their Appendix Table A1. From these estimates, it looks like the population increase in a parish getting a new station between 1831 and 1841 was about 14 percentage points over a 10-year period. Their main results suggest growth of 15 percentage points over the subsequent 20-year period (their Figure 8) for parishes within 2km of a station in 1841, relative to those more than 70km away. Their published version of the paper Bogart et al (2022) does not feature easily comparable estimates.

around 2%. Secondly, cities in the South East, and especially London, might have gained population from areas with major cuts, potentially enhancing productivity through enhanced city size. We assess the scale of these effects by looking at what our estimates imply about the counterfactual distribution of population across cities, had the rail cuts not occurred. Our back-of-the envelope calculations suggest that the aggregate gains from population redistribution across cities were very small, at around 0.2%, leaving a net productivity loss from the rail cuts of around 1.8%.[28, 29]

[28]From these actual and predicted city size distributions described in Section 5.2, we can estimate the additional productivity attributable to agglomeration that was caused by the rail cuts. We follow previous literature in assuming a benchmark city-size productivity elasticity of 0.05 such that aggregate city productivity is proportional to population raised to the power of 1.05.

[29]This has echoes of Robert Fogel's (1964) claim that the social savings from the railroad system in the US were less than 3% of GNP, although the social savings methodology is based on the value of time, rather than any productivity impacts.

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D Historical Background on the Railway System **47**

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A Additional Tables

Table A1. Descriptive statistics

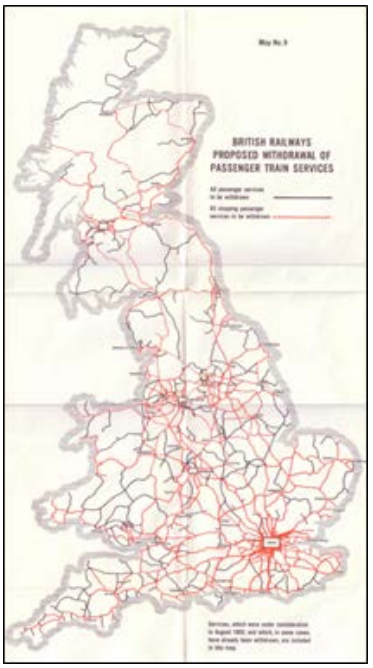
Variable	Mean	SD	Min	Max	N
Parishes					
Population 1951	3678.901	22169.95	2	1.11E+06	13254
Population 1931	3372.066	22120.22	2	1.01E+06	13254
Population 1921	3217.843	21219.18	3	9.24E+05	13254
Population 1911	3065.404	20184.82	2	8.25E+05	13254
Population 1901	2777.213	18757.45	2	7.49E+05	13254
Δ ln pop 81-51	0.121	0.6	-5.796	5.536	13254
Δ ln centrality 81-51 (3 stations)	-1.223	0.277	-2.493	-0.823	13254
Δ local ln centrality 81-51	-0.238	0.204	-0.799	0	13254
Δ global ln centrality 81-51	-0.985	0.143	-2.072	-0.823	13254
Δ ln pop weighted centrality 81-51	-0.39	0.263	-1.681	-0.096	13254
Δ log station distance actual closures	0.699	0.56	-0.163	3.661	13254
Δ ln station distance proposed	0.173	0.316	0	2.61	13254
Lost nearest station proposed	0.357	0.479	0	1	13254
Lost nearest station	0.821	0.383	0	1	13254
Δ log pop weighted m'way centrality	0.698	0.096	0.026	0.951	13245
Length of W-E running lines km	6.98	13.142	0	181.895	13213
Distance to redundant lines km	10.976	18.847	0	364.627	13254
Distance to trunk routes km	16.006	25.593	0	397.24	13254
Distance to non-trunk routes km	1.517	3.126	0	77.833	13213
Distance to stations 1951 km (nearest 3)	7.66	12.217	0.468	404.777	13254
Parish area (km squared)	17.522	41.667	0.027	1106.58	13254
Local Government Districts					
Educated 20 years up 1981	238.139	317.597	2.033	4122.911	1465
Social class 1 1981	523.558	727.939	0	8946.313	1465
Social class 2 1981	2067.721	2488.785	10.076	33083.55	1465
Social class 3 1981	4377.846	6287.431	27.066	1.06E+05	1465
Social class 4 1981	1527.589	2462.769	9.517	50516.73	1465
Social class 5 1981	564.318	1048.782	0	17238.08	1465
Age 0 1981	6795.945	9522.312	59.831	1.78E+05	1465
Age 15 1981	21332.53	30001.71	226.569	5.21E+05	1465
Age 65 1981	4960.488	7208.362	42.524	1.20E+05	1465
Educated 20 years up 1951	205.685	411.882	3	6795	1465
Social class 1 1951	348.121	647.69	6	8425	1465
Social class 2 1951	1529.92	2599.052	44	44647	1465
Social class 3 1951	5564.779	11373.21	86	2.28E+05	1465
Social class 4 1951	1697.926	2762.212	14	55134	1465
Social class 5 1951	1379.66	3301.046	12	62752	1465
Age 0, 1951	6609.07	13409.39	77	2.64E+05	1465
Age 15, 1951	19939.14	39133.6	374	7.45E+05	1465
Age 65, 1951	3289.779	5899.905	101	1.03E+05	1465
Jobs p.c. LA, 1981	-1.129	0.493	-4.11	4.282	1465
Working in the LA, 1981	7.95	1.344	0.916	11.541	1465
Working outside the LA, 1981	8.364	1.225	2.208	12.83	1465

Table A2. Distribution of line opening years

Opening year quintiles	Min	Max
1	1816	1848
2	1849	1859
3	1860	1867
4	1868	1883
5	1884	1940

B Additional Figures

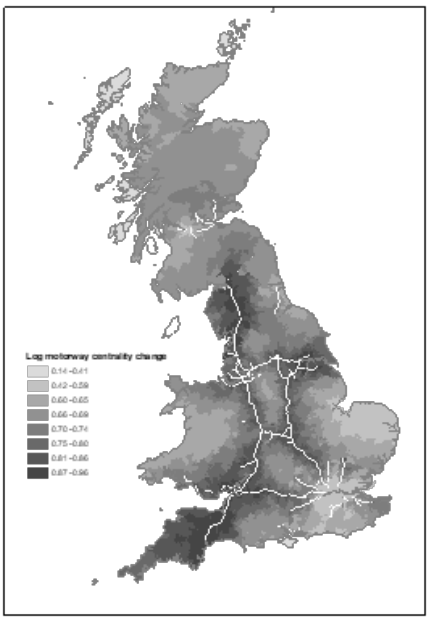
Figure A1. Additional Figures.



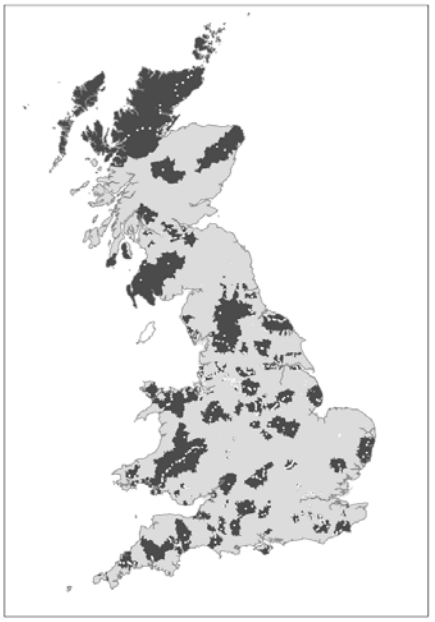
(a) Planned closures in the 1963 Beeching Report



(b) Parishes further than 10km from stations in 1950 and 1980. Closed lines also shown

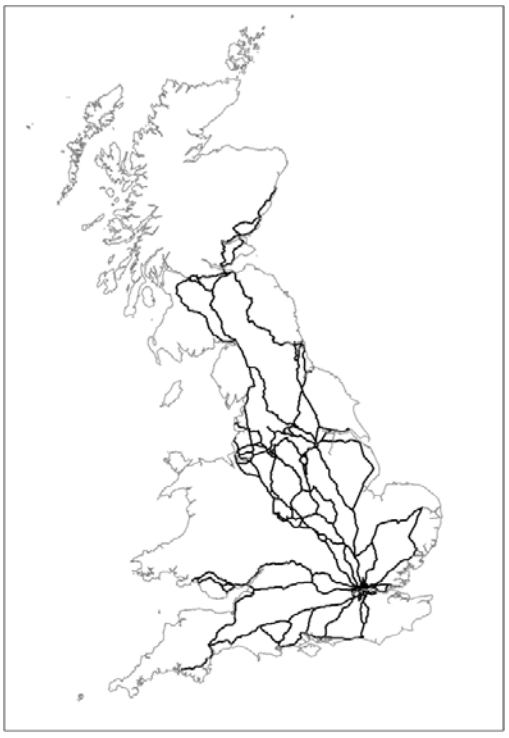


(c) Motorway centrality index change, 1950–1980



(d) Proposed but not closed stations

Figure A2. Predicting the cuts.



(a) Predicted trunk routes based on least distance paths between cities



(b) Redundant lines, imputed by repeating (a) on network after eliminating routes in (a).



(c) Lines opening 1860–1883



(d) Length of East-West running lines intersecting with Parishes, by Parish

C Description of Additional Results

C.1 Rural/urban, centrality and New Towns

In these results we explicitly consider two additional factors that may be expected to drive population movements in our sample window. First, there was a general change in spatial structure that favored central and urban areas in Britain, or those initially well connected by rail, given the cuts disproportionately impacted on peripheral locations. Second, there was planned growth of specific 'New Towns', starting with the New Towns Act (1946) but extending throughout our study period. Planned population in these towns, with retention of the railways serving them, might bias our estimates.

Table A3. Urban/rural and New Towns

	(1) Above median spatial centrality 1951	(2) Above median distance to LGDs population 80k plus	(3) Indicator of New Towns
Δ log rail centrality 51–81	0.357***	0.297***	0.312***
	(0.039)	(0.034)	(0.020)
× Column heading variable	-0.053	-0.055	0.954*
	(0.045)	(0.043)	(0.405)
Column heading variable	-0.062	-0.212***	2.248***
	(0.056)	(0.054)	(0.469)
Observations	13,253	13,253	13,253
R-squared	0.691	0.695	0.698

Notes: HAC robust standard errors in parentheses *** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$. Parish level regressions based on matched pairwise differences, as in Table 1, column 8. First row shows baseline effect of change in centrality in parishes in low access group. Second row shows interaction with high access indicator. High/Low access defined in column headings. New Towns are towns where growth was planned, starting with the New Towns Act (1946) but extending throughout our study period: Basildon, Bracknell, Central Lancashire, Corby, Harlow, Hatfield, Hemel Hempstead, Milton Keynes, Newton Aycliffe, Peterlee, Redditch, Runcorn, Skelmersdale, Stevenage, Telford, Washington, Cumbernauld, East Kilbride, Glenrothes, Irvine, Livingston, Cwmbran, Crawley, Northampton, Peterborough, Warrington.

Table A3 explores these alternative hypotheses. Firstly, we look at the role of geographical centrality of a parish within Britain. Column 1 extends the regression specification by including a dummy for with an indicator for above/below median general spatial centrality, and its interaction with the main rail centrality change variable. By spatial centrality, we mean a standard closeness centrality/population potential index using parish populations as the numerator and straight-line distances between parish pairs as the denominator. The idea here is to see if it is a parish's location in the core or periphery of Britain that is driving population change, rather than the rail cuts per-se. Interestingly, spatial centrality in itself is not strongly related to population change—but then the major metropolitan areas in Britain which experienced growth over this period, apart from Birmingham, are not centrally located. There is no evidence of a significant interaction between this spatial centrality and the impact of the cuts, though the implied

effect of the cuts in spatially peripheral areas—the first row in column 1—are 20% larger than on average in the sample.

Column 2 looks more closely at urban/rural differences, controlling for an indicator of above/median distance to major urban areas, defined as Local Government Districts with populations of 80,000 plus. As we would expect, parishes further away from cities experienced relative population decline (-19% from column 2, row 3) but there is no evidence that places closer to cities were more or less affected by the rail cuts than those further away (column 2, row 2). The main effect of the cuts is unchanged at 0.3. The results are also almost unchanged if we drop potential outlying cases like London, the remote islands of Scotland, or Scotland as a whole.

In column 3 we consider whether planning on New Towns could be driving our findings. We classify parishes according to whether they are in New Towns that were developed during the study period. As expected, parishes in New Towns experienced much higher population growth than others. There is also a strong and significant interaction between rail centrality and New Town location, implying that rail centrality had a much bigger impact on population in areas where there was planned population growth - or in other words, New Towns that were affected by rail cuts over the 1950s–80s period experienced much less population growth than they would have done without the cuts. The effect of the rail cuts outside of New Towns, is, however, unchanged relative to previous estimates at around 0.3.

C.2 Controlling for geographical shocks with grid-square fixed effects

As an alternative way to control for confounding factors at the local and regional level we introduce fixed effects to control for arbitrary spatial trends at the level of grid squares, obtained by rounding the parish coordinates to 20km (667 groups), 50km (146 groups) and 100km (53 groups). These fixed effects control for unobservables affecting population growth and the rail cuts at the grid square level. The results are in Table A4, columns 1-3. The coefficients remained almost completely unchanged once we include these grid square fixed effects. In column 4, we drop the grid square fixed effects but add in controls for demographic characteristics —age structure, education and social class —at the Local Government District level. This specification controls for differential population growth that is correlated with these initial demographic conditions. The sample size is smaller here, because the sample is limited to England and Wales. Again, the coefficient of interest remains largely unchanged and is similar too to what we get if we estimate on this sample without the LGD control variables.

There are also concerns about the standard errors in our main estimates, given the

Table A4. Controlling for geographical time trends and shocks

	(1) 100km grid cells	(2) 50km grid cells	(3) 20km grid cells	(4) LGD demographics
Δ log centrality 51-81	0.315*** (0.023)	0.297*** (0.030)	0.306*** (0.031)	0.284*** (0.024)
Observations	13,253	13,253	13,253	11,589
R-squared	0.718	0.700	0.694	0.692

Notes: Robust standard errors in parentheses, clustered at the level of the geographical grids in the column headings; *** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$. Dependent variable if parish population in 1981 (based on 1951 parish geographical definitions). All regressions include log centrality in 1951, log population in 1951. Estimated on pairwise differences between matched observations ranked on linear predictions from regression of 1951–1981 change in centrality on quadratic in log population in 1901 and quadratics in change in log population 1901–1951, 1911–1951, 1911–1951; 1931–1951 (as Table 1 column 8). Column 4 controls for LGD demographics, age 0–14, age 15–64, age 65+, educated to 20+, social class 1, 2, 3, 4, England and Wales sample only.

spatial interpolation implicit in the construction of the centrality indices, and the likely spatial correlation in unobservables across space. Table A4 also assesses the severity of this threat to inference by clustering the standard errors at the level of the grid squares used to define the fixed effects, so that the standard errors are robust to autocorrelation in unobservables within the grid squares, and heteroscedasticity at the grid square level. The standard errors, though around 50% larger with clustering at the larger spatial scales, still imply t-statistics of at least 9, so Type I errors seem unlikely.

C.3 Alternative treatment definitions and non-linearities

In Table A5 we experiment with different definitions of rail access. The first panel looks at simpler measures based on changes in the distance to the nearest station. In column 1, this measure is just the change in log distance from the parish to the nearest station, due to station closures. Column 2 uses a simple indicator of whether or not a parish lost its nearest station, and column 3 is an indicator of whether the distance to the nearest station doubled as a result of the cuts. In all cases, in line with the results using the centrality index, an increase in station distance (reduction in centrality) is associated with a reduction in population. Note that although the coefficients are smaller in magnitude than those obtained from the more complex rail centrality index, the qualitative implications are similar: the effect of a one standard deviation change in the rail centrality index is around 0.11, while the effect of a one standard deviation change in log station distance is 0.094.

The second panel reverts to using the rail centrality index of equation 3, but with modified assumptions. In column 1, we use destination node parish population weights. There is little difference between this coefficient and that based on unweighted centrality in our main results. Evidently, it is changes in network structure and loss of stations

Table A5. Alternative treatment definitions. Effects of rail access changes on 1981 log population.

	(1) Δ log station distance	(2) Lost nearest station	(3) Nearest station twice as far
Δ rail access	-0.168***	-0.130***	-0.149***
	(0.011)	(0.015)	(0.012)
R-squared	0.693	0.688	0.690
	(4) Population weighted	(5) Centrality 1 station	(6) Centrality 4 stations
Δ rail access	0.311***	0.092***	0.362***
	(0.022)	(0.009)	(0.023)
R-squared	0.676	0.720	0.694
	(7) Centrality 3 stations	(8) Centrality 1 station	(9) Centrality 4 stations
Top quintile cuts	-0.272***	-0.263***	-0.274***
	(0.018)	(0.018)	(0.018)
4^{th} quintile cuts	-0.182***	-0.206***	-0.148***
	(0.018)	(0.018)	(0.018)
3^{rd} quintile cuts	-0.100***	-0.110***	-0.091***
	(0.018)	(0.018)	(0.018)
2^{nd} quintile cuts	-0.064***	-0.059***	-0.058**
	(0.018)	(0.018)	(0.018)
R-squared	0.692	0.725	0.694
Observations	13,253	13,253	13,253

Notes: HAC robust Standard errors in parentheses *** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$. Parish level regressions based on matched pairwise differences, as in Table 1 column 8.

that matter here and the specific weights placed on destinations in the centrality index are irrelevant. Column 2 assigns to parishes the centrality index of its nearest station (inversely weighted by assumed parish-station road travel time), rather than averaging over three stations. The coefficient estimate is now considerably smaller than when using the index averaged over the nearest three stations. Conversely, when we average over four stations in column 3, the effect is larger. The reason why the coefficient varies according to the number of stations is that averaging over local stations smooths out the variation in rail centrality across space, reducing its variance. Again, the implications in terms of the effects of the rail cuts are the same—it is just that the scaling of the index has changed. To see this, the third panel of Table A5 splits the centrality index changes into quintiles, for each of the 1-station, 3-station and 4-station variants.

Two features are evident from these results. Firstly, the patterns of population change from the most cut to the least cut places are broadly similar regardless of the index. The top 1 in 5 parishes in terms of rail cuts experienced 25 percentage points less population growth than parishes in the least cut (i.e. populations grew by about 25% in the least cut parishes from 1951 to 1981, whereas in the most cut there was little change). Secondly, the effects on populations are seen throughout the distribution of cuts, so assuming a log-linear relationship in the main results has little cost. However, there is some non-

linearity, with the marginal effects more marked in the parishes experiencing deeper cuts. The gap in population growth is around 8–10 percentage points between the 5th, 4th and 3rd quintiles, compared to around 4–6 percentage points between the 3rd, 2nd and 1st quintiles.

C.4 Stations proposed for closure, but not closed

As a last step to check that we are not picking up effects due to targeting of the cuts to places that were expected to decline for non-rail related reasons, we implement a test using stations that were proposed for closure but never closed. The 1963 British Railways Board reports provide a lot of detail on the stations that were proposed for closure. Rail enthusiasts have combined this information with historical records to provide various atlases of the stations and lines that were listed in the report and closed, listed and not closed, and those that were closed for other reasons either before the report or afterwards. We use the information from one of these atlases (Waller, 2013) to isolate those stations which were proposed for closure but were not closed prior to 1980. These 474 cases provide a point of comparison for our baseline estimates, since we would not expect to see comparable effects from cuts to stations that were not actually closed. Unfortunately, these proposed closures do not provide an ideal 'placebo' test, since there were usually specific reasons why these lines and stations were preserved meaning that parishes near proposed closures are not necessarily comparable to those where closures went ahead. Typically, lines and stations were spared because they were in some of the most remote rural areas with few roads where rail was deemed to be socially necessary, because they crossed electoral constituencies in which the incumbent party had a slender majority so wanted to avoid electoral damage, or because there was particularly powerful local lobbying. Some lines that were kept open experienced service reductions. Nevertheless, it would be worrying if we found effects from proposed closures of the same magnitude as those from the actual closures.

Table A6 compares the effects of proposed and actual closures using indicators of changes in distance to the nearest station. The first shows the association between proposed station closures and population change. The second row presents the effect of actual station closures. Evidently, there are population changes associated with the proposed closures, even if these were not enacted. However, these are substantially smaller than those linked to actual closures. If we look at the effect of changes in log station distance, the effects from proposed closures are just over half the magnitude of the effects from the actual closures. If we use a simple treatment indicator based on whether or not a parish was set to lose its nearest station, the effects from proposed closures are under

Table A6. Proposed but not closed stations

	(1) Change in log station distance	(2) Lost nearest station
Effect 1	-0.086***	-0.030*
	(0.018)	(0.012)
Effect 2	-0.149***	-0.136***
	(0.010)	(0.015)
Constant	0.0009	0.0000
Observations	13,253	13,253
R-squared	0.686	0.688

Notes:HAC robust Standard errors in parentheses *** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$. Parish level regressions based on matched pairwise differences, as in Table 1 column 8.

one quarter the magnitude of the effects from actual closures. In both cases the difference between the effects from proposed and actual closures is statistically significant.

C.5 Use of housing

A question emerging from the results on population is what happened to the use of local housing, given its durability. Did the fall in local demand in places affected by the rail cuts just mean fewer houses were built, or did houses fall vacant in the long run, or did the use of housing change towards other uses like second homes or holiday-let accommodation? There is only limited historical data on these topics, but we explore answers with the salient Census data in Table A7. The table reports the effects of the 1951–1981 change in rail centrality on three outcomes—numbers of houses which are used as a main residence, not used as a main residence, and vacant—for three different periods, 1981 immediately after the period of rail cuts and in subsequent decades, 1991 and 2001. Specifications are similar to those of Table 1, column 8, but with housing as the dependent variable rather than population.

Columns 1–2 show, unsurprisingly, a similar pattern to the main results on population. The number of houses occupied as a main residence grew in line with the population changes, with more growth in the places least affected by the cuts. This change persisted through to 2001. In contrast, columns 3–4 show the opposite, with more housing no longer occupied as a main residence in the places most affected by a fall in accessibility due to the rail cuts. This does not mean the houses were vacant, as shown in columns 5–6. The number of houses that were vacant was relatively unchanged by the rail cuts, with fewer vacant properties by 2001 in the places experiencing the biggest rail cuts.

Although the exact mechanisms at work here cannot be uncovered by these data, an obvious explanation is that reduction in demand for housing in places affected by the

Table A7. Effects of rail access changes on housing use

	(1) Houses main residence 1981	(2) Houses main residence 1991
Change in rail access	0.294***	0.273***
	(0.019)	(0.022)
	(3) Houses not main residence 1981	(4) Houses not main residence 1991
Change in rail access	-0.313***	-0.360***
	(0.034)	(0.033)
	(5) Houses vacant 1981	(6) Houses vacant 1991
Change in rail access	-0.037	0.021
	(0.022)	(0.022)
Observations	13,253	13,249

Notes:HAC robust Standard errors in parentheses *** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$. Parish level regressions based on matched pairwise differences, as in Table 1 column 8. Number of observations 13253 in 1981 and 2001, 13249 in 1991.

cuts led to re-use of housing in these areas as second homes. This is consistent with the observed rise in ownership of rural and village second homes by urban residents in the UK during the second half of the 20th Century. While it would be a bold claim to pin this rise sole on the rail cuts, they were evidently partly responsible. Reduced housing demand from local workers likely complemented the natural and recreational amenities often available in places outside the cities that were cut off by rail closures.

D Historical Background on the Railway System

D.1 Early Development

In contrast to other countries, the development of the railways in Britain prior to 1900 was led by private enterprise, and can be characterized by an emphasis on market forces, few subsidies, and limited strategic oversight by the state. Although new railways each had to be set up by an Act of Parliament, the process was privately led: entrepreneur-promoters would put forward new schemes to Parliament, which then had to pass through committees in both Houses. In 1845, the Railways Committee Board of Trade, a supervisory body set up in 1840 to provide strategic oversight to the development of the railways, had set out plans for the future structure of the network, but successive Parliaments took little heed of these plans and authorized a vast number of new schemes. For example, between 1845 and 1847 Parliament authorized 580 new schemes, covering more than 8,500 miles of track, although 1560 miles of these were not subsequently built (Foreman-Peck, 1987).

As a consequence, the railways in Britain grew very rapidly in the 19^{th} century, most particularly in the 'Railway Mania' in the 1840s, when the network trebled in size, and in further spikes in the 1850s and 1860s. Extension of the network continued in the early 20^{th} century, although at a much-reduced pace, until around the start of the first World War in 1914. By this point the network consisted of around 20,000 route miles of track with a dense network of rural branch lines, suburban lines with irregular demand, and duplicated lines between many towns and cities. Casson (2009) estimates that equivalent social benefits could have been obtained from 7,000 fewer miles of track, corresponding to roughly a third of the 1914 network.

Some commentators attribute overcapitalisation of the 1914 network to projects in the highly competitive period from around 1870. As (Cain, 1988, p.120) puts it, "there was waste and inefficiency in the railway system of Great Britain between 1870 and 1914." Certainly, this period coincided with a decline in profitability of the railway companies. Some historians, such as Aldcroft (1968), put the decline down to poor investment decisions. Others, such as Irving (1978), attribute the decline to operating inefficiency. More recent interpretations suggest a combination. For example, Mitchell et al. (2011) analysis of ROCE in 1897 finds significant evidence for operating inefficiency, but also conclude that "wasteful use of capital did make an important contribution to declining profitability."

During the First World War the railways came under national control, heralding a shift in policy away from unregulated competition in the sector. Although nationaliza-

tion was ultimately rejected at this time, the 1921 Railways Act reorganized the remaining 120 railway companies into four large regional groups, and subjected them to wage and price constraints. In this inter-war period, around 1,200 miles of lines were closed (Loft, 2006). Nationalization did occur in 1948. As well as repairing infrastructure and embarking on an ambitious program of modernization, the newly formed British Railways (later British Rail) immediately began a modest program of closures of the least profitable lines. Mindful of public support for the railway and extensive consultative procedures around closures, the committee responsible for closures—the Branch Lines Committee—took a cautious approach: as a result between 1948 and 1953 only 1,400 miles of passenger track were closed, including many services that made no revenue at all (Gourvish, 1986, p.119).

D.2 Post-Second World War Development and the Beeching Cuts

A 1955 Modernization Plan (British Transport Commission, 1955) hinted at plans to make economies by closing a considerable part of the railways,[1] although no specific proposals were put forward then, nor, despite ambitions to do so, in the subsequent October 1956 White Paper (Proposals for the Railways). By 1958, Whitehall, led by an increasingly proactive Treasury, was losing faith in the failing (and expensive) modernization program, and was pushing for a more comprehensive rationalization of the network and a fundamental rethink of the role of the railways within a broader transport policy. A reappraisal of the 1955 plan in 1959 proposed a reduction in total route mileage on the network of some 10% over the next four years.[2] Shortly afterwards a Ministerial Group on Modernization (under a wider Strategic Advisory Group) was set up in Whitehall to consider the future role and size and the railways. In response to pressure from these new bodies, in 1960 the Commission proposed a list of lines to be considered for withdrawal over the next 4 years, including 2,554 passenger route miles ((Gourvish, 1986, p. 119);(Loft, 2006, p. 77)).

Although by mid-1962 the passenger rail network was 3,000 miles smaller than in 1950, the railways were still making large losses (Waller, 2013). In 1962, the Conservative government's Transport Act created the British Railway Board (BRB) to take over the running of the railways, with a duty to run the railways at a profit, and established new procedures that facilitated easier closure of lines. Dr Richard Beeching was appointed

[1] For example, on page 32. "Additional fast and semi-fast long-distance services will be provided, with a considerable increase in suburban train miles, but there will be a marked reduction in the stopping and branch-line service, which are little used by the public and which, on any dispassionate review of the situation, should be largely handed over to road transport."

[2] See https://api.parliament.uk/historic-hansard/commons/1959/jul/29/british-transport-commission-annual.

as the BRB's first Chairman, and tasked with reshaping the railways and bringing them back to profitability again. Under Beeching, the BRB embarked on a series of traffic studies before issuing a number of reports proposing a major reduction to the network, including the withdrawal of a third of the track and 2,363 stations. Key reports issued include a 1963 report entitled "The Reshaping of British Railways" (British Railways Board, 1963), but commonly known as the 'Beeching report', and a subsequent 1965 report entitled "The Development of the Major Railway Trunk Routes" (British Railways Board, 1965). Importantly, the 1963 report represented advice to the government about which lines should close based on a narrow criterion: their profitability. The final decision on closures were to be taken by the government following consultation with relevant parties, and would include some assessment of the *hardship* implied by the closures.

The proposals in the 1963 Beeching report were based in part on information gathered in a series of statistical transport studies including passenger density and receipts,[3] which could suggest a potential regression discontinuity design based on pre-policy service levels. However, this would ignore that the Beeching proposals were just one part of a broader program. Actual closures taking place after 1950 do not perfectly coincide with those proposed in the 1963 report: some closures occurred before the publication of the report, some closures proposed in 1963 were reprieved, and other subsequent closures were never listed in the Beeching reports. Such a strategy is also not viable because the rules on which the closure proposals were based are not set out precisely in any public information, and the information on historical ticket sales and service frequencies or freight traffic is unavailable at a suitable level of detail. Besides, the closures proposed by Beeching did not rely on any single source of evidence but rather on a combination of factors, suggesting the decision rules were fuzzy and subjective.[4]

Archival records and other sources reveal that plans to cut one service rather than another were influenced by a number of factors, some of which can be considered to be arbitrary. Firstly, the Beeching proposals were formulated alongside developments in other policy areas, notably urban, regional and road traffic policies. The extent to which the proposals were swayed by consideration of these policies or other political pressures

[3]These studies are described in Appendix 1 to the 1963 *Reshaping* report: Line Density of Passenger and Freight Traffic; Distribution of Passenger Traffic-Station Receipts; Distribution of Freight Traffic-Station Tonnage and Receipts; Distribution of Freight Traffic-Private Sidings; General Merchandise and Minerals Wagon-Load Traffics; Traffic not Carried by Rail; Freight Sundries Traffic.

[4]For example, in response to an inquiry from a member of the public, the Chief PR Officer wrote an internal memo dated 4.9.1963 to the Director of Costing saying that "[the member of the public] makes an entirely wrong assumption when he says that the most serious aspect of the matter is that the density of 10,000 passengers per mile per week has been taken as a yardstick which all stopping passenger services are judged.... He does not appear to have read the Report, which? makes it perfectly clear that the closure proposals have been determined by the particular circumstances of each individual case." This memo is held in the National Archives.

is unclear. As Loft (2006) reports, Beeching had been persuaded by the Ministry not to propose closure of some suburban services losing £25 million per year in the 1963 report. At the same time, it is apparent that ministers had little knowledge of specific proposals until the publication of the report itself.[5]

More arbitrary influences on the closure proposals stem from deficiencies in the data available to the BRB and the complexity of the task they faced. Contemporary commentators and historians point to considerable uncertainties, inconsistencies, and faults in the evidence base underpinning the proposed closures.[6] Beeching had begun with plans to base decisions on detailed studies of current and future transport costs and flows across all transport types, but the pressure to make closures quickly to reduce deficits and a lack of data, expertise, and resources ultimately led to a narrower focus on current rail utilization. The 1963 report was presented as a purely statistical, technocratic exercise, yet it is apparent that the report was based on a hastily constructed figures obtained using a variety of methods. It was clear from that outset that some of the figures would by necessity be based on local 'managerial assessments' rather than actual data.[7] The subjective nature of these judgments introduces a quasi-random element into the data used to determine the closure proposals.

Besides this, there were various other forms of noise in the data and analysis of line profitability: (i) several of the traffic studies were based on one weeks traffic in April 1961, so were likely to miss seasonal traffic; (ii) traffic receipts were counted where tickets were issued so may have understated receipts for holiday destinations, including seaside towns; (iii) profitability was based on current costs and took no account of possible operating inefficiencies such as overstaffing; (iv) passenger and freight were not

[5]Requests for 'special consideration' were certainly sought later on. For example, a letter in late 1963 (after the publication of the report) held in the National Archives from Minister Ernest Marples to Beeching records that, "we had a talk on Thursday about difficulties some of my colleagues are findings over certain passenger closure proposals.... We also discussed a list of cases to which my colleagues have asked me to give special consideration."

[6]For example, (Munby, 1963, p.162) writes "One hoped that the Beeching Report would provide a more solid foundation of facts and argument to substantiate this policy [of closures] than was available before. Unfortunately, it must be stated that the Plan is disappointing, not so much in what it recommends, as in the inadequacy of the facts, the thinness of the arguments in several places, and in the extent to which it accepts official railway viewpoints without critical scrutiny."

[7]A Confidential Memorandum of Meeting taking place at BTS Headquarters Friday 21st July 1961 held in the National Archives reports "The General Managers had given an undertaking that the Traffic Studies could be completed within the suggested timetable. It was essential that as many hard facts as possible should be incorporated: to the extent to which this was not possible there must be reliable managerial assessments and estimates.... As to accuracy of traffic flows, it was thought better to estimate a full year's figures by a combination of facts and managerial assessment than simply to multiply, with all the attendant risks, one weeks figures to produce yearly totals? In regard to passenger traffics, the Costings Divisions passenger traffic analyses might be used, test weeks in March and October probably giving the most balanced results. Some Regions had conducted tests in recent months: others had not had one for many years."

considered jointly (Munby, 1963).[8] The BRB seem to have been acutely aware of the limitations to the data that they had at their disposal. For example, one internal memo to Fred Margetts, General Manager, dated 23 Sept 1963 and held in the National Archives, records that "the data which were used for assessing the stations to be retained or abandoned in the Reshaping Report was admittedly sketchy and based on rough and ready appraisals." The letter goes on to say that evidence obtained after the 1963 Report now suggested that "...in some cases, it does appear that certain stations should be retained which were originally shown to be closed." (Loft, 2006, p. 104) also reports that Minister Ernest Marples "...told his colleagues that these fuller calculations would be open to criticism because they inevitably involved a certain amount of estimation."

The deficiencies of the data likely made the complexity of the task facing BRB—making calculations of line profitability—even more severe. This complexity stems in part from difficult questions about how to allocate shared costs and assess contributory revenue (the value of traffic passing from a branch line to the rest of the system). Here, it is notable that the Ministry of Transport "accepted the BRB's view that the amount of contributory revenue lost on closure was a matter for opinion" (Loft, 2006 pg 7). The ways in which these complex issues were resolved behind closed doors on a case by case basis and to a very tight timetable is likely to introduce further arbitrary elements into the closures proposed in the 1963 report.

It is also important to note that the proposals put forward in the 1963 Reshaping report were solely based on an assessment of current profitability, and the proposals for service cuts did not seek to anticipate future development or changes in demand, nor take into account other wider considerations. The narrow focus on profitability is evident in the Other Considerations Section (pages 55–57) of the Reshaping report, which begins, "The proposals put forward in this Report have been formulated for the purpose of shaping the railways towards a sound and viable condition in the future, without assuming any major changes in the role which they are expected to fill or in the framework within which they are expected to operate. The Railways Board is aware, however, that direct measurement of profitability is not the only criterion which can be applied when determining the best use of railways as a part of the transport system, in relation to the social and industrial structure as a whole. The Board is satisfied, however, that, although they have not shaped their proposals upon the basis of hypothetical changes beyond their

[8] Criticism of evidence used to underpin closures in this period are not restricted to closures proposed by Beeching. Baron Adonis, a former Transport Minister, recently expressed doubts about the data underpinning the later proposed closure of Kingham station (a post Beeching closure proposal) which was close to his school. Baron Adonis and his school friends counted the number of passengers passing the station in a 24-hour period, and concluded that the official figures on which the government was basing the closure were way too low. See http://www.ukpol.co.uk/andrew-adonis-2019-speech-to-the-ippr-on-reversing-beeching/

control, or with regard to responsibilities which do not at present rest upon them, none of the proposals put forward here does violence to concepts which others might reasonably have wished to include." The following sub-section on Long-Term Trends in the Location of Industry and Population then states that, "No novel assumptions have been made about the future distribution of population and industry in the country as a whole. Implicitly, it has been assumed that the pattern will continue to be basically similar to that which exists at present and that, while there may be a continuation or a reversal of existing trends, there is not likely to be any change so radical as to affect the desirability of [the proposals]." A subsequent statement then suggests a slightly more nuanced approach to industrial developments whereby those that were highly advanced would be taken into account, "Therefore, in formulating proposals for line closure, all the Railway Regions have taken account of any developments which are sufficiently specific to be probable, but have not been influenced by quite unsupported suggestions that something might happen some day." The report then further details a number of other factors which were not taken into consideration when formulating proposals including rationalization of transport across modes and social costs and benefits which may arise from the cuts via effects on inter alia congestion, parking spaces, safety, and road building.

Following the 1963 Reshaping report, in 1965 the BRB released a second report entitled "The Development of the Major Railway Trunk Routes". This set out further thinking on the development of the trunk network over the subsequent 20 years, in effect prioritizing some routes over others. The decision rules for prioritization of lines are set out in the (British Railways Board, 1965, p.37): "The process of selection involved consideration of the following factors: (i) the extent to which existing routes coincide with the principal traffic flows of the future, (ii) the comparison of the workable capacity of the alternative routes with the number and type of trains expected to arise from the future area to area flows, (iii) the service of important intermediate centers, (iv) recent expenditure on route modernization, such as track improvement, electrification and resignaling projects, (v) the necessity for large items of future expenditure on trunk routes, (vi) physical characteristics of the routes: the incidence of bridges, tunnels, viaducts, of ruling gradients, and features likely to restrict speeds permanently, (vii) 'network' considerations: the way in which routes selected fit into the future railway trunk network, (viii) the extent to which changes in the trunk system may result in greater lengths of haul."

Finally, a more general indication that the actual Beeching-era cuts were to some extent quasi-random follows from subsequent analysis of the cuts and the profitability of the remaining network. On one side, Henshaw (1991) argues that as many as half of the closures proposed by Beeching were either truly profitable but misrepresented in

the analysis, or could have been made profitable. On the other side, Gourvish (1986) reports that a 1982 government-initiated review concluded that even a 40% cut to the 1982 network would still not be profitable, and that a profitable core network would consist of just 1,630 miles. From these competing conclusions, it is apparent that determining whether many given individual lines were profitable or unprofitable was to some extent arbitrary.

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