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

Stephen Gibbons[1]

Stephan Heblich[2]

Edward Pinchbeck[3]

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[1]Department of Geography and Environment & Spatial Economics Research Centre, London School of Economics and Political Science, Houghton Street, London WC2A 2AE, UK
e-mail: s.gibbons@lse.ac.uk
[2]Department of Economics, Bristol University
[3] Spatial Economics Research Centre, LSE

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Abstract:

Transport investment remains a popular policy instrument and many recent studies have investigated whether new infrastructure generates economic benefits and has spatial economic impacts. Our work approaches the question differently and looks at what happens when a substantial part of a national railway network is dismantled, as happened during the 1950s, 60s and 70s in Britain. Part of this disinvestment occurred following controversial reports on railway profitability and structure in the early 1960s – a course of action known colloquially as 'the Beeching Axe' after the author of the reports. The removal of railways is often blamed for the decline of rural areas and peripheral towns in post-war Britain. This rail disinvestment program was targeted at removal of under used and unprofitable lines and not specifically targeted at local economic performance. Even so, we find that there is a relationship between pre-war population decline and the depth of the rail cuts in the post 1950 period. Conditional on these pre-trends, we show that loss of access by rail did cause population decline, relative decline in the proportion of skilled workers, and declines in the proportion of young people in affected areas. An instrumental variables approach exploiting the fact that the many of lines cut ran east-west across the country yields similar results. An implication of these findings is that rail transport infrastructure plays an important role in shaping the spatial structure of the economy.

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1. Introduction

Theory and common sense suggests that transport plays an important role in shaping the spatial economy. It affects where people choose to live, where people choose to work, affects patterns of trade and potentially shifts productivity. Despite this, it is only quite recently that high quality evidence has emerged, using detail spatial data and modern methods to provide credible estimates of the response of the economy to transport networks (see Redding and Turner 2015 for a recent review). Some of this work focusses on specific schemes within cities. Some turns to historical settings or developing countries in order to find contexts where there is a large expansion in the transport network on which to base estimation. However, there is a formidable empirical challenge in that transport is typically targeted towards places that are already growing, or are otherwise a typical, so it is hard to disentangle causal effects from pre-existing trends. Our work is unique in looking at the effects of disinvestment in rail infrastructure, which offers some advantages in that we are not studying the construction of infrastructure to serve specific local economic demands. Studying partial removal of a rail system also offers interesting insights into whether infrastructure locks in permanent changes in spatial structure, or whether whatever benefits it brings are conditional on the infrastructure staying in place.

The specific context we study is the decommissioning of railways that occurred over the 1950s, 1960s and 1970s in Britain. At this time, the railways were a nationalised industry, under control of British Rail, part of the British Transport Commission. The cutbacks to the rail network started early in this period, though are often blamed on a 1963 report *The Reshaping of British Railways* issued by the chairman of the British Railways Board, Dr. Richard Beeching. The report is commonly known as the 'Beeching report' and its consequences as the 'Beeching Axe'. The main factor motivating the cuts was simply the dire financial situation of the rail transport industry, which was incurring losses of over £100 million per year by the early 1960s (Waller 2013). The reasons for these losses are complex, partly due to the changing patterns of demand with shifts towards buses and road transport, partly due to failed reinvestment programmes and poor management, and partly a legacy of the private sector development of the network during the 19th century which had resulted in some oversupply and redundancy. The bottom line was that over the 1950-1980 period around 13,000 km from 31,000 km of lines and 3700 out of 6400 stations were closed. There has been intense and long running debate over the consequences of these cuts for the British economy, particularly rural areas (Loft 2013).

Our basic approach to answering this question is to link small scale aggregated historical decennial census data from 1901 through to 2001 to a historical GIS of Britain's railway network that details the lines and stations open in each decade. We then use panel data regression-based methods to estimate whether changes in accessibility due to cuts in the railways – measured by a market access/network centrality index – were associated with changes in population and other demographic and socioeconomic area characteristics. There is a lack of institutional or geographical features that yield appropriate instruments for the rail cuts. Therefore we rely primarily on matching geographical units flexibly on pre-existing population trends to address the problem that the rail cuts were not randomly allocated and were more likely to occur in already-declining places. As an alternative, we devise an instrumental variables strategy which exploits the fact that lines running east-west were much more likely to be cut than lines running north-south down the spine Britain towards London. The overall conclusion is that places experiencing large reductions in rail centrality experienced falls in population, the number of educated and skilled workers and an increase in the proportion of older workers, relative to places that were less affected.

In the next section we outline our methods. Following that, we present our key results and conclusions.

2. Methods

2.1 Specification

We estimate the effect, on a number of population outcomes, of changes in the network centrality (or market access) of areas in Britain arising as a result of cuts to the railway network and closures of stations. The focus specifically is on the changes in centrality occurring between 1950 and 1980, on changes in outcomes between the 1951 and 1981 census years. The methods for constructing these changes in centrality are described in Appendix A [To Do]. The fundamental challenge to estimation is that the places subjects to cuts were potentially on very different population trends prior to the cuts. This pattern does not arise through targeting of cuts specifically to areas in economic decline, but as a by-product of the fact that the cuts were targeted to unprofitable rail lines, with low demand.

Our context does not offer many obvious quasi experimental approaches. The bureaucratic nature of the plans to cut the railways based on railway passengers and ticket revenue suggests potential regression discontinuity designs, but information on the precise rules adopted for the cuts is absent. Instead we adopt a number of methods to try to match on the population pre-trends in a careful and flexible way. To do this we either: 1) include lags of historical census population variables back to 1901; 2) control directly for population pre-trends using dummies for quantiles of the distribution of these trends; or 3) use pairwise differences in a semi-parametric estimator to difference out population pre-trends. A number of placebo and robustness tests are available exploiting planned station closures which were not enacted, and we rule out effects from simultaneous growth in the Motorway network. We also devise an instrumental variables approach using the rail line orientation as a robustness check, described in the Results section.

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

$$\ln y_{i81} = \beta(\ln cent_{i81} - \ln cent_{i51}) + \gamma \ln cent_{i51} + \delta \ln y_{i51} + x_i'\lambda + \varepsilon_i \qquad (1)$$

The dependent variable is one of a number of variables describing the population and is taken from the Census. The variable $cent$ is the centrality of place i in the rail network in the corresponding year, constructed as described in Section 2.2. Note that the estimate of β in (1) is identical to that that would be obtained from a regression of the 1951-1981 change in log y on the 1951-1981 change in log centrality, conditional log rail centrality and log y in 1951.

The vector of control variables x_i includes: 1) log population in 1931, 1931, 1911 and 1901; or 2) sets of dummies for 5 percentile intervals in the distribution of the pre-1951 population trends, either since 1901, 1911, 1921 or 1931. In the pairwise-difference estimator we rank observations by an index of the population pre-trends, then transform (1) into differences between adjacent ranked observations (so we are comparing places which are on nearly identical pre-trends). The index used for this ranking is either: a) the 1901-1951 population change ($\ln pop_{i51} - \ln pop_{i01}$); or b) the linear prediction from the regression:

$$(\ln cent_{i81} - \ln cent_{i51}) = \pi_1 \ln pop_{i51} + \pi_2 \ln pop_{i31} + \pi_1 \ln pop_{i21} + \pi_1 \ln pop_{i11} + \pi_1 \ln pop_{i01} \qquad (2)$$

The advantage of this pairwise differencing method is to control flexibly for non-linearities in the relationship between the outcome variables and the pre-trends. This kind of estimator has been proposed for partially linear models (Yatchew 1997; Honore and Powell 2005; Aradillas-Lopez, Honore and 2007) although in our context we do not wish to estimate the non-linear part, only control for it.

2.2 Measuring centrality and market access

This section described the construction of the centrality and market access 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 a market access in the trade and spatial economic literature. In the current application, these indices are constructed first at rail station level. The station-specific indices are then aggregated to the geographical units of analysis (parishes or LGDs) using inverse distance weighting. Formally, the indices have the structure:

$$cent_{it} = \sum_{j \in J_{it}} \left(\sum_{k \in K_t} m_k \times railtime_{jk}^{-1} \right)_j \times roadtime_{ij}^{-1} \qquad (3)$$

In this expression, i represents a geographical units, 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. 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. 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* the straight-line distance between zone i and station j. To estimate the distance from a zone to a station, a set of points are drawn randomly within each zone and the distances from each point to station j are averaged. Weights are station node weights. In our preferred unweighted centrality indices these are set to 1. Alternatively, the weights can be set to the 1951 populations in the Parish in which the station k is located, yielding a market access index [Results to do].

This centrality index can be decomposed into components due to changes in the network (the set of stations K and associated rail links), holding the set of local stations constant, and changes in the set of local stations J holding the global set K constant. This allows us to estimate to what extent the impacts on local economies are due to removal of local stations, or spatially differentiated patterns due to changes occurring elsewhere on the network. [Results to do]

2.3 Data

Outcome variables are taken from historical census data, at either the Parish level, for populations, covering the whole of the GB, or Local Government District (LGD) level covering only England and Wales. Data prior to 1971 have been digitised 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 and digitised. From 1971 onwards, census data is more readily available in electronic form, though for different geographical units. We use data from 1901, 1911, 1921, 1931, 1951, 1961, 1971, 1981, 1991 and 2001 and re-weight all the data to Parish and LGD units as defined for 1951. Our key variables are those that we can reasonably make consistent across the census years of interest: population; the number of 'qualified' workers, which means educated to 20 years plus in earlier censuses, or educated to degree or higher in later years; social class groups; broad age categories. At Parish level, the only useful data available is total population although we have this for the whole of the GB. All other variables are at LGD level and available for England only. There around 1470 LGDs in England and 13350 Parishes in Britain.

Our rail network data was kindly provided to us by Jordi Marti Henneberg, whose team has digitised it from historical atlas of British railways (Cobb 2003). The data provided to us lists stations and lines closed by decade from 1900 to 2000. We made a few corrections, added in the London underground network and cleaned the data to make it useable for as a GIS Network Analysis. We then used the network analyst tools in ArcGIS to calculate station-to-station minimum distance origin-destination matrices. Distances are converted to times using some assumptions about rail speeds over different distances. These matrices are used in the rail centrality indices described in Section 2.2 above.

3. Results

3.1 Descriptive statistics and figures

The railway network as it was in 1950 is shown in Figure 1. Figure 2 shows the lines that were cut over the 1950 to 1980 period, and the resulting changes in rail centrality, computed as in equation 3, with Parish population weights in the numerator. Note, 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 which ever index we use. As expected there is a strong link between the locations of the cut lines and the magnitude of the cut in centrality. Note, most, but not all of the 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. The numbers on the scale indicate the change in log centrality.

Figure 3 illustrates the general patterns in Parish population over the 20th Century, split by quintiles for the strength of the rail cuts that occurred over the 1950-180 period. The darkest lines are the deepest cut areas; the light dotted line represented least affected areas. Populations are in natural logs normalised 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 these are predominantly core city areas. The pre-1950s population trends in the 80% of Parishes that experienced stronger cuts are less differentiated, but can hardly be considered parallel. The empirical challenge is to disentangle whether there are impacts from the rail cuts that go above and beyond what we would have expected based on the pre-trends.

3.2 Baseline regression results for 1981 populations and demographics

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 2.1. Column 1 includes no control variables other than initial log population and centrality in 1951. Column 2 adds in controls for log populations in 1901, 1911, 1921 and 1931. Columns 3-6 control instead for dummies for 5 percentiles bins in the distribution of the changes in log populations in previous decades (from 1901, 1911, 1921 and 1931 respectively). Columns 7-10 implement the pairwise difference approach to eliminating these pre-trends. In the ranked pairwise difference, the standard errors are heteroscedasticity and autocorrelation consistent, using a Bartlett kernel with lag length 2 (implemented using ivreg2 in Stata). Note, that the 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 whether we control for population pre-trends or not, and the method by which we control for pre-trends makes almost no difference to the estimated coefficients. In all cases, the elasticity of population with respect to centrality is around 0.3 i.e. a 10 percent decrease in centrality is associated with a 3 percent decrease in population.

Turning to a wider range of socioeconomic outcomes, Table 2 presents results from regressions with a specification similar to Table 1, column 11, but with various different dependent variables. These regressions use census data at the Local Government District Level (LGD). Column 1 reports the LGD level equivalent to the Parish population regressions in Table 1: Evidently, the impact of centrality on population is similar at LGD and Parish level. From column 2 we see that reductions in centrality reduced the proportions high-qualified in the district. Similarly in columns 3 and 4, there are relative reductions in professional and managerial male workers, offset by a relative increase in workers in lower skill occupations in columns 5-7. 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 there is clear evidence of a negative association between centrality and the number of workers over 65 (i.e. a decline in centrality implies an older population) although there is no evident corresponding decrease in younger population.

3.3 Alternative explanations: spatial centrality and the motorway network

An important question is whether these effects of loss of rail centrality really relate to the rail cuts, or whether they relate to some other contemporaneous changes that were correlated with the rail cuts. One alternative explanation is that there was some general change in spatial structure that favoured central and urban in Britain, given the cuts disproportionately impacted on peripheral locations. A second is the growth of the road network, especially since one of the justifications for closing the railways was that roads were seen as the future of transport. The main change in the road network over this period was the construction of the motorways. This coincided with the rail cuts, the first opening in 1958.

Table 3 explores these alternative hypotheses. The main specifications already controlled linearly for rail centrality in 1951. Column 1 extends the specification by including a dummy for above/below median spatial centrality in 1951 and its interaction with the 1951-1981 change in rail centrality. By spatial centrality, we mean a standard closeness centrality/population potential index $a_i = \sum_j m_j distance^{-1}{}_{ij}$ using parish populations as the numerator and straight line distances between parish pairs as the denominator. Evidently, this has little impact on our findings: the effects of reductions in rail centrality on 1981 populations are general, and unrelated to initial spatial centrality in Britain. Column 2 does a similar thing, but with an indicator of above/below median 1951 rail centrality. Again this has almost no impact on the results. In column 3, we include a dummy for Parishes which are within 10km of a motorway (based on the complete network in 2011) and interact this with the 1951-1981 change in rail centrality. Being close to the final motorway network itself appears to have no impact on populations in 1981 (row 3) suggesting that the growth in the motorway network itself is unlikely to explain our findings. Interestingly interacting the indicator of motorway access with the rail centrality change variable gives an implied elasticity of population with respect to rail centrality is around 0.17 in Parishes close to motorways, compared to 0.3 in Parishes further away. Evidently, better road access did indeed mitigate the adverse effects of the rail cuts although does not appear to have eliminated them.

3.4 Non-linearities

In Table 4 we relax the linear relationship between outcomes and changes in rail centrality, by splitting the distribution of the latter into quintiles and including a corresponding set of dummies. We treat the quintile with the smallest changes in absolute value (i.e. places with the least cuts) as the baseline. Recall, the changes in centrality are always negative in the data due to the rail cuts. We focus on a few key outcomes from Table 1 and Table 2: Parish populations; LGD population with high qualifications; LGD populations aged 65 and over. For populations, these results correspond to those shown in Figure 3, although in these tabulated results we are controlling precisely for the pre-trends in population.

Looking at the table it is evident that the effects on 1981 populations are general throughout the distribution. The top 1 in 5 Parishes with the deepest cuts in rail access saw population fall by a massive 20% relative to the 1 in 5 Parishes with the weakest cuts. The next group saw populations fall by around 15% relative to the same baseline. For the 2nd and 3rd quintile groups saw populations fall by around 8-10%. Clearly the impacts of the rail cuts were pervasive. Turning to education in column 2 reveals a slightly different pattern, with impacts on the proportion of qualified people concentrated in the top 2 in 5 LGDs with the biggest cuts. These areas saw 10-13% falls in the number of high qualified people relative to the baseline LGDs with the weakest cuts. There is little change in qualification levels in the remaining LGDS experiencing less severe cuts. Lastly in column 3, we see a different pattern on the numbers of older people living in the area. The top 80% of LGDs in terms of rail cuts saw an ageing of their population relative to relative the 20% with the weakest cuts, presumably as younger workers moved to more accessible places.

3.5 Longer run population impacts

So far we have looked only at 1981 outcomes. One might wonder whether these effects were only temporary. Perhaps the growth of car transportation meant that people gradually moved back to these areas that were disconnected from the rail network. Table 5 explores this possibility by repeating the specification of Table 1, column 11 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. In columns 2 and 4, we look at the effects conditional in 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 0.6% after 1991.

3.6 Robustness: Instrumental variables estimates

One feature of the post-cuts network that is obvious to anyone who travels in Britain today is that in most of the country it is hard to make cross country journeys without travelling via London. This is because many of the lines that were cut in the 1950-1980 period in the centre and north of the country were those not running towards London, as inspection of Figure 2 will confirm. This pattern does not appear to have been intentional policy, but simply a by-product of cutting the least profitable lines. Based on this empirical observation, we devise an instrument which predicts loss of rail centrality based on the length of local lines running in an east-west orientation (Michaels 2008 uses a similar instrument based on the orientation of US highways). Specifically we select line segments for which the difference in the south and north end points is less than 10km, and then aggregate the length of lines meeting this criterion, within Parishes.

This east-west parish line length provides our instrument. The identifying assumption is that, conditional on 1951 population and rail centrality, that 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.

Figure 4 illustrates the relevance of this instrument visually, by overlaying the 1950-1980 cut lines with the Parishes shaded according the length of east-west lines. Visually line orientation appears to predict the cuts quite well, although not in the South West (where north-south lines were likely to be cut for the same reason), and it over-predicts cuts in London. Table 6 presents the results of this IV approach. Note here we include no other controls for pre-1951 population trends, but include log 1951 population, log 1951 rail centrality and parish land area (to adjust the line length instrument for differences in the size of units over which line lengths have been aggregated; this control in fact makes little difference). The first stage of this IV regression has a high F-statistic so the instrument seems relevant, bearing out the visual evidence from Figure 4. In the first column we present the full-sample results. Although the coefficient on the change in log centrality is now imprecisely measured, it is reassuringly close to that in our main estimates in Table 1. As noted above, the instrument is less relevant in the South West and in London, so in column 2 we exclude these areas by dropping all Parishes south of a horizontal line at the 20000 m national map grid reference. Doing so increases the coefficient substantially to 0.8 and it is now significant at the 5% level, although the confidence interval is wide and encompasses our main point estimates. In summary, these IV results, while imprecise, provide supporting evidence that our main estimates are not seriously upward biased by confounding factors.

4. Conclusions

We studied the impact of a controversial rail disinvestment programme that occurred in Britain in mid 20th Century. While other work has begun to look at the spatial economic impacts of the growth of the rail network and other forms of transport, ours is the first of which we are aware to look at what happens when you remove transport infrastructure on a major scale. As well as providing general lessons regarding the role transport plays in shaping the spatial economy, our research answers a long running controversy over the impact of the 'Beeching Axe'. Did the cuts cause places to decline or were these places declining anyway? The broad finding is that the cuts in access to rail caused falls in population in affected areas, loss of educated and skilled workers, and an ageing population. A 10% reduction in rail access over the 1950-1980 period (measured by a network centrality index) resulted in a 3% fall in population by 1981. Populations did not recover in subsequent decades.

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, extrapolating from previous estimates of the relationship between access to economic mass and firm productivity or wages – elasticities of 0.05 at most (Combes and Gobillon 2015) – suggests that the effects were probably not that large. The average change in centrality and access to economic mass due to the partial removal of the rail network in Britain was around 25%, implying a reduction in productivity of around 1%.[1]

[1] This has echoes of Richard Fogel's claim in the 1960s that the social savings from the entire railroad system in the US were only 2.7% of GNP, although the social savings methodology is based on the value of time, rather than any productivity impacts.

5. References

Aradillas-Lopez, A., B. E. Honore, and J. L. Powell (2007). Pairwise difference estimation with nonparametric control variables. International Economic Review 48, 1119–1158

Cobb, Colonel H.M. (2003) The Railwas of Great Britain; A Historical Atlas, Ian Allen Publishing

Combes, P.P and L. Gobillon (2015) The Empirics of Agglomeration, in G. Duranton, J. V. Henderson and W. Strange (eds), Handbook of Urban and Regional Economics, vol. 5, Amsterdam: Elsevier.

Honore, B. E. and J. L. Powell (2005). Pairwise difference estimators for nonlinear models. In D. W. Andrews and J. H. Stock (Eds.), Identification and Inference for Econometric Models, 520–553. Cambridge University Press.

Loft, C. (2013) Last Trains: Dr Beeching and the Death of Rural England, Biteback Publishing

Michaels, G (2008) "The effect of trade on the demand for skill: evidence from the Interstate Highway System". Review of economics and Statistics, 90(4): pp. 683-701.

Redding, S. and Turner, M. (2015) Transportation Costs and the Spatial Organization of Economic Activity, in G. Duranton, J. V. Henderson and W. Strange (eds), Handbook of Urban and Regional Economics, vol. 5, Amsterdam: Elsevier.

Waller, P. (2013) The Beeching Era: Proposed-Closed-Survived, Ian Allen Publishing

Yatchew, A. (1997). "An elementary estimator of the partial linear model". Economic Letters 57 (2): pp. 135-143

Figure 1: Rail network in Britain in 1950

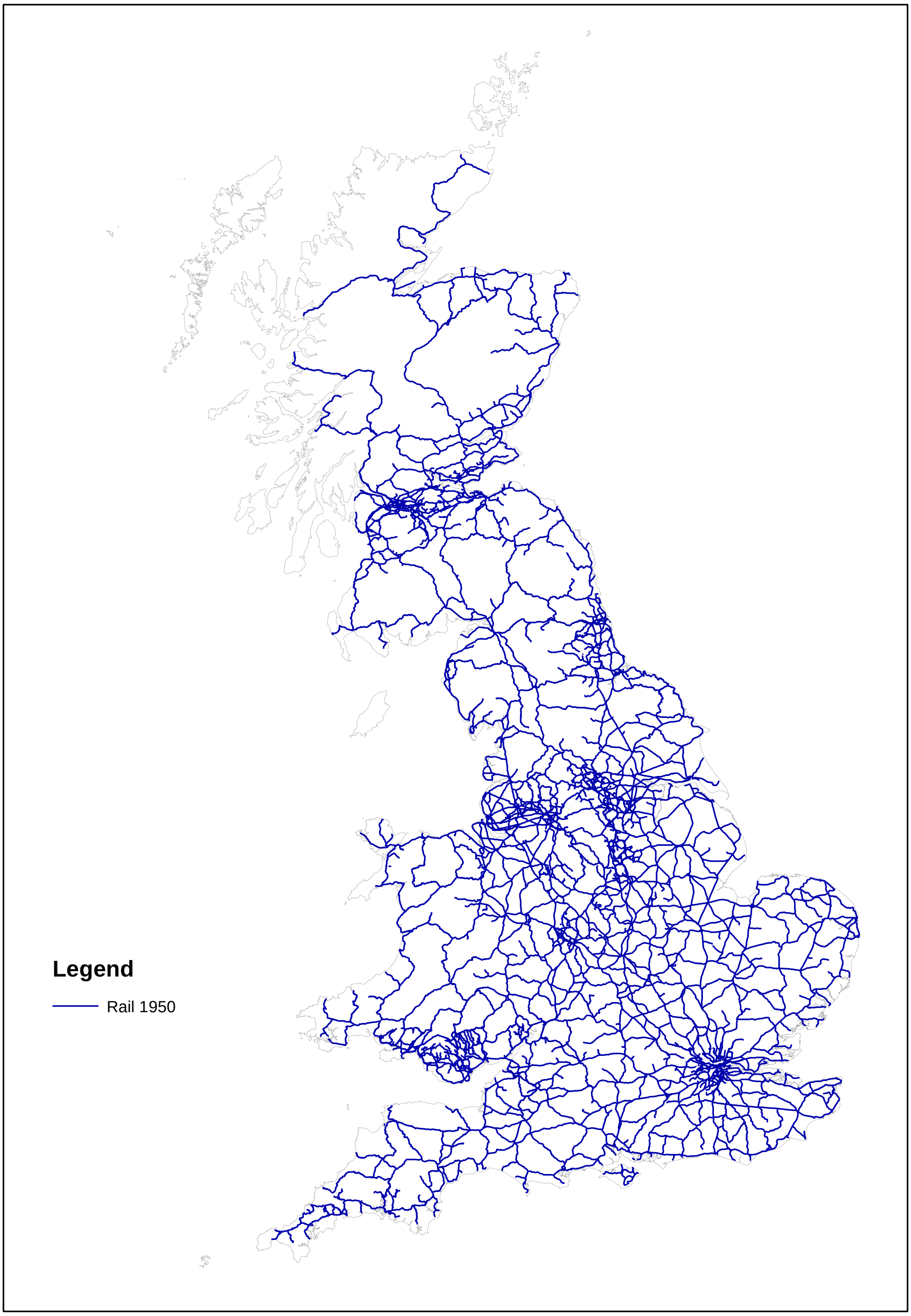

Figure 2: Rail lines cut 1950 to 1980 and changes in centrality/accessibility at Parish level

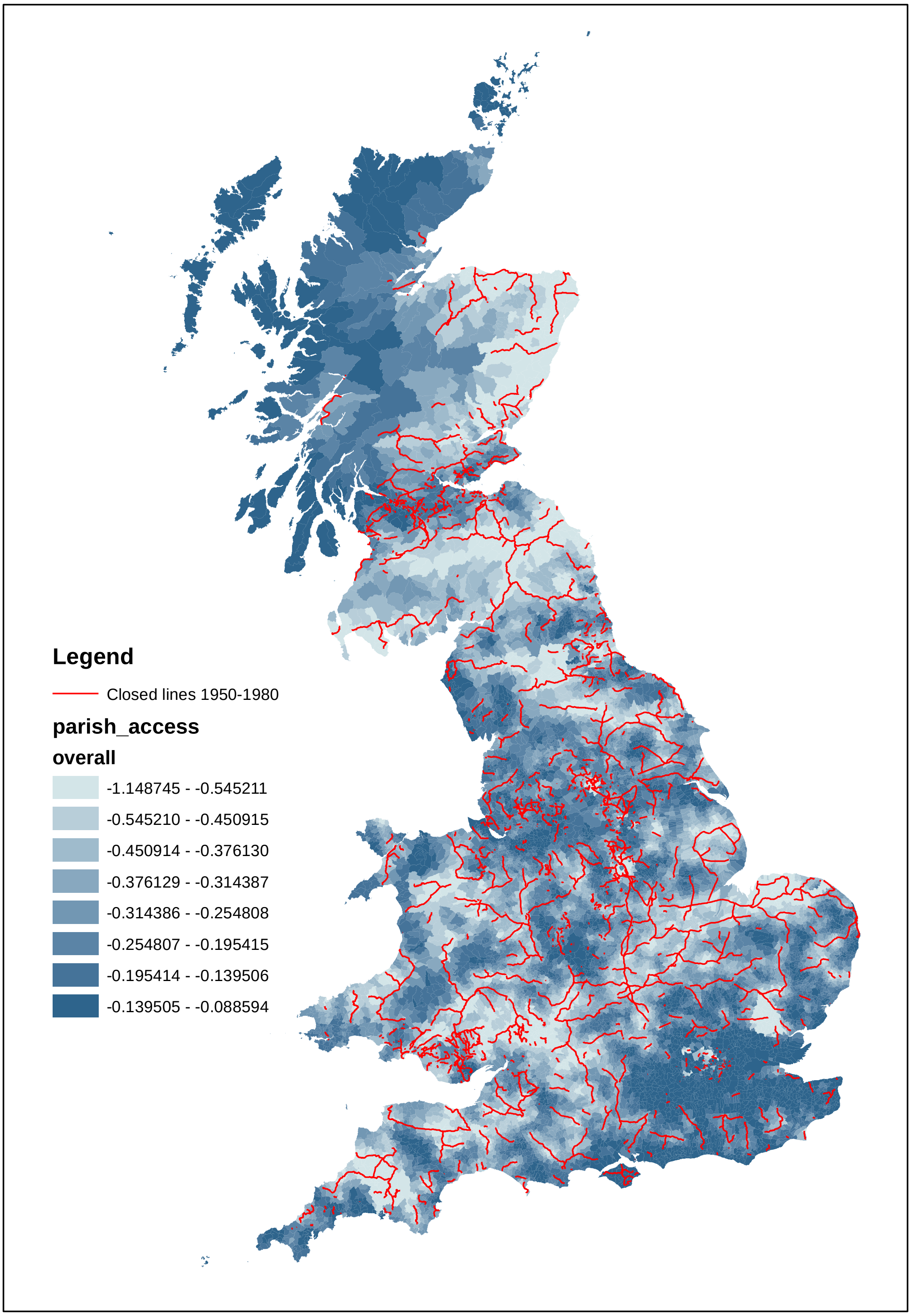

Figure 3: Trends in log population, by depth of rail cuts 1950-1980

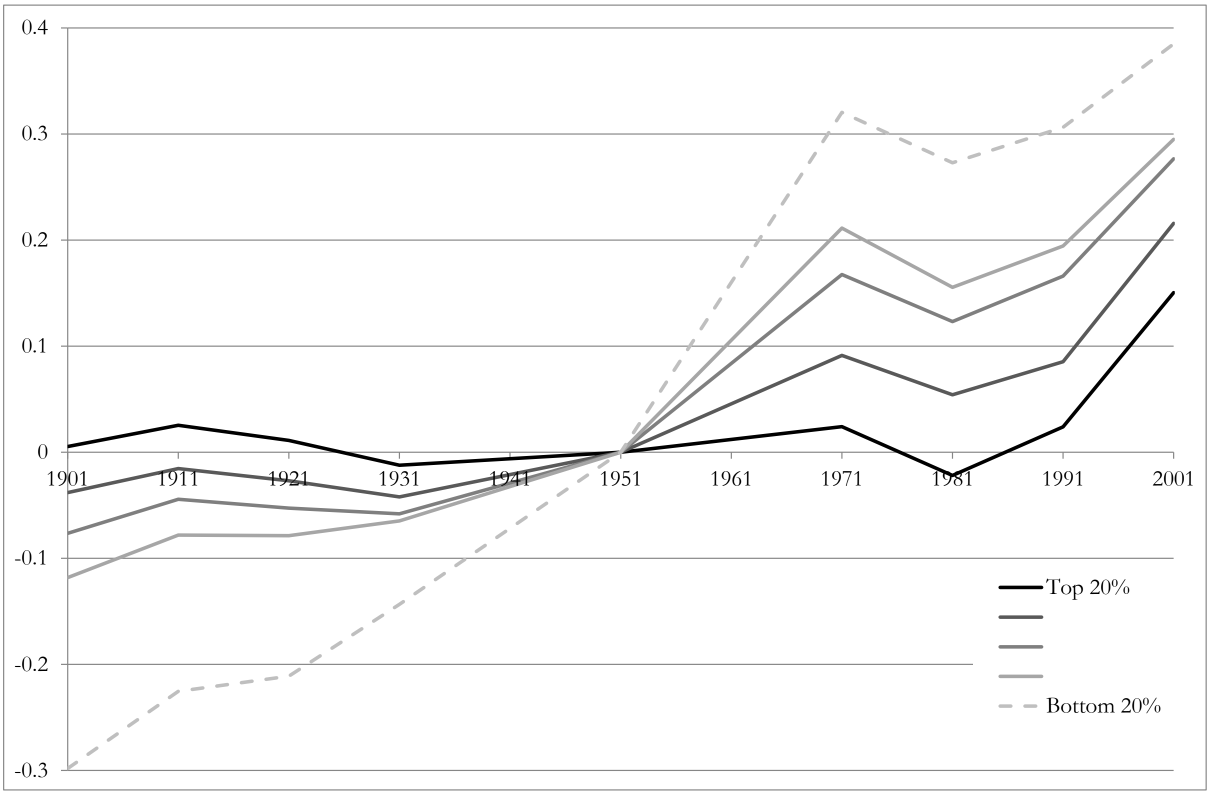

Figure 4: Lines cut 1950-1980 and Parish line lengths running E-W

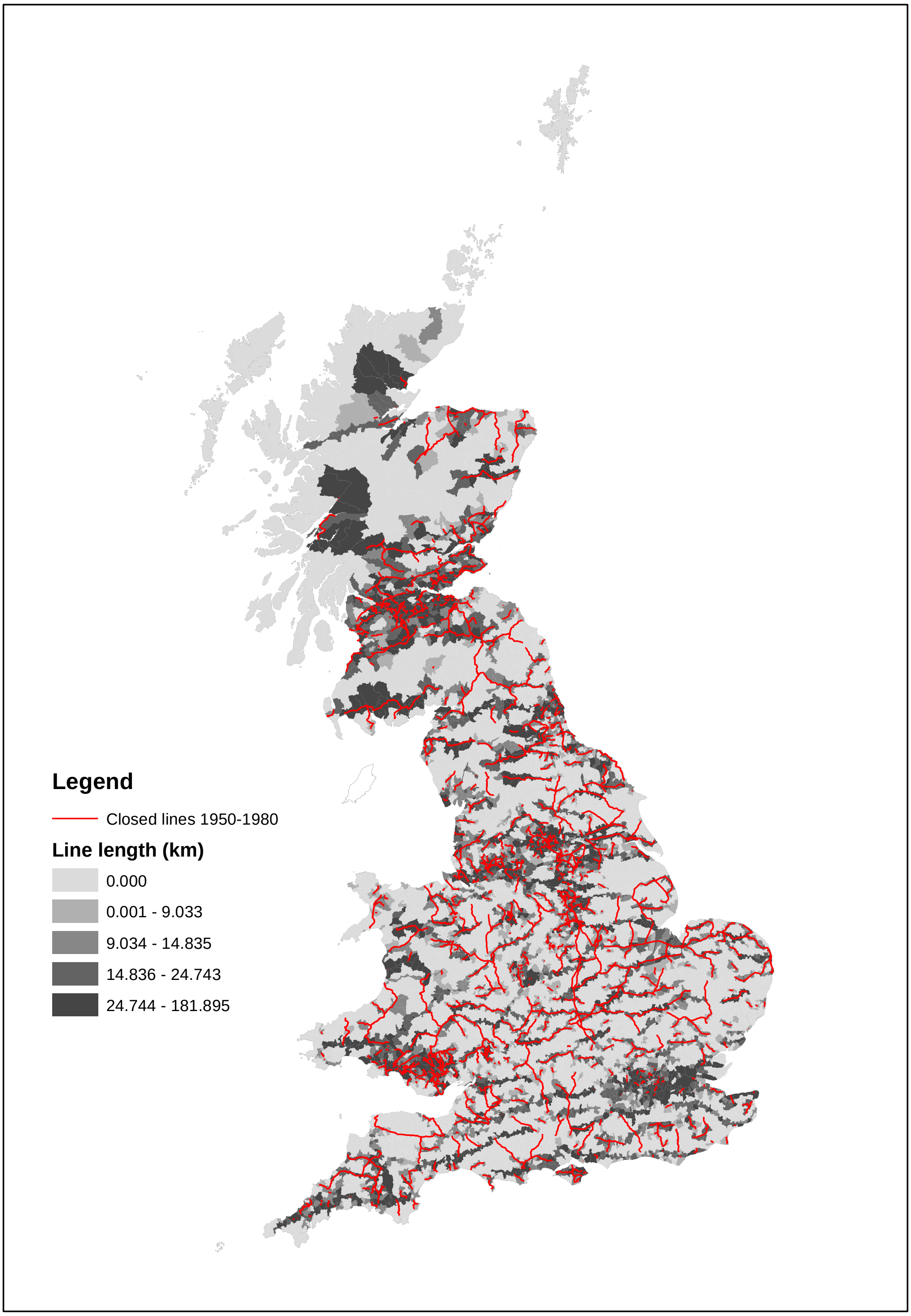

Table 1: Changes in rail network centrality and 1981 populations in Parishes, Great Britain

	(1) OLS no pre trend	(2) OLS lagged pop	(3) OLS pre trend 01	(4) OLS pre trend 11	(5) OLS pre trend 21	(6) OLS pre trend 31	(7) Pairwise diff 01	(8) Pairwise diff 11	(9) Pairwise diff 21	(10) Pairwise diff 31	(11) Pairwise diff matched
Change in log centrality 51-81	0.335***	0.321***	0.295***	0.292***	0.295***	0.295***	0.306***	0.298***	0.308***	0.298***	0.299***
	(0.021)	(0.022)	(0.022)	(0.021)	(0.021)	(0.021)	(0.024)	(0.024)	(0.024)	(0.023)	(0.023)
Observations	13,235	13,235	13,235	13,235	13,235	13,235	13,229	13,225	13,219	13,212	13,207
R-squared	0.895	0.895	0.896	0.897	0.897	0.897	0.853	0.853	0.863	0.872	0.708

Robust standard errors in parentheses, *** 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
Column 1 has no other controls; Column 2 includes log population in 1931, 1921, 1911, 1901; Columns 3-4 include dummies for 5 percentile bins in distribution of changes in log population between given year and 1951; Columns 7-10 estimated on pairwise differences between observations ranked on changes in log population between given year and 1951; Column 11 estimated on pairwise differences between matched observations ranked on linear predictions from regression of 1951-1981 change in centrality on log populations in 1901, 1911, 1921, 1931 and 1951.

Table 2: Changes in rail network centrality and 1981 outcomes in Local Government Districts in England and Wales

	(1) Population Pairwise diff matched	(2) Education Pairwise diff matched	(3) Soc 1 Pairwise diff matched	(4) Soc 2 Pairwise diff matched	(5) Soc 3 Pairwise diff matched	(6) Soc 4 Pairwise diff matched	(7) Soc 5 Pairwise diff matched	(8) Age 0-15 Pairwise diff matched	(9) Age 15-64 Pairwise diff matched	(10) Age 65+ Pairwise diff matched
Change in log centrality 51-81	0.265***	0.156***	0.118	0.138***	-0.058**	-0.122***	-0.088	-0.024	0.009	-0.062**
	(0.042)	(0.041)	(0.061)	(0.030)	(0.019)	(0.032)	(0.094)	(0.013)	(0.005)	(0.019)
Observations	1,462	1,462	1,451	1,462	1,462	1,462	1,462	1,462	1,462	1,462
R-squared	0.552	0.804	0.706	0.873	0.933	0.833	0.455	0.967	0.994	0.899

Robust standard errors in parentheses *** p<0.001, ** p<0.01, * p<0.05
Dependent variables are: (1) log population 1981; (2) log higher educated males; (3)-(7) log males in social class 1-5, (8)-(10) population in age groups
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
All specifications estimated on pairwise differences between matched observations ranked on linear predictions from regression of 1951-1981 change in centrality on log populations in 1901, 1911, 1921, 1931 and 1951.

Table 3: Effects on 1981 population of changes in rail centrality, by motorway access and initial rail centrality

		(1)	(2)
	High/Low spatial centrality 1951	High/Low rail centrality 1951	Closer/further than 10km from motorways built post-1950s
Change in log centrality 51-81	0.294***	0.338***	0.307***
	(0.087)	(0.071)	(0.029)
x High access	0.004	-0.021	-0.134**
	(0.050)	(0.047)	(0.050)
High access	0.004	0.091	-0.030
	(0.061)	(0.059)	(0.061)
Log rail centrality 1951	0.271***	0.153***	0.206***
	(0.023)	(0.025)	(0.022)
Log population 1951	0.972***	0.971***	0.969***
	(0.006)	(0.006)	(0.006)
Observations	13,261	13,261	13,261
R-squared	0.704	0.706	0.707

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 11
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.

Table 4: Effects of cuts by quintile of loss of rail centrality

	(1)	(2)	(3)
	Log population 1981	Log high skill 1981	Log age 65+ 1981
Top quintile cuts	-0.225***	-0.138***	0.063***
	(0.018)	(0.030)	(0.014)
4th quintile cuts	-0.159***	-0.097**	0.053***
	(0.018)	(0.030)	(0.014)
3rd quintile cuts	-0.092***	-0.026	0.065***
	(0.018)	(0.029)	(0.014)
2nd quintile cuts	-0.078***	-0.049	0.038**
	(0.018)	(0.029)	(0.014)
Observations	13,207	1,462	1,462
R-squared	0.708	0.806	0.899

HAC robust Standard errors in parentheses *** p<0.001, ** p<0.01, * p<0.05
Parish and LGD level regressions based on matched pairwise differences, as in Table 1, column 11 and Table 2, columns 2 and 10.

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 and 1981
Change in log centrality 51-81	0.273***	-0.013	0.292***	0.058***
	(0.028)	(0.016)	(0.024)	(0.015)
Observations	13,263	13,261	13,261	13,261
R-squared	0.641	0.876	0.665	0.879

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 11

Table 6: IV estimates based on line orientation

	(1) log pop 81 iv	(2) log pop 81 iv
Change in log centrality 51-81	0.344	0.805*
	(0.280)	(0.317)
First stage coefficient	1.489	1.687
	(0.170)	(0.197)
First stage F	76.74	73.43
Observations	13,275	9,791
R-squared	0.894	0.885

Robust standard errors in parentheses *** p<0.001, ** p<0.01, * p<0.05
Instrument is length of lines in a Parish (km) orientated in E-W direction
Column 2 excludes Parishes south of a horizontal at the 20000 m north grid reference (north of London)
Regressions include controls for log population in 1951, log centrality in 1951 and parish land area