Transport and urban growth in the first industrial revolution

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Abstract[5]

The industrial revolution led to dramatic economic changes which persist to the present. This paper focuses on urban areas in England and Wales, the birthplace of the first industrial revolution, and the role of transport before railways and steamships. We argue that better transport connections, which increased market access, led to higher urban population and a different spatial distribution. Our first contribution is to construct new data on trade costs between hundreds of towns in 1680 and 1830, detailing the roles of changing freight rates and networks of canals, roads, and coastal shipping. The second contribution is to show that lower trade costs contributed significantly to the population growth of towns through greater market access. Our empirical strategy addresses confounding factors and potential endogeneity. A counterfactual suggests that without any change in trade costs the population in 1841 would have been more coastal and inland towns would have been 20 to 25% smaller. Our third contribution shows that higher market access affected other outcomes in urban areas. It led to more migrants and higher child mortality. It also led to less unskilled occupations, like in agriculture. Broadly, transport innovations and improvements significantly shaped the first industrial revolution.

Keywords: Urbanization, transport improvement, market access, industrial revolution.

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The industrial revolution led to major changes in the spatial structures of economies. One striking feature was the growth of urban areas. In England, the very largest industrial centers, like Manchester, Leeds, and Birmingham, became workshops of the world by the mid-19th century. Their experience was not wholly unique. Several English towns grew from relatively small settlements. Many became service or commercial centers, not just industrial hubs. Moreover, many of the cities and towns which emerged in the industrial revolution continue to be major population centers to this day, even though some of their original industries have faded.

The forces shaping the spatial dimensions of the first industrial revolution are debated and various factors have been emphasized, including endowments, like coal, and clusters of skill (see Hanlon 2020, De Pleijt et al. 2020, Fernihough et al. 2021, Mokyr et al. 2022, Kelly et al. 2023). A key omission in the literature is a detailed quantification of transportation improvements and their effects on population and structural change during the formative stages. Most studies of transport highlight the railway and steamship. However, these steam-based technologies came after urbanization and structural change began in England. If transport had a formative role, then perhaps it was through the extensive network of canals, high quality roads, and capable ports made in the 1700s and early 1800s. These infrastructures were primarily developed by private, nonprofit, and municipal groups with a supporting role by the central government in London. They were generally built in response to local needs, but collectively they formed a national network. There were also significant technological advances in sailing, which along with infrastructures better connected distant regions by both land and sea.

Estimates for the collective impact of canals, roads, and advances in sailing have been elusive because of limited data on transport change and disaggregated economic outcomes (Crafts and Wolf 2014, Trew 2020). In this paper we address this limitation in the literature by estimating inter-urban trade costs at the dawn of the industrial revolution (1680) and after 150 years of transport improvement and innovation (1830). We also use a theoretical framework, featuring market access, to estimate how transport affected urban population. Our definition of urban is broad, including small markets, medium-sized county seats, regional centers, and London. We emphasize urban population in part because early industrialization generally occurred in or near towns. Urban areas were also the centers for the growing service sector. As one example provincial newspapers first emerge in towns like Bristol and Norwich in the early 1700s. Newspapers were printed in 60 towns by 1760 (Matthews 2015). We use our estimates to quantify how urban populations would have been different if trade costs did not change, ultimately explaining how urban development during the first industrial revolution would have been more limited and redistributed in space without transport improvement and innovation.

Our first main contribution is to estimate trade costs in 1680 and 1830 using new multi-modal models of the English and Welsh transportation system. The models identify the lowest freight transport cost between 590 market towns. In each year, the model allows for any combination of shipment by wagons along roads, by barges on inland waterways, or by ships traveling coastal routes, each of which differs in their per ton mile cost. Also, the local cost of using roads and waterways differs depending on the elevation and the quality of infrastructure. To our knowledge, no other transport model includes such details. Moreover, as freight costs are not directly observable between most town pairs, our model generates new data.

The inter-urban freight costs are used to construct estimates of more than 170,000 unique inter-urban trade costs in 1680 and 1830. For the baseline, trade costs between town i and j equal one plus the ratio of their transport costs to the average pithead coal price. Coal is emphasized as it was the most important commodity shipped in terms of weight. We find that trade costs declined substantially between 1680 and 1830, across all towns by an average of 59%. Expansions in the inland transport network account for approximately half of the decline. The rest is attributed to technological change, like better sailing ships and wagons, and other factors.

Our second main contribution is to estimate how lower trade costs increased town populations. We use a theoretical framework which emphasizes market access. In the standard model, it reflects the potential for local firms to sell to consumers through trade networks, and likewise local consumers potential to purchase goods from firms through the same networks (Redding and Venables 2004, Easton and Korum 2002). If there is a shock to market access, which affects real wages, then the standard models predict that migration will occur, leading to a new equilibrium population. In practice, market access is measured with the combination of location-pair specific trade costs and the population of all relevant locations. It has proven to be a powerful tool for identifying how transportation improvements throughout the network change the distribution of population.[6] To our knowledge, we are the first to apply the market access methodology to the first industrial revolution, especially at a granular spatial level.

Data limitations are a major challenge in studying spatial outcomes related to the early industrial revolution. Complete population statistics are not available until the first census of 1801. We overcome this challenge using a new dataset on estimated town populations in 1560 and 1680 linked with the first census in 1801, a later census in 1841, and further linking to registration sub-districts in 1851. The dataset also has town geographic, economic, and institutional characteristics dating to the late 1600s. In our baseline, we regress the difference in log 1841 and log 1680 town population on the difference in log 1830 and log 1680 town market access. Many controls are added to address potential confounders. Broadly, our specification is meant to capture the effects of all transport improvements and innovations over 150 years through their impact on market access.

The main identification challenge concerns how the selection of network connections for a town is correlated with unobservable factors affecting its population growth. We address this issue with a series of robustness checks, like removing local transport connections from the calculation of market access. We also use an instrumental variable related to the Grand Cross Canal Plan, first made in the 1760s. The routes were shaped by geographic conditions and had few viable alternatives. When the Plan was implemented, some towns got 'incidentally connected' with canals and the broader transport network. Building on this logic, one of our instruments is the increment to market access from incidentally connected towns more than 50 km away, holding their population fixed at 1680 levels. Another instrument is the distance to 1680 inland waterways. Both instruments are strong predictors of market access change.

Our preferred ordinary least squares (OLS) estimate shows that increasing a town's market access significantly increased its population. Specifically, a 10% increase in market access would increase its town population by approximately 1.6%. The estimates in various robustness checks and instrumental variables are similar in magnitude or larger, which suggests OLS gives a

[6] See Donaldson and Hornbeck (2016), Donaldson (2018), Jaworski and Kitchens (2019), Jacks and Novy (2018), Heblich et al. (2020), Herzog (2021), Jaworski, Kitchens, and Nigai (2022).

lower bound for the effect in this context. Building on our estimates and the underlying theoretical model, we quantify how all English and Welsh urban populations would have changed if trade costs remained constant between 1680 and 1830. The calculations essentially consider a counterfactual where there was no transport improvement and innovation during the early stages of the industrial revolution. The estimates imply that the total urban population would have been 9.6% lower in 1841. Our interpretation is that potential urban dwellers would have stayed in rural areas. We also argue there would have been substantial population redistribution to the coast. Inland urban areas, like Manchester and Leeds, would have had 25% less population, while coastal urban areas, like Liverpool and Bristol, would have had little loss or some increase. The reason is that inland areas experienced much greater trade cost reduction. In sum, population would have been distributed very differently, implying that transport shaped fundamental shifts in economic geography which lasted for centuries.

Our third man contribution is to analyze the effects of market access on other related outcomes. We start with migration, mortality, and fertility outcomes, available at the registration sub-district level in 1851.[7] They are interesting on their own and help identify the mechanisms by which market access increased population. We link 1851 registration sub-districts (RSDs) to our sample of towns and also calculate market access at the town-RSD level using 1830 trade costs and 1851 RSD populations. We show that higher market access significantly increased the population share of long-distance migrants in 1851. Higher market access is also shown to increase early childhood mortality, but it had no effect on fertility. Aside from individual findings, we conclude that market access increased urban population through greater in-migration.

We close by estimating the effects on socio-economic status (SES) measured through the male occupation of men in 1851 RSDs.[8] We find that higher market access significantly reduced the population share in the lowest SES status associated with unskilled manual workers, including farm laborers. The estimates imply that lower trade costs up to 1830 contributed to England's

[7] Registration sub-district data come from Populations Past –Atlas of Victorian and Edwardian Population Data. See Reid et al. (2018). Note data limitations prevent us from rigorously studying migration, mortality, and fertility changes before 1851.

[8] We use Historical International Social Class Scheme (HISCLASS) provided by Reid et al. (2018). Unfortunately, we don't observe women's occupations.

long-term shift away from unskilled employment. We also show that higher market access significantly increased the share in the second highest SES status, lower skilled non-manual workers such as clerical and sales personnel. This result implies higher market access contributed to the rise of England's service sector, which grew since at least the 1700s (Shaw-Taylor and Wrigley 2014). Finally, we estimate a positive, but imprecise, effect on the second lowest SES status, lower skilled manual, including miners and many factory workers.

Our paper contributes to many literatures. The first uses history to study transport improvement and economic development.[9] The most related examine economy-wide effects of improving networks using a market access approach.[10] Many of these studies analyze railways and highways. This paper is one of the first to analyze market access impacts for earlier infrastructural and technological innovations, whose effects are less clear.[11] Also related, there are several studies highlighting new shipping technologies related to sailing.[12] Others focus on internal improvements, such as canals and roads, and innovation in freight services.[13] Yet these studies rarely emphasize inter-modality and network structure. As we show, trade costs depended on improvements across transport modes and throughout the network.

Second, we shed new light on the causal factors explaining urban growth over the long-run. The literature focusing on the pre-industrial era generally emphasizes skills, institutions, and contingencies associated with new technologies.[14] Here market access is highlighted as a fundamental factor, consistent with Adam Smith's key insight that the division of labor is limited by the extent of the market. Our findings are also consistent with an emphasis on the role of market access in causing urban development in recent times.[15]

[9] See Atack et al. (2010), Tang (2017), Garcia-López (2015), Hornung (2015), Berger and Enflo (2017), Jedwab (2017), Bogart et al. (2022).
[10] See Donaldson and Hornbeck (2016), Donaldson (2018), Jaworski and Kitchens (2019), Jacks and Novy (2018), Heblich et al. (2020), Herzog (2021), Jaworski, Kitchens, and Nigai (2022).
[11] To our knowledge only Zimran (2020), Trew (2020), and Flückiger et al. (2022) study access in the pre-steam era.
[12] See Ville (1986), Harley (1988), Armstrong (1991), Solar (2013), Pascali (2017), Kelly and Ó Gráda (2019), Bogart et al. (2020), Kelly et al. (2021).
[13] See Gerhold (1996, 2014), Bogart (2005), Maw (2011), Bogart, Lefors, and Satchell (2019), Allen (2023).
[14] Dittmar (2011), Bosker et al. (2013), Cantoni and Yuchtman (2014), Dittmar and Meisenzahl (2020).
[15] See Duranton and Turner (2012), Fabor (2014), Allen and Arkolakis (2022).

Third, our paper contributes to the literature on the industrial revolution, especially its location within England.[16] As stated earlier, one view is that endowments were a major factor, especially being on the coalfields since they gave energy cost advantages in home heating and steam powered manufacturing.[17] Another view is that economic specialties in the past had persistent effects on industrialization in the 1700s.[18] We advance this literature since most studies focus on county-level outcomes. Also, we provide the first rigorous estimates on the effect of reduced trade costs and increased market access in the industrial revolution context.

The following section describes how technological and infrastructural changes combined to fundamentally alter transport from the late-1600s to the mid-1800s. It also introduces the new data on inter-urban freight rates and trade costs. Section II explains how trade cost change could lead to urban growth. Section III describes our estimation strategy. Section IV reports estimates for the effect of market access changes on urban population and our main counterfactual. Section V shows the effects of market access on outcomes relating to migration, mortality, fertility, and occupational SES at the town-RSD level. Section VI concludes.

I. The early transportation revolution

Transportation was revolutionized in England prior to the rise of railways and steamships.[19] Transport got better from the mid-1600s as some rivers were made navigable, carts began replacing packhorses, and ship building started to change. However, transport development took a major step forward with the improvement of several inland waterways, starting around 1700 and especially after the introduction of canals in the mid-1700s.

Inland waterway projects were initiated by local interests and then approved in Parliament through special acts. Landowners and traders, along with county and city officials, were the main promoters, while engineers helped design the routes. If the project was approved, promoters usually formed a trust or private corporation to raise capital. Central Government

[16] See Shaw-Taylor and Wrigley (2014), Trew (2020), Heblich, Trew, and Zylberberg (2021).
[17] See Wrigley (2010), Crafts and Wolf (2014), Stuetzer et al (2016), Warde (2018), Hanlon (2020), Fernihough and Hjortshøj O'Rourke (2021).
[18] See Heblich and Trew (2019), Kelly et al. (2023), Mokyr et al. (2022).
[19] For an overview see Dyos and Aldcroft (1969), Aldcroft and Freeman (1983), Bagwell (2002).

funding was not available. Powers of compulsory land purchase were given by the act and toll revenues paid for maintenance, dividends, and interest payments.

River navigation projects, making short cuts and clearing obstructions, were the first phase between 1660 and 1750.[20] One impetus came from the evolution of the pound lock, a chamber with gates at both ends that allowed boats to travel by water to higher elevations. Pound locks helped extend navigation inland and thereby increasing accessibility to the coast. Yet since locks were expensive, several rivers with greater elevation changes were not improved. This meant many inland towns were not reached, and most river navigation projects involved short-distance improvements.

Canals were the next phase of inland waterways, mainly from 1760 to 1830. Canals were like a straightened river with artificial cuts, and made more use of locks, tunnels, and reservoirs.[21] The first was promoted and financed by the Duke of Bridgewater. It linked the Duke's coal mines in Worsley with the emerging industrial town of Manchester in 1762. Making the Bridgewater canal required several engineering feats, including tunnels and an aqueduct crossing the river Irwell. Its leading engineer was James Brindley, often considered a pioneer of canals. The Bridgewater canal was soon extended from Manchester to Runcorn, near the river Mersey and hence to Liverpool. Runcorn was a rural settlement before the canal; later it would become a major transit point for coastal vessels and barges.

The Bridgewater generated national interest in canals soon after it opened. Brindley helped foster this interest by proposing the 'Grand Cross,' a cross-shaped network that would link the four major river basins of England (Thames, Mersey, Severn, and Trent) with two continuous lines of canal, and thereby connect the coastal centers of Hull, Bristol, Liverpool, and London. The Grand Cross was made by several joint stock companies, each using local sources of capital. The companies would connect their canal lines with one another and with rivers (Figure 5 in section IV shows a map of the Cross Plan). Many smaller towns were connected in the process as they were on the best route between the major river basins and centers. The Trent and Mersey

[20] For more on river navigations see Willan (1964) and Bogart (2018).
[21] For more on canal development see Hadfield (1969), Ward (1974), Maw (2014), Satchell (2017).

Canal provided a key link. One endpoint was Runcorn, where barges could reach Liverpool through the River Mersey. The other was the navigation head of the river Trent, whose mouth was in the Humber and hence linked to Hull. The Wolverhampton Canal linked the Trent and Mersey with the River Severn, and hence Bristol. Its endpoints, Stourport and Haywood, were both previously small settlements. The Coventry and Oxford Canals provided a single Cross link from the Trent and Mersey to the river Thames and ultimately London. Their southernly route had few elevation changes and terminated at Oxford. The Leeds and Liverpool Canal was an extension of the original Cross plan. It linked the Mersey and Humber basins via the river Aire in West Yorkshire. Leeds and Liverpool served as endpoints because they were emerging industrial and trading towns. The route in-between was shaped by the terrain in this rugged region.

Land costs were also an important factor in canal route selection. According to Hadfield (1968), in laying out the line, canal companies avoided houses and valuable buildings to save costs. Their powers of compulsory purchase did not always apply to land with houses, which could lead to significant hold-up problems. Moreover, some canals required building water reservoirs which consumed a lot of land (Harvey-Fishenden and Macdonald 2021). Therefore, many canals were routed through rural areas and small towns on their way to larger centers.

The various canal companies involved in the Cross Plan had their projects approved in the 1760s and 70s and several opened in the decades after. Collectively it represented an ambitious upgrade to the inland waterway network, consisting of hundreds of kilometers overall. Canal promotion and building continued through the 1820s. Some of the later canals addressed limitations in the early Cross Plan. For example, the Grand Junction canal provided a more direct link between the Thames and Mersey basins, bypassing Oxford.[22] With time, canals were more widely used by private shippers and scheduled-public freight services (Maw 2013, Bogart, Lefors,

[22] Other examples. In the southwest, there was the Severn and Thames Canal followed by the Kennet and Avon Canal providing another route linking the Severn and Thames, via the river Avon near Bristol and Bath to Newbury. In the west midlands, the Birmingham and Worcester Canal, and the Birmingham and Fazeley canal formed a shorter link between the Severn and Humber through Birmingham. Also in the West midlands, the Ellesmere canal provided a new link between the river Dee, near the Mersey, and the Severn. In the East Midlands, the Union canal and the Leicester navigation linked ‘the Wash’ with the Humber basin through river Nene. In the north, the Rochdale canal provided a new link between the Mersey and Humber through the Bridgewater canal and the Calder and Hebble and Aire navigations.

and Satchell 2019). The canal barge became a common feature along the wharfs of inland towns, transporting coal and other heavy goods.

While canals were a major improvement, they were often used in conjunction with roads and coastal ships when goods were shipped between regions. The famous Pickford's firm provides a good illustration as it used roads and canals to ship between Manchester and London (Turnbull 1979). Generally, river navigations and canals linked with major ports, making them more useful. We now briefly explain improvements in these other transport modes.

I.A Improvement of roads, ports, and shipping

Wagon transport became more productive due to better roads, more powerful draft animals, and logistical innovations among carriers. There is evidence for some of these changes beginning in the late 1600s (Gerhold 1996). However, productivity in wagon road transport accelerated in the 1700s when turnpike trusts began improving roads.[23] Turnpike trusts were given statutory powers to improve individual roads and to levy tolls on users. They were like canal companies in organizational form, local planning, and financing, except with the legal provision that trustees could not profit like shareholders. By 1830, there were close to 1000 trusts managing different sections of the main road network. They were generally successful in building new roads and raising their quality, but the degree of change was not the same everywhere. Quality improvements were greatest near the industrial north and southern coast. Trusts in these areas recruited better engineers. Also, roads were better where investors took more risks in lending on the security of future toll revenues (Rosevear et. al. 2023).

Improvements in sea transport were also significant in this period with technological change playing a key role. In the early sailing era, voyages had long and unpredictable travel times, which meant higher costs. Gradually, there were innovations, like copper sheathing and improved rigging, which increased speed and reliability.[24] Navigation also improved with better charts and the chronometer. Shipping innovations were widely adopted, following the leadership of the East India Company and the British Navy. In ports, there were also innovations like wet

[23] For the literature on turnpikes and their effects, see Bogart (2005) and Rosevear et. al. (2022).
[24] For the literature on speeds and shipping innovation, see. Armstrong (1991), Solar (2015), Solar and Ronnback (2015), Kelly and O'Grada (2019), Bogart et. al. (2020), Kelly, O'Grada, and Solar (2021).

docks, which shut water in and kept it at a given level to facilitate loading. Wet docks were constructed in Liverpool, Bristol, London, and Hull as well as emerging ports (Pope and Swann 1960). Improvements followed the same system as inland waterways and roads through special acts empowering trusts or joint-stock companies (Jackson 1983). Lighthouses also evolved greatly with the invention of new lamps, lenses, and light vessels. New lights were created by private actors and by Trinity House, a seaman's guild. They famously collected fees, called light dues, igniting a later debate about the provision of public goods.[25] For our purposes, the key point is that they lit up most of the English coastline by 1830, improving shipping.

I.B New multi-modal models of transport in 1680 and 1830

Early transport improvements are well described in the literature, but there are no detailed, spatially granular estimates of how transport costs changed throughout the economy. In this sub-section, we describe a new multi-modal model of the English and Welsh transport system, which addresses this data limitation. The model yields estimated freight transport costs between 590 towns in 1680 and 1830. The first date is chosen to detail how transport worked before the era of major improvements, which started with river navigations. The end date of 1830 is chosen because few canals and new roads were built beyond this year due to railways and steamships emerging around that date. The 590 towns are selected as having a population of at least 2500 in the late 1600s or after 1801 (appendix, section I gives more details on towns).

The freight transport model combines several modes to identify the least cost route between points representing the 590 towns.[26] The polylines represent specific transport modes like roads, waterways, and coastal routes and together they form a network. To ensure connectivity, interpolated straight lines between point layers and networks are created. A 'global turns policy' is used to allow movements within and between each network. Dijkstra's algorithm finds the least cost route, minimizing a cost accessibility function between all towns i and j.

[25] For the literature on lighthouses, see Coase (1974), Candela and Geloso (2018), Bogart et. al. (2022).

[26] We refer the reader to Alvarez, Bogart, Satchell, and Shaw-Taylor (2022b) for details on the multi-modal model.

Historic transport networks are crucial data for the multi-modal model.[27] Our networks are derived from detailed historical sources. The definition of a port is broad and includes 479 loading/unloading places identified in a variety of sources.[28] Coastal routes between ports were digitized according to the navigation charts of the era and physical geography. In 1680, inland navigation consists of the network of navigable rivers. In 1830, it also includes canals and river navigations made since 1680, all of which are traced in detail using historical maps and published sources.[29] The 1830 inland navigation data also includes locks. The road network in 1680 includes principal roads identified in John Ogilby's Atlas of 1675. It also includes important secondary roads identified from a military survey of 1686.[30] Information on terrain slope and vehicle accessibility, either packhorse or wagon, are also added. The principle and important secondary roads in 1830 are represented by a digitization of the turnpike trust road network.[31] Along with slope, road quality is incorporated based on a parliamentary survey of 1838.[32] Bridges and ferries are added as singular segments of roads digitized from the same sources.

Figure 1 shows the full picture of transport networks. Aside from important coastal routes, in 1680 there are many roads and inland waterways extending from the major river basins. In 1830 several canals then linked distant basins. There are also additions to the road network by 1830, especially in the northwest. Ports were common in both periods and therefore the regional differences in ports are not a major emphasis here.

Each transport mode in the model has been assigned a unique ton per mile cost and some have fixed fees along the route or varying costs due to terrain and quality. The modal costs are summarized in table 1. The costs come from various sources which are explained at length in a model summary document by Alvarez, Bogart, Satchell, and Shaw-Taylor (2022b).

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[27] They come from a wider project creating GIS maps of historic ports, coastal routes, inland waterways, and roads in E&W. See 'Transport, urbanization and economic development in England and Wales c.1670-1911' https://www.campop.geog.cam.ac.uk/research/projects/transport/.
[28] See Alvarez and Dunn (2019) for GIS data on ports and coastal routes.
[29] For a digitization of waterways open in 1680 and 1830, see Satchell, Shaw-Taylor, and Wrigley (2017a,b).
[30] See Satchell, Rosevear, Dickinson, Bogart, Alvarez, Shaw-Taylor (2017) for GIS data on 1680 roads.
[31] See Rosevear, Bogart, Shaw Taylor, and Satchell (2023) for GIS data on 1830 roads.
[32] High quality corresponds to trustees rating their roads as good, very good, and excellent. Trustee ratings of middling and below are coded as bad quality. See Rosevear et al. (forthcoming).

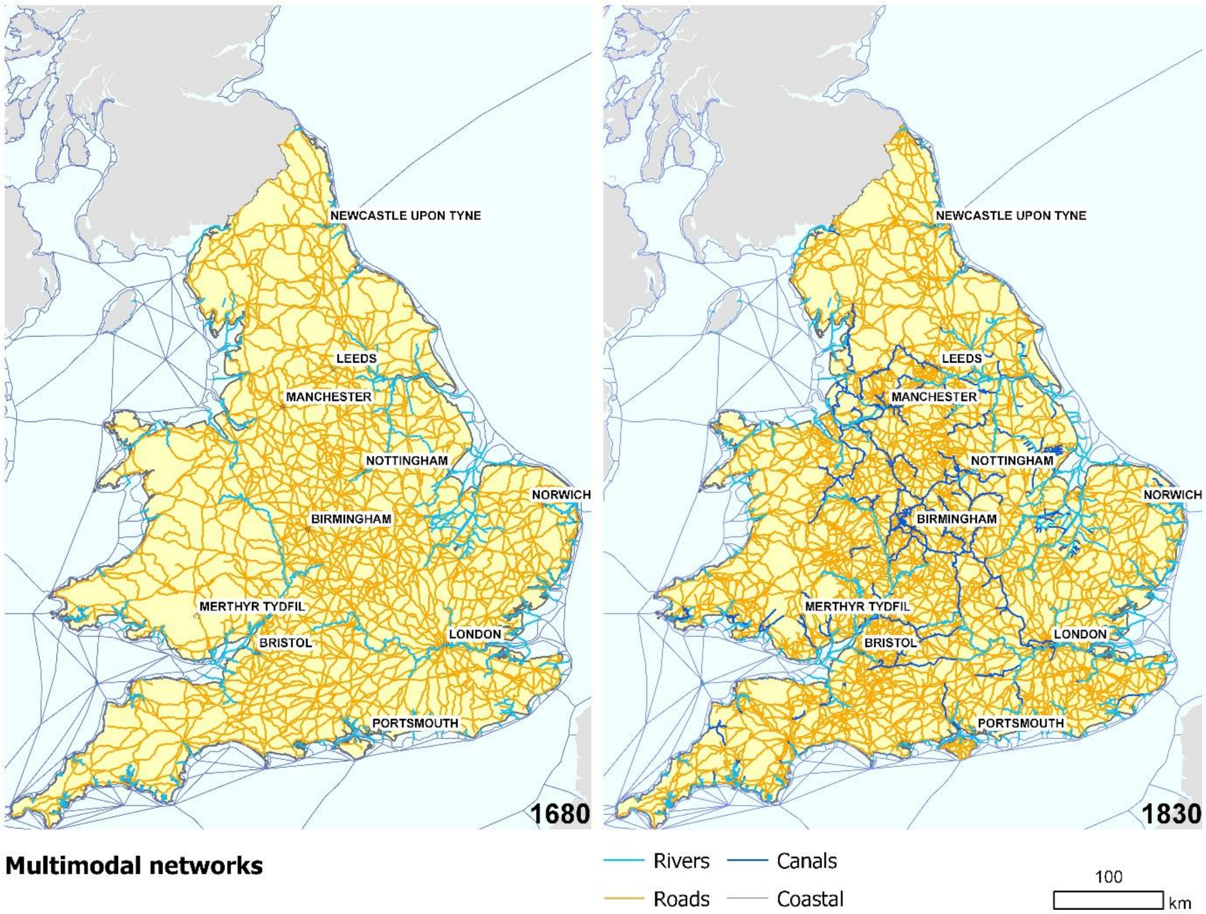

Figure 1. Transport networks in 1680 and 1830.

Source: Made by authors drawn from sources described in text.

There are several cost features worth noting. First, inland waterway per ton mile costs were 4.7 times more than sea transport per ton mile costs in 1680. Inland waterways become relatively more expensive by 1830, mainly because canals charged tolls above any lock fee. Second, seaport fees declined reflecting improvement to ports. Nevertheless, they were non-trivial. In 1830, seaport fees equaled about 10 miles of inland waterway freight costs. Third, depending on the number of locks and road conditions, per ton mile costs for roads were around 3.3 times more than inland waterways in 1830. Consequently, the arrival of a canal near an inland town could lower its local transport costs by 70%. Fourth, assuming zero slope, differences in quality can change road transport costs by approximately 30% in 1830. Fifth, road transport costs with the best quality and no slope were between 44 and 47 times more expensive than sea transport costs. Not surprisingly, it was generally more economical to ship by sea. Last, but not least, sea transport rates per ton mile fell significantly from 1680 to 1830. This reflects better shipping technology and nautical skills, but also the reduction of warfare which raised costs.[33]

Table 1: Per ton and per ton mile costs for multi modal models in 1680 and 1830.

	1680 cost	1830 cost
Sea transport, pence per ton mile	0.211	0.168
Sea port fee in pence per ton	27.1	22.9
inland waterways in pence per ton mile	1	2.25
lock fee in pence per ton	NA	1
Trans-shipment fee, road to water in pence per ton	17.14	13.9
Low quality road, pence per ton mile as a function of height/length	11.2+(h/l)*(298.67)	9.87+(h/l)*(238.93)
High quality road pence per ton mile as a function of height/length	9.97+(h/l)*(298.67)	7.5+(h/l)*(238.93)
ferry pence per ton	1	2.25

Notes: (h/l) means height/length of segment or slope. For more details and sources see Alvarez, Bogart, Satchell, and Shaw-Taylor (2022b).

We re-emphasize that historical inter-urban freight costs are generally unobserved and so the model outputs represent new data based on detailed network, geographic, and logistic information. Even so, there are limitations. The assigned modal freight costs per mile could vary locally for reasons we do not capture. The quality of the infrastructures embedded in the networks might be greater or less than is accounted for. Geography could have further effects than just slope. In appendix, section IV, we examine the reliability of the transport cost data using coal prices and find they are a good predictor of trade costs, which we now detail.

I.C New estimates of trade costs in 1680 and 1830

Transport costs are used to estimate inter-urban trade costs, or the wedge between prices paid by consumers and prices received by firms. We follow a large trade literature in defining the trade cost τ_{ij} between locations i and j as $\tau_{ij} = \frac{tc_{ij}}{ProducerPrice} + 1$ where tc_{ij} is the monetary freight transport cost per unit and $ProducerPrice$ is the average per unit price paid to producers. The trade cost τ_{ij} is interpreted as the ratio of final good prices in i relative to j (or the mark-up) if the product was shipped from j to i, with no other transaction cost.

In our baseline analysis, we get freight transport costs tc_{ij} from our multi-modal model and use the average pit head price of coal in England as our producer price (see appendix,

[33] Solar (2013), Kelly and Ó Gráda (2019), Bogart et al. (2020), Kelly et al. (2021).

section III). The literature emphasizes the importance of coal for home heating and industrial uses (e.g., Wrigley 2014). The challenge of transporting coal has also been emphasized (Allen 2023). The main coalfields were along the northeast coast, near Newcastle upon Tyne, along the South Welsh coast, and in the inland north and midlands (see maps in appendix, section I). As coal's value was low relative to its weight, the high cost of horse-drawn vehicles made road transport economical only at short distances. Most coal was shipped by coast and second by inland waterways. This meant that many large urban areas were near the coast, where coal could be cheaply imported, or along inland waterways.

As an illustration, we calculate the average trade cost for each town i to all other towns labelled as $\overline{\tau_i}$. For interpretation, a value of $\overline{\tau_i}$ equal to 10 would imply that due to trade costs, the price of a heavy good would be marked up 10 times when it was shipped from town i to any other town on average. The English and Welsh average across all town pairs i, or $\bar{\tau}$, was 14.1 in 1680. In 1830, the average across all town pairs was 5.8, or a 59% decrease from 1680. This substantial decline in average trade costs is consistent with a transport revolution. In Appendix, Section IV we give additional evidence for greater integration in the market for coal.

The average trade costs for each town, $\overline{\tau_i}$, are mapped in figure 2 to better understand the spatial dimensions. We see that in 1680, inland towns faced very high average trade costs, generally above 20. Towns near the coast or navigable rivers had average trade costs generally less than 10. There is significantly more uniformity in average trade costs in 1830. They remain lower for towns near the coast, but relatively less than in 1680.

We also isolate the role of network expansion in reducing trade costs. We do this by making transport cost calculations using 1680 networks with 1830 per ton and per ton mile costs shown in table 1. The resulting trade costs using 1830 producer prices are labeled $\tau_{ij1830\,w/1680\,net.}$.[34] The average value across all towns i, or $\overline{\tau_i}$, is 9.1 in 1830, which is a 35% decrease from 1680. In other words, if networks did not change after 1680 then trade costs would decline by 35% instead of 59%. There is an implicit assumption here that network size and freight rates are independent, with the latter being driven by other factors, including

[34] Note we use 1830 coal prices to calculate trade costs, which is consistent with using 1830 transport rates.

technology. While it is beyond this paper to verify this assumption completely, research on sailing indicates that network structures or volume did not drive most productivity.[35]

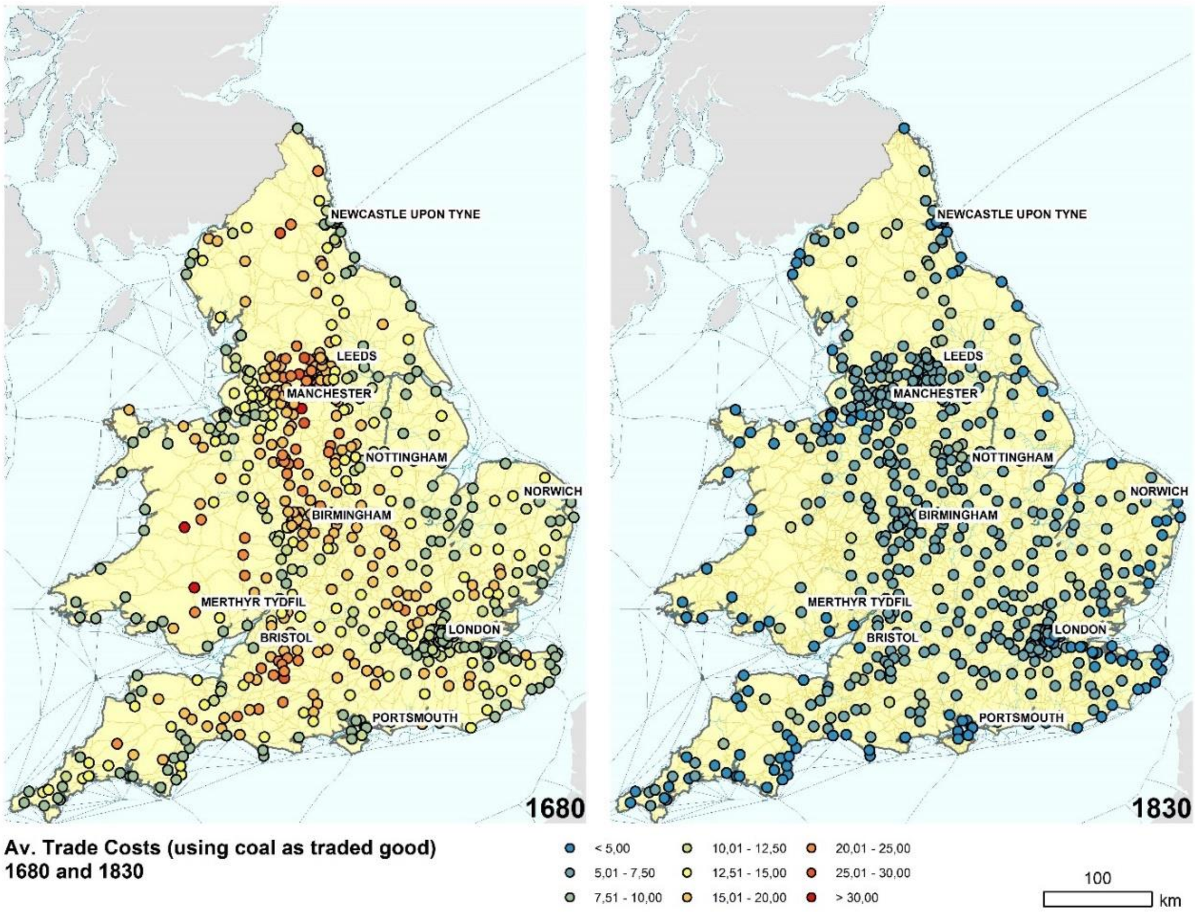

Figure 2: Average trade costs for each town to all other towns in the sample

Source: Author's creation. See text for details.

The location of river navigations and canals significantly affect our trade cost estimates. Holding other factors constant, we estimate that for every km of distance to an 1830 inland waterway a town's difference in log average 1830 trade and log average 1680 trade costs rose by 1.2%.[36] As an example, trade costs between the northern towns of Liverpool and Leeds decreased by 65%. This was largely driven by the construction of the Leeds and Liverpool canal. Cheaper coastal shipping was another factor generally. For example, the trade cost between

[35] Solar (2013), Kelly and Ó Gráda (2019), Bogart et al. (2020), Kelly et al. (2021).

[36] We hold distance to 1680 inland waterways constant. Note we can also show that For every 1 km of distance to 1830 turnpike roads, the log difference in 1830 and 1680 trade costs rose by 0.9%.

London and the coal port of Newcastle declined by 10.8% between 1680 and 1830, which is notable as this pair was almost entirely served by coastal ships and ports.

In an extension, we calculate trade costs using coal and grain as the traded good. Effectively that means assuming the producer price in as $\tau_{ij} = \frac{tc_{ij}}{ProducerPrice} + 1$ is a weighted average of the grain and coal prices. Appendix, section III gives the details. Adding grain, we find that trade costs averaged 7.6 across all town pairs in 1680 and 2.8 in 1830, representing a 63% decrease. As we show later, our conclusions are little affected when we compare trade costs using only coal versus using coal and grain.

II. From the transport revolution to urban growth

The dramatic reductions in trade costs documented in the previous section would have consequences for the industrial revolution. Our initial focus is on how lower trade costs affected urban population change. For context, the total population of England and Wales is estimated to have grown from 5.21 million in 1700 to 8.67 million in 1801, and 17.03 million in 1851. Moreover, an increasing portion of the population lived in urban areas. Shaw-Taylor and Wrigley (2014) estimate that 16.3% of the English population lived in cities and towns of 5,000 or more in 1700. This figure rose to 20.5% in 1750, 29.5% in 1801, and 43.5% in 1851.

Migration was one of the main drivers of urban population growth, and the factor that we emphasize in this paper. Urban areas attracted migrants by providing more employment in manufacturing, including textiles, food, household goods, and metal working (Shaw-Taylor and Wrigley 2014). The new factories were normally set up in or near towns, which brought increased employment opportunities (Berg 2005). In rural areas, mortality rates were lower, which created a surplus of labor. In terms of distances, some migrants went to nearby towns, while others travelled further to large cities like London (Pooley and Turnbull 2005). Urban to urban migration also occurred, for example when apprentices trained in one town and migrated to another for work (Leunig, Minns, and Wallis 2011, Long 2005).

Importantly, for our analysis the rate of urban growth was not even across cities and towns. Figure 3 shows town or city populations around 1680 and 1841. These figures are drawn from a new database on urban populations described in Alvarez et al. (2023a). Unfortunately, there is no detailed town population data in the 1700s. Nevertheless, the long-run changes are evident. In 1680, London is the only large city. Seven towns or cities have a population over 10,000, but most were less than 2500. In 1841 London is still the largest, but remarkably towns in the west midlands and northwest have grown significantly. The latter two regions have urban clusters in 1841 which are absent in 1680. For example, Manchester and Liverpool's population grew from approximately 2500 to 300,000. Appendix, Section I reports the top 20 towns by population in 1680 and 1841.

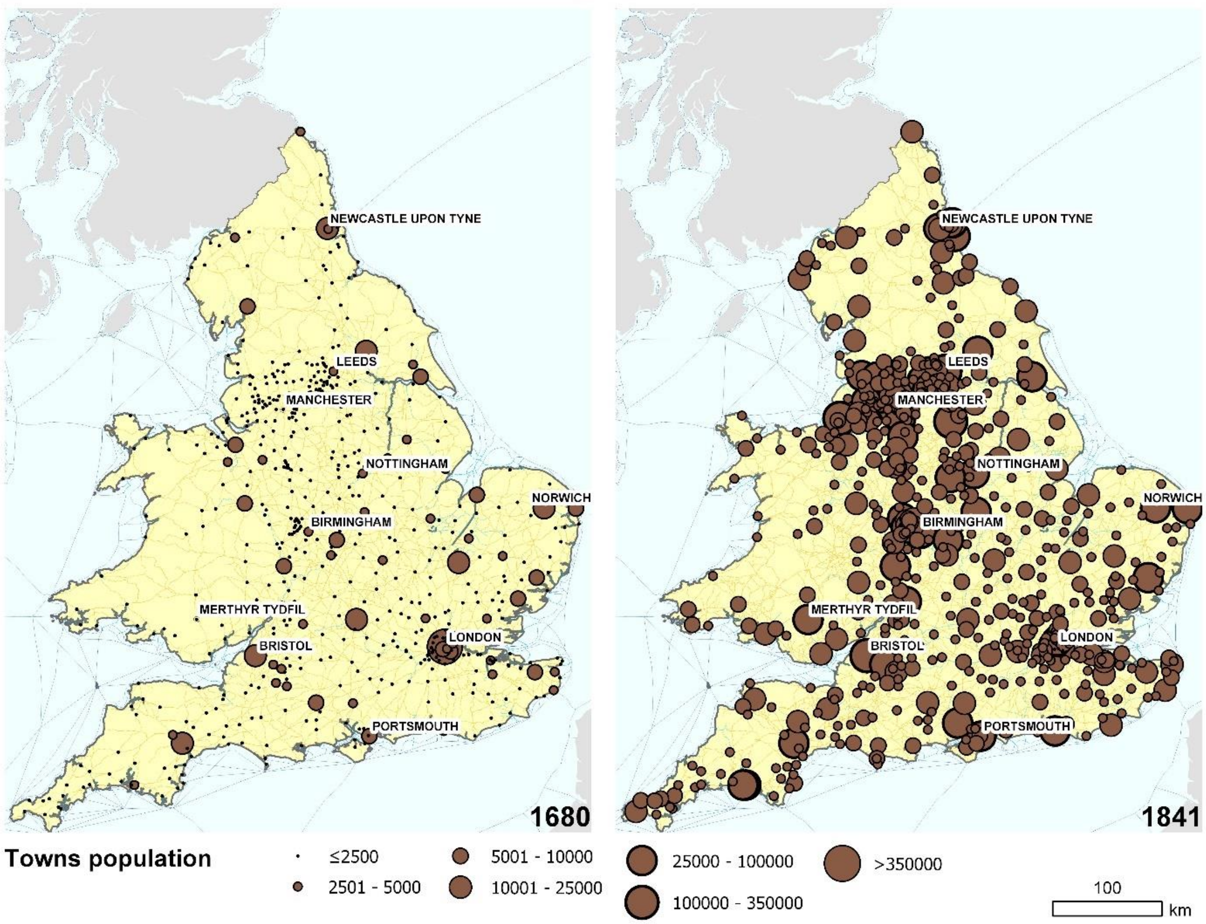

Figure 3: English and Welsh city and town populations in 1680 and 1841

Sources: Made by authors, see text and Appendix, Section I for details.

In the literature, there are several explanations for varying urban growth in this period.[37] Proximity to a coalfield is considered important because coal provided home heating and fueled steam engines, attracting both population and industry (Fernihough et al. 2021). Having access to water (either for trade or power to run machines) is another emphasized natural advantage. Another explanation is that some urban areas grew more because of long-held industrial specialties, which were favored by technological change in the 1700s or because they involved transferable skills. Examples would be cloth making, mining, or milling (see Mokyr et al. 2022).

Our empirical analysis focuses on another explanation for urban growth: well developed transport connections. Our approach builds on standard general equilibrium trade models, following Eaton and Kortum (2002) and Redding and Venables (2004), which are extended to urban economies. In these models, households choose their location based on wages, prices for consumption goods, and rents. Goods are generally cheaper in locations where consumers have greater access to low-cost firms producing in other markets. This greater access will attract households willing to migrate. On the production side, firms rent land and hire labor to produce a unique product variety. Firms will want to produce in locations with higher productivity, where wages are lower, and where they can sell to more consumers locally and via trade networks.[38]

We draw on Donaldson and Hornbeck's (2016) expression for the theoretical determinants of population in location i. Their model implies $\ln\ pop_i = \kappa_1 + \kappa_2 lnMA_i + \kappa_3 lnA_i + \kappa_3 lnL_i$, where $\ln\ pop_i$ is log population in i, $\kappa_1$is a constant, $lnMA_i$ is log market access for i, lnA_i is log productivity, and lnL_i is log land area. Market access is given by equation (1):

$$MA_i = \kappa \sum_j^J ({\tau_{ij}}^{-\theta} pop_j) * MA_j^{-(1+\theta)/\theta} \qquad (1)$$

where κ is a constant, pop_j is the population of location j, indexed from $j = 1, .. n$, τ_{ij} are trade costs between i and j, and θ is a parameter greater than 1 measuring the inverse

[37] Stobart (2000) provides a good overview of a large historical literature.

[38] There are extensions of the standard GE model with trade costs, as in Arkolakis (2014), Redding (2016), Coşar and Fajgelbaum (2016), Ramondo et al. (2016), Allen and Arkolakis (2022). These models emphasize congestion, dual structures, and scale economies which are less appliable for an early industrial England and Wales.

variation in productivity across locations.[39] In the summation, the first term $(\tau_{ij}{}^{-\theta} pop_j)$ implies that market access for i is higher when it has low trade costs to more populated locations all else equal. The second term ($MA_j{}^{-(1+\theta)/\theta}$) captures trade resistance and implies that as the market access of other locations j increases, then MA_i decreases.

There are some challenges in using a market access model. First, one needs accurate estimates of trade costs τ_{ij}. We provide those trade costs for 1680 and 1830 using our multi-modal transport model and producer prices. Second, notice in equation (1) that market access in i is a non-linear function of market access in all other locations j. Thus, there is no closed form solution for market access. One must solve the system using computational methods. Third, the parameter θ is not observed and could vary across contexts. It must be estimated.

III. Data and empirical specification for urban population

Our main estimating equation builds on a two period-panel specification shown in (2)

$$\ln pop_{it} = \beta lnMA_{it} + \alpha_i + \delta_t + \delta_t(\gamma \cdot x_i) + \mu_{it} \qquad (2)$$

where $\ln pop_{it}$ is the natural log of town i's population in year t,, $lnMA_{it}$ is the natural log of market access for town i in year t, α_i is a town fixed effect, δ_t is the time fixed effect equal to 1 in 1841 and zero in 1680, and x_i is a vector of controls varying by town. We analyze a sample of cities and towns from a new and unique historical urban dataset for England and Wales.[40] The main features are the following: (1) Population estimates for 1051 urban settlements around 1680 linked with their census populations in 1801 and 1841. (2) Population estimates for a subset of settlements in 1560. (3) Economic, political, and infrastructure characteristics for a subset of settlements around 1673. (4) Settlement locations based on historical structures and public spaces. (5) Settlement natural resources, geographic, and climate features. Briefly, the settlement populations in 1680 are derived from Langton (2000), and for 1560 from Clark and Hosking (2005) and Wrigley (1985). These pre-1801 population figures are estimates and require

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[39] As explained by Donaldson and Hornbeck (2016), the parameter θ captures, inversely, the (log) standard deviation of productivity, which corresponds to the scope for comparative advantage. A low θ means town productivity draws are dispersed, creating large incentives to trade because of productivity differences.

[40] The dataset is described in Alvarez, Bogart, Satchell, Shaw-Taylor (2022a).

assumptions about the sources. Nevertheless, the data are very accurate in comparing total town populations across counties, where estimates are more certain. We refer the reader to the summary document, Alvarez et al. (2022a), for more details on this new urban dataset.

For the analysis in this section and the next, we use 461 towns with non-zero population at dates t=1680 and 1841 and trade costs to other towns at dates 1680 and 1830. We drop 13 towns which were part of a larger neighboring town to arrive at a 'baseline estimating' sample of 448 towns. Later as a robustness check, we reweight our sample to match the distribution of population growth for all 1051 towns in the dataset. We also link to 155 towns with non-zero population at dates t=1560, 1680, and 1841. Appendix, Section I describes the properties of the sub-sample in relation to our baseline estimating sample.

Market access MA_i is calculated in several steps at two key dates. For 1680 we use estimated trade costs τ_{ij} and town populations from that date. In 1830 we use trade costs from 1830 and town population in 1841. In each year, we use equation (1) and computational methods in Matlab to solve a system of 448 non-linear equations choosing a value of $\theta = 2$. We estimated cross-sectional versions of equation (2) for 1680 at different values of θ and selected 2 as it gave the highest R-square or best fit across various specifications.[41] Later we check robustness for different values of θ.

The resulting 'baseline' market access for all towns in the sample are shown in figure 4. In 1680 market access was highest near London and along the east coast. By 1830 market access had changed dramatically, growing the most inland and in the northwest. The growth of market access from 1680 to 1830 is positively and significantly correlated with the growth in town population from 1680 to 1841, which previews one of our main findings.

[41] Moreover, if we use values of theta above 3.5 our solution implies that some towns had negative market access in 1680, which theoretically does not make sense.

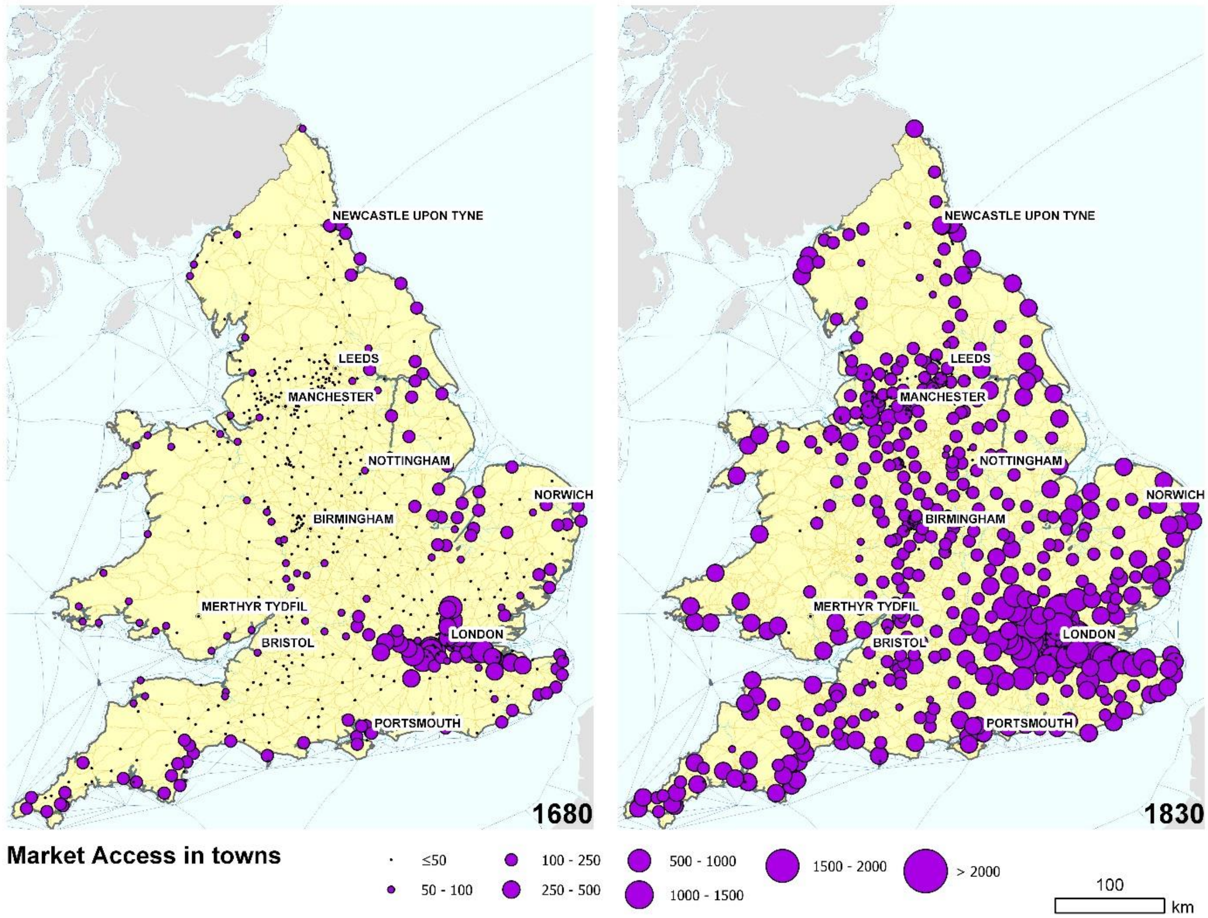

Figure 4: Estimated market access for towns in 1680 and 1830.

Source: Author's creation, see text. Note 1830 uses 1841 town population.

As we have two dates with market access, measured 150 years apart, our baseline estimating equation reduces to the long-differenced equation given by (3)

$$\Delta \ln pop_{it} = \beta \Delta lnMA_{it} + \gamma \cdot x_i + \varepsilon_{it} \qquad (3)$$

where $\Delta \ln pop_{it}$ is the difference between town i's natural log 1841 population and its natural log 1680 population, $\Delta lnMA_{it}$ is the difference between town i's natural log 1830 market access and its natural log 1680 market access, and x_i is a vector of controls that vary with specification.[42] Note that the town fixed effects, α_i, which capture time-invariant aspects of productivity and land area suitable for building, are eliminated by the differencing.

[42] Note we exclude town i's population from the calculation of i's market access.

The controls x_i address potential confounders. We start with x_i including a 2nd order polynomial in town latitude and longitude coordinates along with nine region fixed effects. The 2nd order polynomial flexibly addresses the spatial patterns of population growth. The fixed effects capture unobservable factors at the regional level. In some specifications, we go further and use 53 county fixed effects. Next, we add variables for town geography, including (i) an indicator for being on an exposed coalfield, (ii) average elevation, (iii), the standard deviation of elevation, (iv) average rainfall, (v) average temperature, and (vi) distance to nearest port in 1565.[43] These variables are made from linking towns to a rich database of 9700 spatial units, comprised of parishes and townships.[44] We further address confounders by including 16 pre-industrial controls drawn from Richard Blome's *Britannia*, originally published in 1673 (see Blome 1962). They include classifications of each town's market and economic specialties, say in mining or cloth manufacturing. There are also infrastructure classifications like whether the town was on a navigable river or was a port of significance. Some are also political, like whether the town was represented in parliament. Appendix, Section I gives more details on the pre-industrial controls drawn from Blome and included in our urban dataset. Appendix Section VI gives summary statistics for all variables in the regression.

It is important to clarify that market access for town i is not directly selected by its residents. It is mainly due to technological and infrastructure developments elsewhere. Nevertheless, in the sections that follow our baseline results we address potential endogeneity using alternative market access specifications and instrumental variables.

IV. Estimated effects of market access on town population

Table 2 reports ordinary least squares (OLS) estimates in our baseline specifications. Standard errors clustered on the county are reported in all tables. Appendix, Section VI reports Conley S.E. addressing spatial correlation. They are very similar to Table 2. In column (col.) 1, a parsimonious specification, the coefficient for $\Delta lnMA_i$ is positive and

[43] The Exposed coalfields were more easily exploited compared to concealed coal (Satchell and Shaw-Taylor 2013). Rainfall and temperature come from the FAO and are averaged from 1961 to 1990. Nonetheless, variation in rainfall and temp. across English and Welsh towns is likely to have been similar in the late 18th century.

[44] See Bogart, You, Alvarez, Satchell, and Shaw-Taylor (2022) for details on spatial units and their variables.

significant. In col. 2 and 3, geographic and pre-industrial revolution controls are added (see Appendix, Section VIII). The coefficient for $\Delta lnMA_i$ gets larger, and the standard errors remain similar. Our interpretation is that geographic and pre-industrial characteristics of towns are correlated with changes in market access, and by capturing their effects we partly address omitted variable bias. Col. 4 is our most demanding and preferred OLS specification as it uses 53 county fixed effects. The coefficient implies that for every 10% increase in market access, a town's population rose by 1.69%. Alternatively, a one-standard deviation increase in $\Delta lnMA_i$ (0.659) led to a 0.136 standard deviation increase in $\Delta \ln pop_{it}$.

Table 2: Effect of market access on town population change: baseline OLS estimates

	1	2	3	4	5
Dep. Var.		ln1841pop-ln1680pop			ln1680pop-ln1563pop
	Coeff. (st. err.)	Coeff. (st. err.)	Coeff. (st. err.)	Coeff. (st. err.)	Coeff. (st. err.)
$\Delta lnMA_{it}$	0.101 (0.059)*	0.179 (0.062)***	0.234 (0.062)***	0.170 (0.079)**	-.0134 (0.203)
Region FEs	Y	Y	Y	N	N
Geo. Controls	N	Y	Y	Y	Y
Pre-IR controls	N	N	Y	Y	N
County FEs	N	N	N	Y	Y
N	451	448	448	448	145
R-squared	0.234	0.310	0.366	0.454	0.674

Notes: All regressions include a 2nd order polynomial in latitude and longitude. For definitions of Geographic (Geo.) and pre-industrial revolution (Pre-IR) controls see text and appendix. Standard errors clustered on the county are reported. *, **, and *** represent statistical significance at the 10, 5, and 1% levels.

How robust is this estimate? We start to address this question with a placebo test in col. 5. The dependent variable is the difference in log 1680 population and log 1560 population, available for a subset of towns. Under our identifying assumption, $\Delta lnMA_i$ should not affect population growth a century earlier. The OLS results from the placebo test in col. 5 confirm no precisely estimated effect. The same conclusion holds if we include pre-IR controls dated in 1673, which are potentially endogenous with respect to 1680 population.

Next, we report estimates using a simplified formula for market access as an alternative to equation (1). Omitting the time subscript, 'simplified market access' is defined as $MA_i =$

$\sum_j^J pop_j \tau_{ij}^{-\theta}$, where j are towns indexed from $j = 1, .. n$ (omitting i). The main advantage is that the simplified MA_i can be easily calculated. The disadvantage is that it omits the trade resistance term ($MA_j^{-(1+\theta)/\theta}$), which generally reduces the theoretical measure of MA_i. Table 3 gives estimates of $\Delta lnMA_i$ using the simplified formula. In col. 1 we use $\theta = 2$ as in our baseline. The coefficient for $\Delta lnMA_i$ is nearly identical, which is reassuring. In col.'s 2 to 4 we show estimates for θ =1, 4, and 8. The coefficients are different, yet the standardized coefficients for a one-standard deviation change in market access in standard deviation units of the dependent variable are similar. Thus, the conclusions are little changed with different values of theta.

Table 3: Estimates for town population using simplified market access and other checks

	1	2	3	4	5	6
	MA with different values of θ				reweight obs. to match growth in 1051 sample	Use coal and grain as traded good
	$\theta = 2$	$\theta = 1$	$\theta = 4$	$\theta = 8$		
	Coeff. (st. err.)	Coeff. (st. err.)	Coeff. (st. err.)	Coeff. (st. err.)	Coeff. (st. err.)	Coeff. (st. err.)
$\Delta lnMA_i$	0.166 (0.061)***	0.349 (0.128)***	0.069 (0.031)**	0.025 (0.013)*	0.134 (0.061)**	0.193 (0.090)**
Standardized coefficient	0.181	0.173	0.167	0.119	0.159	0.139
Geo. Controls	Y	Y	Y	Y	Y	Y
Pre-IR controls	Y	Y	Y	Y	Y	Y
County FEs	Y	Y	Y	Y	Y	Y
N	448	448	448	448	448	448
R-squared	0.457	0.456	0.455	0.452	0.456	0.454

Notes: The dependent variable is ln1841pop – ln1680pop. The simplified MA in col. 1 uses $MA_i = \sum_j^J pop_j \tau_{ij}^{-2}$. All regressions include a 2nd order polynomial in latitude and longitude plus stated controls. For details of re-weighting in col. 5 see the text. For details on trade costs using coal and grain in col. 6 see appendix Section III. Standard errors are clustered on county. *, **, and *** indicates statistical significance at the 10, 5, and 1% levels.

Two additional robustness checks are shown in table 3. In col. 5 we report a specification that reweights observations in our baseline sample to match the distribution of population growth in the dataset with 1051 towns created by Langton (2000). Specifically, we identify 10 quintiles for the distribution of growth and identify the proportion of each in our sample. We then weight observations in the regression by the inverse of the sample weights. The estimates use simplified MA_i and $\theta = 2$ and are very similar. In col. 6 we use trade costs with coal and grain as the traded good. The estimate for $\Delta lnMA_i$ is larger, but similar. Our choice of coal as the traded good is therefore not driving our results.

IV.A. Additional identification strategies

There may be a concern that the estimate for $\Delta lnMA_i$ is biased despite the various robustness checks employed so far. Specifically, one could be concerned that the selection of infrastructure connections throughout the network for town i is correlated with the unobservable factors affecting the population growth of town i, which are contained in the error term ε_{it}. The direction of this bias is unclear. Towns which shared positive unobserved productivity shocks, increasing their population, might be more likely to get connections with one another (positive network selection). On the other hand, towns which had negative productivity shocks might have been more attractive in route selection as their land was cheaper for infrastructure builders. We discuss this negative selection more below.

Three alternative market access variables using the simplified MA_i formula for 1830 address various concerns about bias. The first uses 1680 town population to calculate 1830 market access, meaning $MA_{i1830} = \sum_j^J pop_{j1680}\tau_{ij1830}{}^{-2}$. Fixing population means we are effectively estimating the effects of reducing trade costs to towns that were populous already in 1680, eliminating the interaction between $\tau_{ij1830}{}^{-2}$ and pop_{j1830} in our baseline measure of MA_{i1830}. The second alternative uses $MA_{i1830} = \sum_j^J pop_{j1680}\tau_{ij1680\,net,1830par}{}^{-2}$, recalling that $\tau_{ij1830\,w/1680\,net,}$ are 1830 trade costs holding networks fixed to 1680. The idea is that unobservable factors associated with town growth could not influence market access changes that were the result of changing per-unit shipping costs on the networks available to them in 1680. Recall from the discussion in section I.B that changes in freight rates from 1680 to 1830 were potentially independent of network size. The third alternative restricts the accessed towns j to be more than 50 km from town i, or $MA_{it} = \sum_j^J D_{ij}^{far} pop_{jt}\tau_{ijt}{}^{-2}$, where D_{ij}^{far} is an indicator if town j is more than 50 km from i in straight line distance. It is meant to reduce concerns about selection of infrastructure connections between nearby towns, which might have common unobservable factors. A related strategy adds controls for local infrastructure connections, like the log ratio of town distance to 1830 and 1680 waterways and the same for distance to main roads. If these two variables are related with connections more broadly, then the coefficient on $\Delta lnMA_i$ should change once they are included.

The estimates for the alternative market access variables are reported in table 4. Col. 1 repeats the OLS estimates using the simplified market access without any alteration for comparison. Col. 2 adds the local infrastructure controls. The coefficient on $\Delta lnMA_i$ increases marginally. Col. 3 shows a larger effect of increased market access when omitting towns within 50 km, although not statistically different from col. 1. In col. 4 estimates are based on fixing 1680 population in MA_i. The coefficient is similar to col. 1, so there does not appear to be any selection where towns with positive unobservable factors got different connections to towns that would become more populous by 1841. In col. 5, we find a much larger coefficient when holding 1680 population and 1680 networks fixed in calculating 1830 trade costs. Thus, isolating increases in market access from changing per-ton shipping costs on fixed networks tends to increase the estimated effects. This finding suggests that the network-wide selection of infrastructure connections may have been negatively related to unobservable factors driving higher population growth.[45]

Table 4: Estimates for town population change using alternative market access formulas.

	1	2	3	4	5
Alternative market access formulations	Simplified MA_i		omit towns within 50 km	Fix 1680 pop in 1830 MA	Fix 1680 pop and 1680 networks in 1830 MA
	Coeff. (st. err.)	Coeff. (st. err.)	Coeff. (st. err.)	Coeff. (st. err.)	Coeff. (st. err.)
$\Delta lnMA_i$	0.166 (0.061)***	0.186 (0.079)**	0.202 (0.062)***	0.185 (0.064)***	0.351 (0.161)**
Geo. Controls	Y	Y	Y	Y	Y
Pre-IR controls	Y	Y	Y	Y	Y
County FEs	Y	Y	Y	Y	Y
Local Infras. controls	N	Y	N	N	N

[45] It is worth adding that a regression related to col 5 estimating effects of increased market access fixing 1680 population and holding per-ton shipping costs fixed when calculating 1830 trade costs yields a smaller effect, although still significant: coef.=0.145 and s.e. 0.060.

N	448	441	448	448	448
R-squared	0.456	0.458	0.458	0.458	0.454

Notes: The dependent variable is ln1841pop - ln1680pop. The simplified MA in 1 uses $MA_i = \sum_j^J pop_j \tau_{ij}{}^{-2}$. For further MA_i definitions see the text. All regressions include a 2nd order polynomial in latitude and longitude plus stated controls. Local infrastructure controls are Ln(dist1830waterway/dist1680waterway) and Ln(dist1830mainroad/dist1680mainroad). Standard errors are clustered on county. *, **, and *** indicates statistical significance at the 10, 5, and 1% levels.

One might ask how could there be negative selection on connections if infrastructure was generally made by profit seeking companies, like canals? While the argument cannot be proven completely, recall there is evidence that productive centers were targeted as the end-points for infrastructure connections, while the villages and towns in-between were selected for low land acquisition costs, which could mean they had unobservable factors which kept population growth lower. If the in-between towns were numerous then selection could generally be negative.

We further address potential endogeneity using two instrumental variables. The first IV is the added market access to distant towns incidentally connected to the 1779 Grand Cross Plan, given by equation (4)

$$IV_i = \ln\left[\sum_j^J D_{ij}^{far} D_j^{inc} pop_{j1680}\, \tau_{ij1830}{}^{-2}\right] - \ln\left(\sum_j^J pop_{j1680} \tau_{ij1680}{}^{-2}\right). \qquad (4)$$

where D_j^{inc} is an incidental indicator equal to 1 if town j was within 2.5 km of the 1779 plan and the town name was NOT included on a 1779 Cross Plan Map. D_{ij}^{far} is an indicator if town j was more than 50 km from i in straight line distance. Notice that incidental town populations are fixed at 1680 levels (pop_{j1680} in the first term) to omit the growth of incidental towns up to 1841 which might be related to the growth of larger towns targeted by the Canal Plan. The second Ln term is simplified market access in 1680, which is why we say (4) gives added market access from distant, incidentally connected towns.[46]

The canals included in the 1779 Grand Cross Plan are shown in figure 5, along with all towns to help illustrate the idea for the instrument (see Appendix, Section II for an image of the actual plan). Several towns are not named on the 1779 map and we regard them as being incidentally

[46] Herzog (2021) uses a similar instrument to study interstate highways. The idea of an incidental location comes from previous studies of local transport improvement, see Redding and Turner (2015) for a summary.

connected. Balance tests in appendix, Section V show that incidental towns were no different from others in their 1680 population and most pre-industrial revolution controls, which supports our argument that they were not targeted by the Cross Plan. We expect the instrument to have high relevance as incidental towns got an extra reduction in trade costs being near canals. Exclusion of the instrument is defensible as there is no reason to think connections between distant incidental towns and any town i were selected.

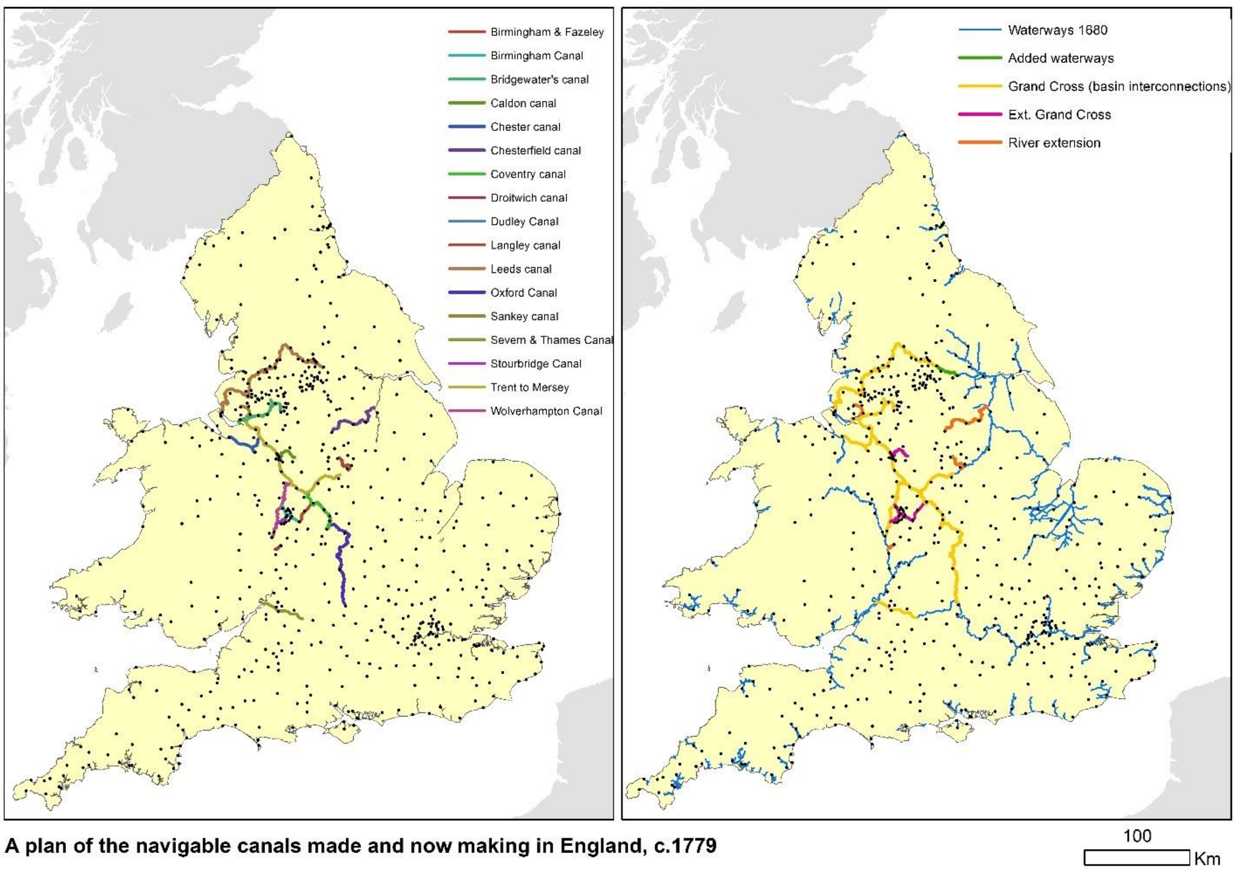

Figure 5: Representation of the Grand Cross Plan 1779 (left), with classification and waterway connections (right)

Notes and sources: Author's creation based on Henshall's plan 1779 using Antique Maps, https://www.raremaps.com/gallery/detail/50049/a-plan-of-the-navigable-canals-made-now-making-in-england-henshall. Dots represent towns in our sample. On classifications (right), Grand cross canals connected river basins, added waterways are river navigations from 1680 to 1760 which linked Cross canals to 1680 waterways, extensions to Grand cross were branch canals, river extensions were part of the Cross plan, but not canals.

We also use a second instrument, the natural log of distance to 1680 inland waterways, which are shown in blue in figure 5. This variable should be negatively correlated with the change in market access since canals were not built parallel to rivers and transport costs rose for the latter with time (see table 1).[47] Exclusion is defensible on the grounds that distance to waterways is determined by geography and in our baseline we control for whether a town is directly next to a navigable river by 1673 (part of our pre-industrial revolution controls).

Table 5 shows the estimates. For comparison, col. 1 reports our preferred OLS specification. Col. 2 is the same but uses the added market access from towns incidentally connected by the 1779 canal plan as the instrument. The first stage is strong as indicated by the F-stat. Estimates of the first stage are shown in Appendix, Section VI. The IV coefficient is very similar to OLS, supporting its general validity. In col. 3 we use distance to 1680 inland waterways as the instrument. The first stage is strong also. The second stage IV estimate is larger in col. 3, although the endogeneity test implies we cannot reject that $\Delta lnMA_i$ is exogenous.

Table 5: Instrumental variable estimates for the effect of market access

	1	2	3
Instruments for $\Delta lnMA_i$	None, OLS Coeff. (st. err.)	$\Delta lnMA_i$ to far towns incidentally connected to Plan Coeff. (st. err.)	ln dist. to 1680 inland waterways Coeff. (st. err.)
$\Delta lnMA_i$	0.170 (0.079)**	0.159 (0.075)**	0.286 (0.113)**
Geo. Controls	Y	Y	Y
Pre-IR controls	Y	Y	Y
County FEs	Y	Y	Y
Kleibergen-Paap F statistic		633.2	152.39
Endogeneity test stat., p-value		0.818	0.277
N	448	448	448
R-squared	0.454	0.454	0.451

Notes: The instrument in col. 2 is $\ln\left[\sum_j^J D_{ij}^{far} D_j^{inc} pop_{j1680}\, \tau_{ij1830}{}^{-2}\right] - \ln\left(\sum_j^J pop_{j1680} \tau_{ij1680}{}^{-2}\right)$. The instrument in 3 is ln distance to 1680 inland waterways. All regressions include a 2nd order polynomial in latitude and longitude and along with stated controls. Standard errors are clustered on counties. *, **, and *** indicates statistical significance at the 10, 5, and 1% levels.

[47] Donaldson and Hornbeck (2016) using a similar instrument based on distance to Great Lakes and rivers.

Overall, addressing the selection of infrastructure connections suggests OLS may be biased downwards, if at all. In the counter-factual analysis which follows we use an estimate for β in equation (3) between our baseline in col. 1 and some of the alternatives, which are larger.

IV.B Counter-factual of no trade cost change

In this sub-section, we estimate how the whole urban population would have evolved in England and Wales if trade costs did not change between 1680 and 1830. Effectively, this assumes transport technology did not change and no infrastructure was built or improved in these 150 years. For $t = 1841$, we rewrite our two period panel equation (2) as $lnpop_{i1841} = \beta lnMA_{i1841} + e_{i1841}$, where $e_{i1841} = \alpha_i + \delta_{1841} + \delta_{1841}(\gamma \cdot x_i) + \mu_{i1841}$. This says that counterfactual 1841 log town population is given by $lnpop^C_{i1841} = \beta lnMA^C_i + e_{i1841}$, where counterfactual market access is $MA^C_i = \kappa \sum_j^J {\tau_{ij}}^{-\theta} pop^C_{i1841} {MA^C_j}^{-(1+\theta)/\theta}$ with τ_{ij} fixed at 1680 trade costs. We use $\theta = 2$ and $\beta = 0.214$, which is an average of our OLS and IV estimates. The constant κ continues to be normalized to 1.[48] We assume that $e_{i1841} = \ln\ pop_{i1841} - 0.214 \ln MA_{i1841}$, that is actual log 1841 population minus the estimated effect of actual market access. The difference captures the effects of all our control variables plus the regression residual.[49]

With the crucial parameters defined, the computation is done in two steps: First, we rewrite our expression for counterfactual population as $pop^C_{i1841} = {MA^C_i}^{0.214} \exp(e_{i1841})$ and substitute this into the equation for counterfactual market access MA^C_i. The substitution yields a system of n non-linear equations, $MA^C_i = \sum_{j\neq i}^J {\tau_{ij}}^{-2} {MA^C_i}^{0.214} \exp(e_{i1841})\, {MA^C_j}^{-(3/2)}$, in n unknown variables MA^C_i. We solve this system using computational methods as before. In the second step, pop^C_{i1841} is obtained through substitution into ${MA^C_i}^{0.214} \exp(e_{i1841})$.

[48] One caveat is that κ is a function of worker utility in the Donaldson and Hornbeck (2016) model, which means there is an implicit assumption of constant worker utility. This assumption could be justified if urban workers were elastically supplied by rural areas, which beyond E&W could include Scotland, Ireland, Europe, and the new world. In this larger economy, utility appeared more fixed and plausibly independent of E&W trade costs.

[49] We make the assumption that in the absence of lower trade costs population would continue to grow. If worker utility was not fixed, then population would decrease further following a Malthusian logic.

In the counterfactual where trade costs did not change between 1680 and 1830, our estimates imply that the total town population in England and Wales would be 9.6% lower in 1841 or 0.67 million less. These former town-dwellers would have presumably stayed in rural areas, as happened in other economies without a transport-industrial revolution. A summary of actual and counterfactual populations in 1841 for the top 20 cities and towns are shown in table 6. Most lose population in the counterfactual, but not all. For example, London loses 7.3% of its 1841 population, while Norwich, an early textile center in East Anglia, would increase in population by 7.9%. Broadly, there is a redistribution of population from inland to the coast. Bristol and Liverpool, two coastal towns, would have 2-4% lower population. Inland towns like Manchester, Birmingham, and Leeds would have 21-28% less. In other words, the large inland urban areas would have been much smaller had trade costs not changed from 1680 to 1830.

Table 6: Counterfactual 1841 populations for top 20 cities and towns if trade costs do not change

	(1)	(2)	(3)	(4)	(5)
		No change in trade costs from 1680 to 1830		Extension where freight rate parameters change but networks do not	
Town, (I. for inland, C. for coastal or 1680 rivers)	Actual pop. 1841	Counterfactual pop. 1841	ratio (2) to (1)	Counterfactual pop. 1841	ratio (4) to (1)
LONDON, C.	1948417	1807493	0.9276	1828633	0.9385
MANCHESTER, I.	311269	246339	0.7914	278115	0.8930
LIVERPOOL, C.	286487	274476	0.9580	295741	1.0323
BIRMINGHAM, I.	182922	134773	0.7367	150144	0.8208
LEEDS, I.	152074	118481	0.7791	131304	0.8634
BRISTOL, C.	125146	123095	0.9836	129327	1.0334
SHEFFIELD, I.	111091	85108	0.7661	95954	0.8637
WOLVERHAMPTON, I.	93245	73466	0.7878	80525	0.8635
NEWCASTLE U. TYNE, C.	70337	72141	1.0256	75032	1.0667
HULL, C.	67308	70448	1.0466	70938	1.0539
BRADFORD, I.	66715	48989	0.7343	55675	0.8345
NORWICH, C.	61846	66768	1.0795	66183	1.0701
NEWINGTON, C.	54606	55422	1.0149	59793	1.0950
SUNDERLAND, C.	53335	54228	1.0167	56954	1.0678
BATH, I.	53196	40191	0.7555	46146	0.8674
PORTSMOUTH, C.	53032	55255	1.0410	56617	1.0676
NOTTINGHAM, C.	52360	54504	1.0409	52604	1.0046
BOLTON, I.	51029	40605	0.7957	46025	0.901
PRESTON, I.	50887	49622	0.9751	52745	1.0365

LEICESTER, I.	50806	37769	0.7434	42049	0.8276

Notes: author's calculations. See text for details.

We analyze another counterfactual, supposing infrastructure networks remained the same between 1680 and 1830, but per ton mile freight costs and fees evolved as shown in table 1. As we have explained, this scenario aims at quantifying the impact of not adding inland waterways and not building new roads, while assuming shipping and road transport continued to get more productive as reflected in their lower freight rates (see table 1). We estimate the total town population would have been 4.5% lower in 1841 or 0.32 million less. Col. 4 shows the counterfactual populations in 1841 for the top 20 towns in this second scenario. Inland towns, like Birmingham, Wolverhampton, and Sheffield, lose the most population, as they were especially dependent on the inland canal network. Coastal towns generally lose less population, and some—like Liverpool—are even larger.

In summary, we find that through changing trade costs, the effect of transport improvements and innovation on urban population was large. Approximately half of the aggregate effect was due to network expansion. Moreover, we learn that some urban areas gained more population from transport changes, especially those inland.

V. Market access effects on other outcomes

Migration and demographic outcomes are the initial focus of this section. They are interesting on their own, but they also speak to the mechanisms by which greater market access led to higher urban populations. In the theoretical models we use (e.g., Easton and Korum 2002), a positive shock to market access, will increase real wages, which then leads to in-migration until an equilibrium is reached. The historical literature suggests this channel is very plausible as migration was common and often related to work or employment changes. Based on a sample of more than 6000 life histories covering the years 1750 to 1830, Pooley and Turnbull (2005) estimate most of the population moved residences at least once and that approximately half of all moves were for work reasons according to their sources (pp. 39, 72). Men and those under 20 were especially likely to move for work. Just under 75% of the moves in Pooley and Turnbull's sample of life histories were to a different settlement (p.97). The average move was 37 km. About two thirds of moves were to settlements of a similar population size (plus or minus 5000), and most of the rest were to settlements of a larger size.

The literature also argues that natural increase (more births than deaths) contributed to urban growth. For example, Williamson (1988) argues about half of urban growth from 1776 to 1846 was due to natural increase. Market access could increase fertility through higher income, following a Malthusian framework. However, working against this channel, England was undergoing the demographic transition during the 19th century, which would weaken the income-fertility link. It is also possible that market access did not create differences in real income across space, as they were eliminated by migration. The potential effects of market access on mortality are also unclear. If incomes were increased, then mortality might fall as the population could purchase more life-saving inputs. On the other hand, market access might change industrial production, affecting pollution, or it could change the density of housing which might lead to the spread of diseases.

Data limitations prevent us from studying migration and demographic outcomes prior to the mid-19th century. Fortunately, there is rich information at the sub-registration district level provided in the 1851 census. Data on sub-registration districts (RSDs) come from the 'Atlas of Victorian Fertility Decline' Project (see Reid et al. 2018). We link 563 of our sample towns and cities to English and Welsh RSDs. An initial link is made when the coordinates of the market or town center lie within the boundaries of parishes or townships that belong to the RSD. A unique town-RSD linking is used for 511 towns and cities. The remaining 52 are linked differently as they were larger. 48 are linked with between 2 and 9 RSDs which share their name (e.g., Colchester town is linked with Colchester first ward, second ward, and third ward). The last 4 cities (London, Manchester, Plymouth, and Lambeth) were linked with additional RSDs that approximate urban boundaries in 1851.[50] More details are given in Appendix, Section VIII.

We use the same theoretical structure which says $\ln\, pop_i = \kappa_1 + \kappa_2 lnMA_i + \kappa_3 lnA_i + \kappa_3 lnL_i$ and study the following specification:

[50] We also drop 27 towns that share the same RSD with a larger town based on their coordinates. As we study RSD outcomes, these would represent duplicate observations. Results are robust if we include these towns.

$$y_{i1851} = \beta lnMA_{i1830/50} + \gamma \cdot x_i + \varepsilon_{i1851} \qquad (5)$$

where y_{i1851} are various town-RSD outcomes in 1851 and $MA_{i1830/50}$ is calculated using equation (1), RSD-town populations in 1851, trade costs in 1830, and $\theta = 2$. The control variables x_i are as in section IV and include county fixed effects, town geographic controls, and Pre-IR variables. We also include controls for latitude and longitude of RSD coordinates and land area. The key difference from our earlier estimates is that we cannot include RSD-town fixed effects, given equation (5) is a cross-section for 1851. Therefore, we use an instrumental variable to give more credible identification. Building on our earlier specification, the instrument is log market access restricted to the 1680 population of towns incidentally connected to the 1779 Cross plan and more than 50 km away, $\ln\left[\sum_j^J D_{ij}^{far} D_j^{inc} pop_{j1680}\, \tau_{ij1830}{}^{-2}\right]$. Relevance should be high for the reasons explained earlier. Likewise, it is excludable as 1830 trade costs to such distant towns are independent of unobservable factors influencing town $i's$ outcomes in 1851.

Our first results in this section replicates the urban population findings in section IV using the natural log of town-RSD population in 1851 as the outcome y_{i1851}. In col. 1 of table 7 we show a parsimonious specification and find a positive and significant effect of market access. Adding geographic and pre-industrial controls in columns 2 and 3 yields estimates that are not statistically different from col. 1. The IV estimate in col 4 is also similar. It implies that a 10% increase in market access raises 1851 town-RSD population by 0.034%. This estimate is larger than what we found for town populations from 1680 to 1841, but broadly similar.

We now turn to town-RSD birth distance-residency outcomes, which are reflective of migration status in 1851. The Victorian Fertility Decline Project gives the percentage (%) of the RSD population who was born in England and Wales and was either (1) born within 10 km of where they reside in 1851, (2) born 10-49 km of where they reside, or (3) born more than 50km of where they reside. The variable (1) could be interpreted as the % of non-migrants if moving 10 km is the threshold for migration. One might expect market access to have a negative effect on (1) if it increased population through in-migration. One limitation is that a threshold greater than 10 km might be preferred and some of the population in variable (2), the % born 10-49 km of where they reside, are then non-migrants. Thus, market access may not have a precisely estimated effect on (1) or (2). Variable (3), the percentage born more than 50 km away, is useful as it certainly includes only migrants in 1851. We expect a positive effect of market access on (3). The same prediction applies to a fourth variable for the % residing in each English and Welsh RSD and who was born in Scotland.

Table 7: Effect of market access on town-RSD log population in 1851

	1	2	3	4
	OLS Coeff. (st. err.)	OLS Coeff. (st. err.)	OLS Coeff. (st. err.)	IV Coeff. (st. err.)
$lnMA_{i1830/50}$	0.312 (0.093)***	0.273 (0.137)*	0.435 (0.099)***	0.338 (0.093)***
Added controls				
County FEs	Y	Y	Y	Y
Geographic vars.	N	Y	Y	Y
Pre-IR vars.	N	N	Y	Y
Kleibergen-Paap F statistic				460.8
Endogeneity test stat, p-value				0.513
N	538	538	538	538
R-squared	0.138	0.154	0.430	0.428

Notes: All regressions include latitude, longitude, and RSD land area. $lnMA_{i1830/50}$ is computed using equation (1) with 1851 RSD populations and 1830 trade costs. The instrument in 4 is the log of market access restricted to incidental towns more than 50 km away using their 1680 population and 1830 trade costs, or $\ln\left[\sum_j^J D_{ij}^{far} D_j^{inc} pop_{j1680}\, \tau_{ij1830}{}^{-2}\right]$. Standard errors clustered on the county are reported. *, **, and *** represent statistical significance at the 10, 5, and 1% levels.

Table 8 shows estimates for effects of market access on four birth-residence variables. We report OLS using our most demanding specification like col. 3 in table 7. We also report IV estimates, which address potential endogeneity of market access. In col. 1, the OLS estimates imply market access negatively and significantly affects the % born within 10km of where they reside. However, the IV estimates in col. 2 suggest an upward bias to OLS and the effect, while negative, is not precisely estimated. As we argue above, it may be that this variable is not an accurate measure of the share of non-migrants, which produces a less precise estimate. Columns 3 and 4 show that market access has no significant effect on the % born 10-49 km from where they reside. This makes sense as this dependent variable probably captures both migrants and non-migrants. In columns 5 and 6 we find that market access positively and significantly effects the % born more than 50 km from where they reside. The IV estimate is smaller than OLS, but we cannot identify a significant difference. The same positive and significant effect applies for the % born in Scotland living in an English and Welsh town-RSD (see col. 7 and 8).

Table 8: Effect of market access on birth-residency outcomes in 1851

	1	2	3	4
	OLS	IV	OLS	IV
Dep. var.	Pop. % born < 10 km of residence (mean=69.9)		Pop. % born 10-49 km of residence (mean 18.35)	
	Coeff.	Coeff.	Coeff.	Coeff.
	(st. err.)	(st. err.)	(st. err.)	(st. err.)
$lnMA_{i1830/50}$	-5.000	-2.806	1.641	0.908
	(1.532)***	(1.782)	(0.996)	(1.008)
Endogeneity test stat., p-value		0.059		0.296
N	538	538	538	538
R-squared	0.469	0.466	0.372	0.371
	5	6	7	8
	OLS	IV	OLS	IV
Dep. var.	Pop. % born >50 km of residence (mean=9.68)		Pop. % born in Scotland and residing in E&W (mean=0.51)	
	Coeff.	Coeff.	Coeff.	Coeff.
	(st. err.)	(st. err.)	(st. err.)	(st. err.)
$lnMA_{i1830/50}$	2.488	1.642	0.272	0.203
	(0.863)***	(0.899)*	(0.108)**	(0.095)**
Endogeneity test stat., p-value		0.182		0.236
N	538	538	538	538
R-squared	0.576	0.574	0.597	0.596

Notes: All regressions include latitude, longitude, RSD land area, county fixed effects, geographic controls, and pre-industrial revolution controls. The instrument is the same as table 7., the log of market access to incidental towns more than 50 km away. The Kleibergen-Paap F stat. is 460.8 in all specifications as in table 7. Standard errors clustered on the county are reported. *, **, and *** represent statistical significance at the 10, 5, and 1% levels.

The magnitudes in table 8 suggest a large effect of market access on variables which most clearly capture migrant populations. According to the IV estimates, a one standard deviation increase in $lnMA_{i1830/50}$ (0.466) increases those born more than 50km by 0.765 percentage points (p.p.), which is 11% of the 8 p.p. mean. The same increase in market access increases the Scottish born residing in England and Welsh town-RSD by 0.09 p.p., which is 19% of the mean.

We now estimate how market access affects demographic variables in 1851. The Victorian Fertility Decline Project gives two important variables: (1) the total fertility rate, defined as the number of children born to women between 20 and 49 years of age, and (2) the early childhood mortality rate, defined as the number of children 1 to 4 years of age (inclusive) who died per 1000 in that age group. The estimated effects of market access on these two demographic outcomes in 1851 are shown in the top panel of table 9. We find no significant effect of higher market access on total fertility. The coefficients are small and imprecise in both OLS and IV. The likely explanations are that market access did not affect incomes, or the income-fertility link was weak in England. Regardless there is no clear link between fertility and market access in this context.

Table 9: Effect of market access on fertility, mortality, and age outcomes in 1851

	1	2	3	4
	OLS	IV	OLS	IV
Dep. var.	Total fertility rate (mean=4.47)		Early childhood mortality rate (mean=111.8)	
	Coeff.	Coeff.	Coeff.	Coeff.
	(st. err.)	(st. err.)	(st. err.)	(st. err.)
$lnMA_{i1830/50}$	-0.020	0.035	16.754	14.250
	(0.067)	(0.089)	(4.631)***	(4.544)***
Endogeneity test stat., p-value		0.460		0.477
N	538	538	538	538
R-squared	0.506	0.505	0.597	0.596
	5	6	7	8
	OLS	IV	OLS	IV
Dep. var.	Av. age of marriage, women (mean=25.72)		Average age in years (mean 25.98)	
	Coeff.	Coeff.	Coeff.	Coeff.
	(st. err.)	(st. err.)	(st. err.)	(st. err.)
$lnMA_{i1830/50}$	-0.192	-0.259	-0.459	-0.495
	(0.188)	(0.203)	(0.125)***	(0.151)***
Endogeneity test stat., p-value		0.553		0.733
N	538	538	538	538
R-squared	0.409	0.409	0.588	0.587

Notes: All regressions include latitude, longitude, RSD land area, county fixed effects, geographic controls, and pre-industrial revolution controls. The instrument is the same as table 7., the log of market access to incidental towns more than 50 km away. The Kleibergen-Paap F stat. is 460.8 in all specifications as in table 7. Standard errors clustered on the county are reported. *, **, and *** represent statistical significance at the 10, 5, and 1% levels.

Next, in col. 3 and 4, we find that higher market access significantly increased the early childhood mortality rate. A one S.D. increase in market access led to 6.64 more early childhood deaths per 1000, or 6% of the mean, according to the IV estimate. The explanation requires more research, but one potential channel is through migration-induced over-crowding of cities which had negative health consequences especially for the young (see Tang (2017), Hanlon (2020), Zimran (2020), Davenport (2020) for related arguments). Summarizing, the findings in table 9 suggest that natural population increase (higher births minus deaths) cannot account for the positive effects of market access on population.

In the bottom panel of table 9, we report estimates for other relevant demographic variables. There is no significant impact of market access on the average age of marriage for women. Earlier marriage tends to be associated with more fertility, for which we find no effect as well. We do find that higher market access significantly reduced the average age of the population. A younger population usually indicates more migration, and therefore this result further supports the argument that market access increased population through in-migration.

V.A Effects of market access on socio-economic status

We finish this section by analyzing socio-economic status (SES) outcomes associated with occupation. As noted earlier, there was a decline in unskilled occupations during the English industrial revolution, especially in agriculture. It was coupled with a growth in lower-skilled manual occupations, especially in factories and mines, and lower skilled non-manual occupations, like clerks and sales personnel. At the level of a town-RSD, we expect that higher market access reduced the share of the unskilled. It meant higher population density and more intensive use of land, which should lead to less agricultural production where many of the unskilled occupations applied. Necessarily, higher market access increased employment in other categories if it decreased the unskilled. The two prime candidates are lower skilled manual and lower skilled non-manual occupations.

We estimate effects on occupational-SES status 1851 using data reported at the RSD level. The Victorian Fertility Decline Project reports occupational percentages in 5 SES categories using the Historical International Social Class Scheme. We do not analyze the top SES class, high-skilled non-manual, such as higher managers and professionals, as it represents a relatively small share. The second through fifth SES groups capture the categories of interest. Table 10 reports estimates using the same specifications above. We find that higher market access increased SES category 2, lower skilled non-manual. The IV estimates are larger than OLS, but we cannot reject the null of exogeneity. Market access has no clear effect on SES 3, higher skilled manual. The estimated effect is positive for SES 4, lower skilled manual, but the estimates are not precise. The literature emphasizes the importance of endowments and clusters of skill for manufacturing, especially textiles (e.g., Crafts and Wolf 2014). While the control variables capture several of these factors, we may not measure all and thus the effect is perhaps less precisely estimated. In col. 7 and 8 we show that higher market access significantly reduced SES 5, unskilled manual. This last result is significant as market access is shown to reduce the agricultural share of occupations.

Table 10: Effect of market access on male socio-economic status outcomes in 1851

	1	2	3	4
	OLS	IV	OLS	IV
Dep. var.	SES 2 lower skilled non-manual (mean=11.32)		SES 3 higher skilled manual (mean 26.14)	
	Coeff. (st. err.)	Coeff. (st. err.)	Coeff. (st. err.)	Coeff. (st. err.)
$lnMA_{i1830/50}$	2.638 (0.659)***	3.167 (1.016)***	0.340 (0.692)	-0.524 (1.001)
Endogeneity test stat., p-value		0.346		0.300
N	538	538	538	538
R-squared	0.552	0.552	0.431	0.429
	5	6	7	8
	OLS	IV	OLS	IV
Dep. var.	SES 4 lower skilled manual (mean=24.61)		SES 5 unskilled manual (mean=34.28)	
	Coeff. (st. err.)	Coeff. (st. err.)	Coeff. (st. err.)	Coeff. (st. err.)
$lnMA_{i1830/50}$	2.155 (2.064)	3.216 (2.196)	-5.466 (1.741)***	-6.199 (2.233)***
Endogeneity test stat., p-value		0.370		0.598
N	538	538	538	538
R-squared	0.724	0.724	0.709	0.709

Notes: SES 2 includes HISCLASS 3-6, occupations such as clerical and sales personnel, SES 3 is HISCLASS 7-8 occupations such as plasterers, blacksmiths, farmers, and fishermen, SES 4 is HISCLASS 9-10 occupations such as miners and many factory workers. SES 5 is HISCLASS 11-12, occupations such as farm labourers and general labourers (see Reid et al. 2018). All regressions include latitude, longitude, RSD land area, county fixed effects, geographic controls, and pre-industrial revolution controls. The instrument is the same as table 7., the log of market access to incidental towns more than 50 km away. The Kleibergen-Paap F stat. is 460.8 in all specifications as in table 7. Standard errors clustered on the county are reported. *, **, and *** represent statistical significance at the 10, 5, and 1% levels.

We interpret the magnitudes using a counterfactual like sub-section IV.A. Suppose that trade costs did not decline from 1680 to 1830. Also suppose that each town-RSD population would have a fundamental size e_{i1851} absent market access effects which we define as $e_{i1851} = \ln pop_{i1851} - 0.338 * \ln MA_{i1830/50}$ following our estimates in table 7. We solve for counter-factual market access $MA^C_{i1830/50}$ and town-RSD population pop^C_{i1850} with 1680 trade costs. The calculations yield an estimate of 18% lower total town-RSD population than existed in 1851. Counterfactual market access is also lower, which according to table 10 implies a different occupational structure. For each SES group j, we compute $SES^C_{ij} = SES_{ij} + \beta_j \ln \left(\frac{MA^C_i}{MA_i}\right)$, where SES_{ij} is the observed SES % for town-RSD i in group j, β_j is the estimated effect of market access on SES % in group j, and $\frac{MA^C_i}{MA_i}$ is the ratio of $i's$ market access in the counterfactual versus reality. We make this calculation for all town-RSDs and for three SES groups.

A population-weighted average across town-RSDs gives the key aggregate findings. With 1680 trade costs, the total % of men in SES 5, unskilled manual, increases from 26.0 to 30.0%. To give some perspective, the share in SES 5 would fall from 0.35 in 1851 to 0.20 in 1911 in all of England and Wales (see Reid et al. 2018), or a 15-percentage point (p.p.) drop. Thus, we find that lower trade costs up to 1830 contributed to the long-term shift away from agricultural or unskilled employment through a 4 p.p. change. Our counterfactual estimates further show that the total % in SES 2, lower skill non-manual, decreases from 14.6 to 12.5% and the total in SES 4, lower skill manual, decreases from 27.3 to 25.2%. For perspective, employment in both these SES groups increased from 5 to 10 percentage points from 1851 to 1911, with SES 2 increasing more. Therefore, with no change in trade costs, England would have had less labor-intensive service and less labor-intensive manufacturing occupations.

VI. Conclusion

This paper offers new insights on the role of transport improvements in altering the spatial structure of the economy during the first industrial revolution. We emphasize the extensive network of canals, high quality roads, and capable ports made in the 1700s and early 1800s. We also emphasize technological advances in coastal sailing ships, which along with infrastructures, better connected distant regions by both land and sea. Our first main contribution uses two new multi-modal models of the English and Welsh transportation system to calculate freight costs and then inter-urban trade costs. Strikingly, we show trade costs between cities and towns declined by 59% on average between 1680 and 1830.

Our second main contribution estimates how lower trade costs affected town populations through greater market access. We find large, positive effects. We use the estimates to make a new counterfactual calculation regarding the effects of all early transport improvements and innovations. We estimate that the total urban population in England and Wales would have been 9.6% lower if trade costs remained unchanged between 1680 and 1830. There were also impacts on the spatial distribution. Inland towns are estimated to have been 20-25% smaller in 1841 without changes in trade costs. Other cities, mainly on the coast, would have seen little change or a small population increase.

Our third contribution examines the effect of market access on other urban outcomes in 1851. We show that higher market access significantly increased the population share of long-distance migrants. Higher market access is also shown to increase early childhood mortality, but it had no clear effect on fertility. Based on these findings, we conclude that market access increased urban population through greater in-migration, not natural increase. Lastly, we show that market access led to a lower share of unskilled occupations, like in agriculture. By contrast, it led to a higher share of lower-skilled, non-manual occupations, like services. Broadly, transport innovations and improvements before the railway and steamship significantly shaped the structure and growth of urban economies during the first industrial revolution. The impacts have lasted to the present.

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Appendix for Transport and urban growth in the first industrial revolution

I. Historical Urban population data and sample properties

Appendix table A.1.1 shows the population of the largest 20 towns in 1680 along with their population estimates at two dates. London is at the top of the list, naturally. London grows from 1680 to 1841, but many others do not. Salisbury and Deptford are two towns that fall out of the top 20 in 1841. Several other large towns in 1680 are not as exceptional in population by 1841.

Appendix Table A.1.1: Population of the largest 20 towns 1680 in comparison with situation in 1841

Town Name.County	Pop 1680	Pop 1841	Rank 1841
LONDON.MIDDLESEX	310941	1948417	1
NORWICH.NORFOLK	14216	62116	14
YORK.YORKSHIRE NORTH RIDING	14201	28842	38
BRISTOL.GLOUCESTERSHIRE	13482	136276	6
NEWCASTLE UPON TYNE.NORTHUMBERLAND	11617	99870	8
OXFORD.OXFORDSHIRE	11065	23834	48
CAMBRIDGE.CAMBRIDGESHIRE	10574	24453	46
EXETER.DEVONSHIRE	10307	38425	28
IPSWICH.SUFFOLK	9774	25264	45
GREAT YARMOUTH.NORFOLK	9248	27863	40
CANTERBURY.KENT	7671	15435	70
WORCESTER.WORCESTERSHIRE	7046	25401	43
DEPTFORD.KENT	6919	27676	101
SHREWSBURY.SHROPSHIRE	6867	18285	63
SALISBURY.WILTSHIRE	6811	10086	102
COLCHESTER.ESSEX	6647	17790	65
HULL.YORKSHIRE EAST RIDING	6600	67606	12
COVENTRY.WARWICKSHIRE	6427	37806	29
CHESTER.CHESHIRE	5849	23112	49
KENDAL.WESTMORELAND	5730	11770	91

Source: Langton (2000). Further details are given in Alverez, Bogart, Satchell, and Shaw-Taylor (2022a).

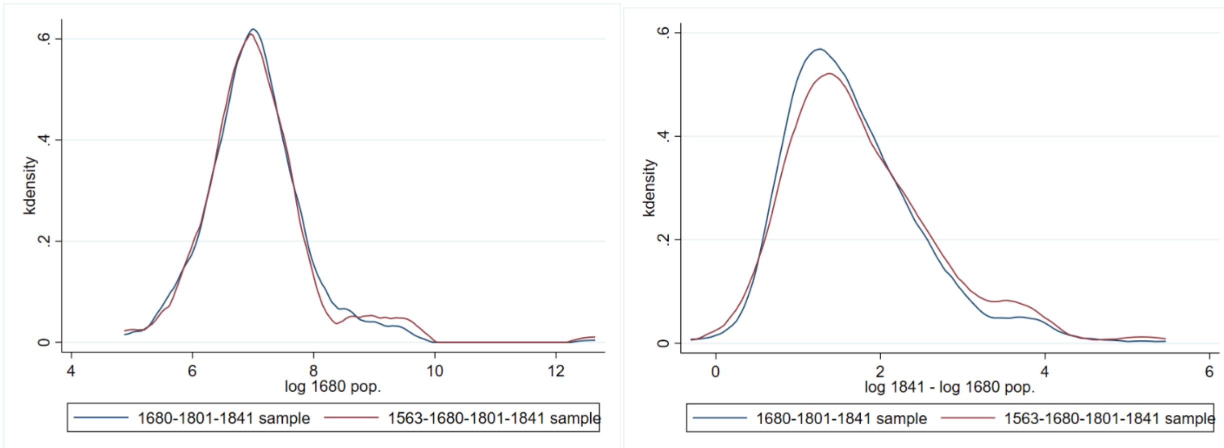
Appendix table A.1.2 shows the population of the largest 20 towns in 1841 and their population estimates at the two dates. London is again at the top. But interestingly the next two, Manchester and Liverpool, are not large towns in 1680. Liverpool is not even in the top 100 in in 1680. Bradford is another example of a town that grows significantly by 1841.

Appendix table A.1.2: Population of the largest 20 towns in 1841 in comparison with situation in 1680

Town Name.County	Pop 1680	Pop 1841	Rank C17th
LONDON.MIDDLESEX	310941	1948417	1
MANCHESTER.LANCASHIRE	2356	340708	64
LIVERPOOL.LANCASHIRE	1210	318852	123
BIRMINGHAM.WARWICKSHIRE	2745	197680	49
LEEDS.YORKSHIRE WEST RIDING	3501	146523	37
BRISTOL.GLOUCESTERSHIRE	13482	136276	4
SHEFFIELD.YORKSHIRE WEST RIDING	2050	109690	87
NEWCASTLE UPON TYNE.NORTHUMBERLAND	11617	99870	5
NOTTINGHAM.NOTTINGHAMSHIRE	4264	83102	28
PLYMOUTH.DEVONSHIRE	4000	82946	32
BRADFORD.YORKSHIRE WEST RIDING	940	82732	128
HULL.YORKSHIRE EAST RIDING	6600	67606	17
PORTSMOUTH.HAMPSHIRE	5007	66542	22
NORWICH.NORFOLK	14216	62116	2
BATH.SOMERSETSHIRE	2652	59497	56
BOLTON.LANCASHIRE	1830	58856	106
SUNDERLAND.DURHAM	1147	54740	125
HUDDERSFIELD.YORKSHIRE WEST RIDING	610	53504	138
STOCKPORT.CHESHIRE	1303	52831	121
PRESTON.LANCASHIRE	1700	50887	110

Source: Langton (2000). Further details are given in Alverez, Bogart, Satchell, and Shaw-Taylor (2022a).

We now discuss some sample properties. The left panel in Appendix figure A.1.1 shows a kernel density estimate of log 1680 population in the 1680-1801-1841 baseline estimating sample and the subsample with 1560 population. The distributions are similar, including have a long right tail for larger cities. The right panel of Appendix figure A.1.1 shows the kernel density estimate for the difference in log 1841 and log 1680 population in the baseline estimating sample and sub-sample. The distributions for growth are broadly similar.



Appendix figure A.1.1: kernel density estimates of log 1680 population and the difference in log 1841 and log 1680 for the baseline estimating sample and subset with 1560 populations.

Source: author's calculations, see text.

The new urban dataset from Alverez, Bogart, Satchell, and Shaw-Taylor (2022a) includes historic controls drawn from Richard Blome's Britannia published in 1673. These variables were digitized and first used in Bogart (2018). We use 16 variables from this dataset. To summarize, based on Blome's town description, the following 11 indicator variables equal 1 if the town (1) had cloth manufacturing, (2) had brewing, (3) had other manufacturing, (4) had mining, (5) had a harbour, (6) had an almshouse, (7) had a free school, (8) had municipal government, which, for simplicity, is one if the town had at least one type of official like mayors or council members, (9) was represented by MPs, (10) was on a navigable river, and (11) was on the coast. Blome also described the town's market including the number of days. Variable (12) is the number of market days. Blome also describes the market anywhere from small and poor to medium, good, large, and impressive. Variable (13) is an indicator equal to 1 if the market was described with words like large and zero otherwise. Variable (14) is an indicator equal to 1 if the market was described with words like small and zero otherwise. The omitted group are markets described with words like medium. Variable (15) uses Blome's county maps to create a dummy variable equal to 1 if the town was not on a navigable river but was on a stream. Finally, this dataset supplements Blome with Robert Morden's, The New Description of the State of England. Morden (1701) provides maps of roads in each county in the 17th century before turnpikes. Variable (16) is an indicator equal to 1 if the town was on the 1700 road network. As an illustration Figure A.1.2 shows towns identified has having cloth manufacturing and mining.

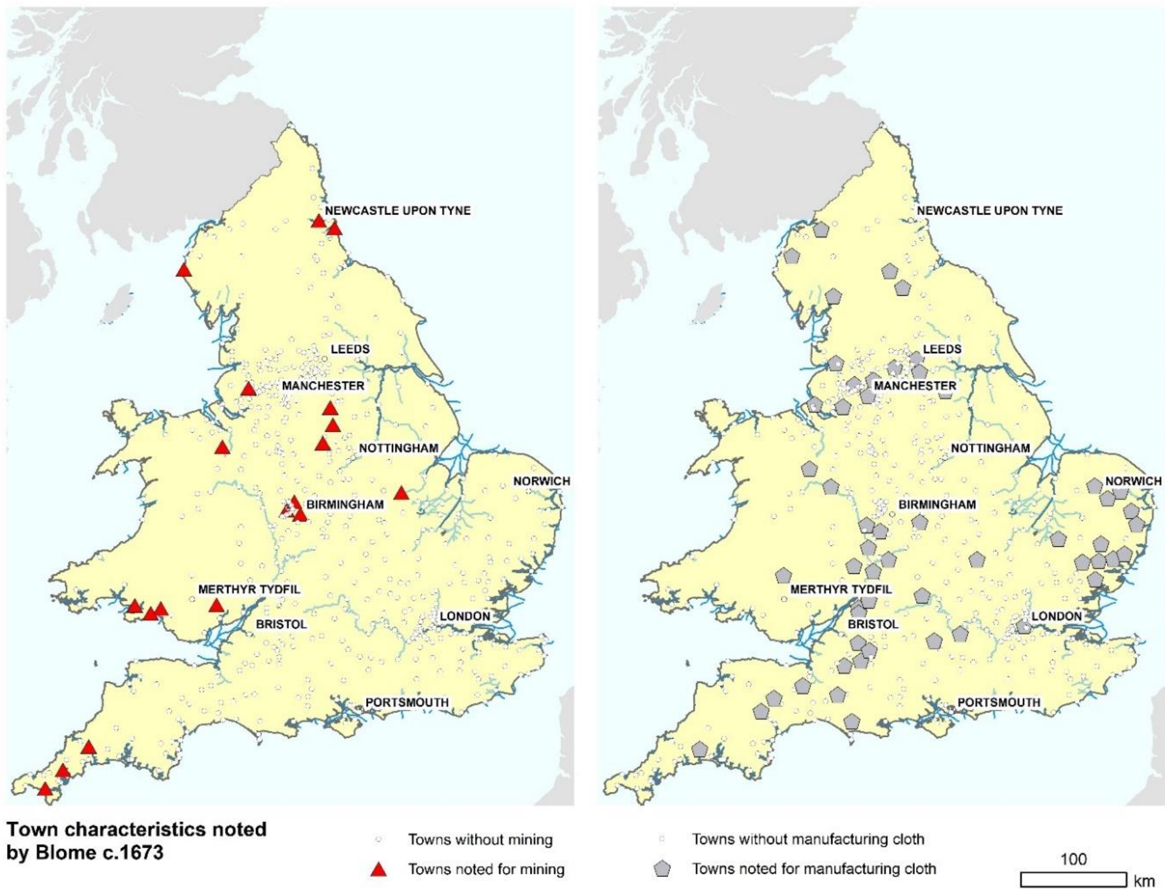


Figure A.1.2: 1680-1801-1841 sample towns noted for mining and cloth manufacturing specialties by Blome's Britannia in 1673

Source: Digitization of Blome variables drawn from Alverez, Bogart, Satchell, and Shaw-Taylor (2022a).

II. Maps of Grand Cross and planned canals

Figure A.2.1 shows a conceptual illustration of the canals associated with the Grand Cross Plan. The contoured routes reflect hilly terrain in some areas. Notice also that the industrial midlands were connected by the Cross, but its towns were not the main targets. While this was largely the case, there were exceptions as the main text explains.

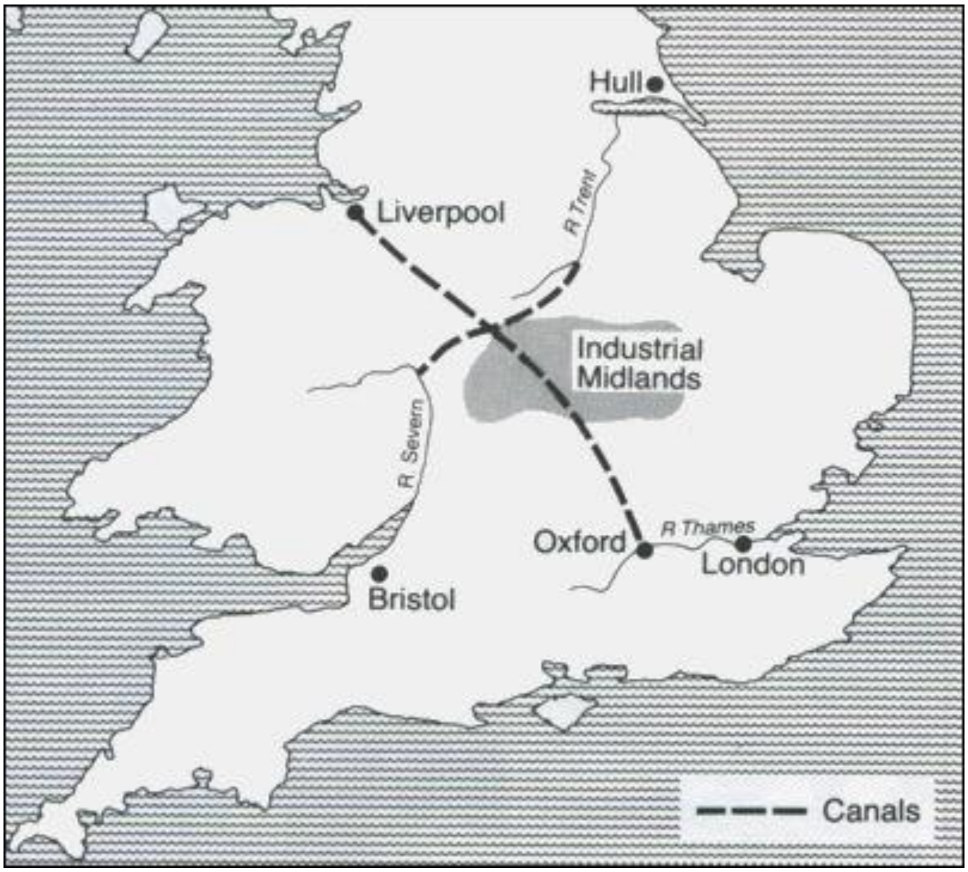


Figure A.2.1: Conceptual illustration of the Grand Cross Plan

Source: The "Grand Cross" of canals
http://www.thepotteries.org/location/districts/boathorse2.htm

Figure A.2.2 is a map of planned canals around 1779 by Hugh Henshall and John Cary. We use this map as the basis for our instrument.

Figure A.2.2: A plan of the navigable canals made and now making in England, 1779 by Hugh Henshall and John Cary

Source: Antique Maps, https://www.raremaps.com/gallery/detail/50049/a-plan-of-the-navigable-canals-made-now-making-in-england-henshall.

III. Producer prices for trade costs

This appendix explains how we determine average producer prices starting with the pithead price of coal. One can find references to the price of coal in Newcastle in the 1600s and early 1700s but on the other coalfields it is scarce. We looked at Houghton's price data in 1701 which was a year of peace (See Rogers 1987). There we find prices for coal in Newcastle and near Carlisle and Penrith in Cumberland (CU). The price of Newcastle coal is very stable at around 46 pence per ton. The price in Cumberland is also stable around 70 pence a ton. We then find coal prices in the same two locations from the PLU data c.1843 which shows that coal prices in Newcastle and in Cumberland were 63.6 and 108 pence a ton respectively.[51] We then take the average price of the two coalfields. For our calculation, the average pithead coal price in 1680 would be 58 pence a ton and the average coal price in 1830 would be 86 pence a ton.

In our extension, we estimate trade costs using coal and grain as the traded good. For example, let $\alpha * avcoalprice^{1680} + (1-\alpha) * avgrainprice^{1680}$ be the price of traded goods in 1680. The parameter α is meant to capture coal's share of traded goods by tonnage and $1 - \alpha$ is grain's share of traded goods. In this calculation we are assuming only coal and grain were traded. In our Baseline we set $\alpha = 1$ and focus just on coal.

We know from the coastal shipping data that the top two commodities shipped coastwise were coal and grain. Within grain we can break grain into wheat, barley, and oats. Armstrong and Bagwell (1983 pp. 154-156) report coastal tonnage in these commodities between 1819 and 1825 (see Table A.3.1). Coastal shipping represents a good share of all transport, so we think it is defensible to use these figures to calculate shares of trade goods (i.e. $\alpha's$). The alpha for coal would be 0.921 and the alphas for wheat, barley, and oats would be 0.032, 0.024, and 0.021 or in total 0.079.

Table A.3.1: Commodities carried coastwise c1830.

Commodity	Tons carried coastwise c1830 in 000s tons
wheat	169.7
barley	125.5

[51] Satchell, Bogart, and Taylor (2016) for the PLU data and see Satchell (2017f) for a description.

oats	110.6
coal	4761.0

Source: Armstrong and Bagwell (1983 pp. 154-156).

We now focus on farmgate grain prices, specifically wheat, barley, and oats. Overton (2002, p. 37) estimates percentages of acres planted with wheat, barley, and oats by county in 1801 and 1841. Overton creates categories of wheat, barley, or oats acreage. We focused on the top category for wheat and barley, and the top two categories for oats. We then identified counties that were in the top (or top 2) acreage categories in both 1801 and 1841, which had very different price levels. The rationale is that some counties would produce these grains throughout time perhaps because they had some advantage. For wheat the following counties had were in the top category in 1801 and 1841: Kent, Sussex, Hampshire, Buckinghamshire, Warwickshire, Shropshire, Cheshire, West Riding, Durham, Essex. For barley the following counties had were in the top category in 1801 and 1841: Hampshire, Huntingdon, Rutland. For oats, the following counties were in the top 2 categories in 1801 and 1841: Derby, Chester, Durham, Northumberland.

The next task is to find the grain prices in these counties c.1680 and c.1830. We focus on the following six markets: Chichester, Andover, Chelmsford, Lewes, Southampton, Rumford. Houghton has wheat prices in several of these places in the peace year 1700. For 1830, the corn returns https://www.cornreturnsonline.org/ give grain prices. The average wheat price in 1701 in the six markets above was 3.07 shillings a bushel or 1179 pence a ton. The average wheat price in 1830 in the markets above was 7.38 shillings a bushel or 2834 pence a ton. For barley we could find prices in 1701 and 1830 in Andover, St. Ives, and Stamford. The average barley price in 1701 was 624 pence a ton and in 1830 the average barley price was 1461 pence a ton. For oats, we could find prices in 1701 and 1830 in Nottingham and Ripon. The average oats price in 1701 was 360 pence a ton and in 1830 it was 1162 pence a ton.

Combining average coal, wheat, barley, and oats prices along with the shares of traded goods we get the following average price of trade goods in 1680 and 1830.

$$\alpha * avcoalprice^{1680} + (1-\alpha) * avgrainprice^{1680} = 115$$

$$\alpha * avcoalprice^{1830} + (1-\alpha) * avgrainprice^{1830} = 233$$

IV. Market integration and the reliability of trade cost estimates

The first goal of this appendix is to give evidence on coal market integration. We compare coal prices across 35 towns with data in both our periods. These are reported in table A.4.1, with sources at the bottom. We calculate the average coal price between 1691 and 1703 in those 35 towns. The coefficient of coal price variation, CV, was 0.37. The CV across the same 35 towns in 1842 was 0.31. The lower CV is one indication of greater market integration, with the caveat that the 35-town sample is not necessarily representative.

Table A.4.1: Coal prices in 35 towns c.1700 and 1842.

TOWN.COUNTY	Average coal price 1691 to 1703 in pence per ton	Average coal price 1842 in pence per ton
ABINGDON.BERKSHIRE	324	262
BEDFORD.BEDFORDSHIRE	193	346
BERKHAMSTEAD.HERTFORDSHIRE	411	285
BERWICK UPON TWEED.NORTHUMBERLAND	86	84
BRENTFORD.MIDDLESEX	300	223.5
BURY ST EDMUNDS.SUFFOLK	190	343
CAMBRIDGE.CAMBRIDGESHIRE	238	294
CHICHESTER.SUSSEX	426	288
COLCHESTER.ESSEX	235	288
DARTFORD.KENT	226	300
DERBY.DERBYSHIRE	50	98
DEVIZES.WILTSHIRE	253	224.5
EXETER.DEVONSHIRE	240	268.5
GUILDFORD.SURREY	286	402
HERTFORD.HERTFORDSHIRE	380	354
HITCHIN.HERTFORDSHIRE	463	396
HULL.YORKSHIRE EAST RIDING	235	192
IPSWICH.SUFFOLK	214	252
KINGS LYNN.NORFOLK	193	328
LEWES.SUSSEX	264	303
LONDON.MIDDLESEX	279	211.5
MONMOUTH.MONMOUTHSHIRE	252	129
NORTHAMPTON.NORTHAMPTONSHIRE	336	240
NORWICH.NORFOLK	209	249
NOTTINGHAM.NOTTINGHAMSHIRE	86	117
OAKHAM.RUTLANDSHIRE	171	219
OXFORD.OXFORDSHIRE	354	318
PEMBROKE.PEMBROKESHIRE	125	143

PETERBOROUGH.NORTHAMPTONSHIRE	214	293
READING.BERKSHIRE	303	300
ROMFORD.ESSEX	273	306
SOUTHAMPTON.HAMPSHIRE	303	342
STAMFORD.LINCOLNSHIRE	241	286.5
WALLINGFORD.BERKSHIRE	309	342
YORK.YORKSHIRE NORTH RIDING	183	150.0563
Average price	252.71	262.22
Std. dev. In price	92.82	81.87
Coefficient of variation	0.37	0.31

Source: Authors calculations using Houghton's coal prices reported in Rogers (1987) and Poor Law Union (PLU) accounts.

Next, we report the ratio of London to Newcastle coal prices from 1805 to 1845. Once can see that the price ratio fell over time (see figure A.4.1) supporting the argument actual trade costs fell.

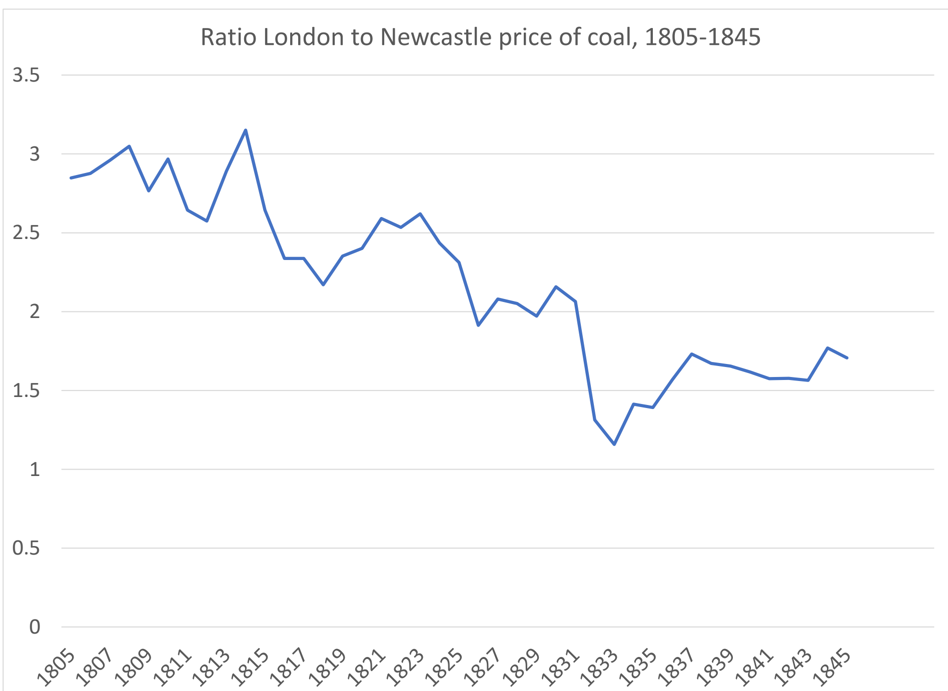


Figure A.4.1 The ratio of London to Newcastle coal prices

Source: For Newcastle we use Porter (1851, p. 277) who reports prices in shillings per ton. For London we use Great Britain, Coal Commission (1871, appendix table 152, p. 1292), which reports best coals at the ship side June price shillings per ton.

The next step is to show that our estimated trade costs are similar to observations of actual trade costs. We report the price of coal in coastal towns relative to their coastal supplier and the estimated trade cost between the same two. Due to data limitations, we can only do this comparison for 8 coastal towns in 1680. See table A.4.2. But we can make the comparison for 51 towns n 1830/1842. See table A.5.3.

Table A.4.2: Coal prices in coastal towns and their supplier compared with estimated trade costs in 1680

	1	2	3	4
TOWN.COUNTY	Av. coastal town coal price, 1697_1702	Av. coastal supplier coal price, 1697_1702	ratio 1:2	estimated trade cost between coastal town and supplier 1680
SANDWICH.KENT	234	46	5.087	3.529
PLYMOUTH.DEVONSHIRE	216	137	1.577	2.943
SOUTHAMPTON.HAMPSHIRE	299	137	2.182	3.748
FALMOUTH.CORNWALL	189	137	1.380	2.788
LONDON.MIDDLESEX	237	46	5.152	4.241
HULL.YORKSHIRE EAST RIDING	192	46	4.174	3.150
CHICHESTER.SUSSEX	354	46	7.696	6.667
LEWES.SUSSEX	239	46	5.196	3.751
Correlation (3),(4)				0.82

Source: Authors calculations using Houghton's coal prices reported in Rogers (1987) and estimated trade costs in 1680.

Table A.4.3: Coal prices in coastal towns and their supplier 1842 compared with estimated trade costs in 1830

	1	2	3	4
TOWN.COUNTY	Av. coastal town coal price, 1842	Av. coastal supplier coal price, 1842	ratio 1:2	estimated trade cost between coastal town and supplier 1830
GREAT DUNMOW.ESSEX	363	63.6	5.708	5.378
WATCHET.SOMERSETSHIRE	255	80	3.188	1.91
ABERYSTWYTH.CARDIGANSHIRE	222	80	2.775	2.272
TRURO.CORNWALL	215.5	80	2.694	2.39
FAREHAM.HAMPSHIRE	370	80	4.625	2.839
BIDEFORD.DEVONSHIRE	174.5	80	2.181	2.219
PENZANCE.CORNWALL	196	80	2.45	2.262
ST IVES.CORNWALL	264	80	3.3	2.202
CARMARTHEN.CARMARTHENSHIRE	135	80	1.688	2.252
MAIDSTONE.KENT	289	63.6	4.544	3.403
KINGS LYNN.NORFOLK	328	63.6	5.157	2.832
CHEPSTOW.MONMOUTHSHIRE	150	80	1.875	2.643

IPSWICH.SUFFOLK	252	63.6	3.962	2.711
WEYMOUTH.DORSETSHIRE	278	80	3.475	2.58
MALDON.ESSEX	292.5	63.6	4.599	2.968
GATESHEAD.DURHAM	68	63.6	1.069	1.022
BECCLES.SUFFOLK	276	63.6	4.34	2.596
ST GERMANS.CORNWALL	203.25	80	2.541	2.498
WOODBRIDGE.SUFFOLK	285	63.6	4.481	2.69
SELBY.YORKSHIRE WEST RIDING	90	63.6	1.415	3.776
BERWICK UPON TWEED.NORTHUMBERLAND	84	63.6	1.321	1.985
FORDINGBRIDGE.HAMPSHIRE	402	80	5.025	5.387
MARGATE.KENT	282	63.6	4.434	2.638
STROOD.KENT	297	63.6	4.67	3.08
DOVER.KENT	252.5	63.6	3.97	2.666
WISBECH.CAMBRIDGESHIRE	215.5	63.6	3.388	3.003
SOUTHAMPTON.HAMPSHIRE	342	80	4.275	3.036
HASTINGS.SUSSEX	286	63.6	4.497	2.63
LLANELLY.CARMARTHENSHIRE	98	80	1.225	2.131
BRISTOL.GLOUCESTERSHIRE	153	80	1.913	2.68
MILTON.KENT	261	63.6	4.104	2.953
PRESTON.LANCASHIRE	113	64	1.766	1.751
SPALDING.LINCOLNSHIRE	222	63.6	3.491	3.075
GREAT YARMOUTH.NORFOLK	236.5	63.6	3.719	2.346
CHATHAM.KENT	232	63.6	3.648	3.052
SWANSEA.GLAMORGANSHIRE	126	80	1.575	1.196
GAINSBOROUGH.LINCOLNSHIRE	182	63.6	2.862	3.809
LONDON.MIDDLESEX	211.5	63.6	3.325	3.787
FAVERSHAM.KENT	238.5	63.6	3.75	2.836
RYE.SUSSEX	286.5	63.6	4.505	2.698
BRIDPORT.DORSETSHIRE	298	80	3.725	2.828
ST AUSTELL.CORNWALL	224	80	2.8	2.799
ULVERSTON.LANCASHIRE	153.5	64	2.398	1.882
HULL.YORKSHIRE EAST RIDING	192	63.6	3.019	2.8
PEMBROKE.PEMBROKESHIRE	143	80	1.788	2.153
HELSTON.CORNWALL	243.5	80	3.044	3.181
COLCHESTER.ESSEX	288	63.6	4.528	3.536
WHITBY.YORKSHIRE NORTH RIDING	168.25	63.6	2.645	1.937
BRIDGWATER.SOMERSETSHIRE	233.75	80	2.922	2.426
CARDIFF.GLAMORGANSHIRE	126	80	1.575	2.098
correlation (3),(4)				0.6

Source: Authors calculations using 1842 PLU coal prices and estimated trade costs in 1830.

V. Balance tests for incidentally connected towns

For the balance tests, we create a dummy variable for 25 sample towns that were incidentally connected to the 1779 canal plan. Specifically, they are within 2.5 km of 1779 planned canals and do not include the endpoint and through towns identified in the Plan. We also create a dummy variable for 22 sample towns that we consider as targeted by the 1779 Canal Plan. Specifically, they are within 2.5 km of 1779 planned canals and are named on the plan as the endpoint or through towns. To visualize the names, see Appendix Section III.

We compare 25 incidentally connected towns with all other towns, excluding targeted. An important first point is that the mean log 1680 population is 6.925 for incidentally connected towns, which is not statistically different from 7.029, the mean log 1680 population of all other non-targeted towns. In table A.5.1 we report differences in geographic controls. Several geographic variables, like log distance to coast, exposed coal, elevation, are statistically different from the other 398 towns in our sample. This is to be expected, since geography and exploitation of coal played a role in identifying the best routes. That said, we have controls for geography in our specification, so we are less concerned about this imbalance. There is no evidence that being an incidentally connected town meant greater selection into Blome's town summaries c.1670. Also, as shown in table A.6.4 there are few differences regarding the 16 Blome variables. This aspect is reassuring in that incidentally connected towns were no more likely to be early manufacturing towns.

Table A.5.1: Geographic covariate imbalance for incidentally connected towns vs. all non-targeted towns

	Variable mean (Stan. Dev.)		
	(1)	(2)	(3)
Variable	All non-targeted towns	incidentally connected towns	Difference (2)-(1) (standard error)
logdistcoastkm	-4.183	-2.951	1.232***
	(1.610)	(0.475)	(0.323)
exposedcoal	0.181	0.600	0.419***
	(0.385)	(0.500)	(0.081)
averagerain	782.037	848.100	66.063*
	(190.781)	(176.598)	(39.175)
averagetemp	8.979	8.700	-0.279*
	(0.718)	(0.540)	(0.146)

elevation_mean	80.896	109.412	28.516**
	(65.438)	(60.512)	(13.437)
elevation_sd	29.688	27.436	-2.252
	(27.615)	(24.148)	(5.656)
noentryinBlome1670	0.166	0.240	0.074
	(0.372)	(0.436)	(0.078)
Observations	398	25	423

Note: Endpoints and through towns identified on canal plan are excluded from (2).

Also, as shown in table A.5.2 there is only one difference regarding the 16 Blome variables, having a 1700 road. Incidentally connected towns were also less likely to be coastal which make sense. Overall, these balance tests are reassuring in that incidentally connected towns were similar to non-targeted towns.

Table A.5.2: Blome covariate imbalance for incidentally connected towns vs. all non-targeted towns

Variable mean (Stan. Dev.)			
	(1)	(2)	(3)
Variable	All non-targeted towns	incidentally connected towns	Difference (2)-(1) (standard error)
		economic & political historical vars.	
harbour1670	0.108	0.000	-0.108
	(0.311)	(0.000)	(0.072)
mining1670	0.045	0.053	0.007
	(0.208)	(0.229)	(0.049)
cloth1670	0.139	0.053	-0.086
	(0.346)	(0.229)	(0.080)
brewing1670	0.033	0.000	-0.033
	(0.179)	(0.000)	(0.041)
othermanuf1670	0.084	0.053	-0.032
	(0.278)	(0.229)	(0.065)
freeschool1670	0.096	0.053	-0.044
	(0.296)	(0.229)	(0.069)
alms1670	0.027	0.000	-0.027
	(0.163)	(0.000)	(0.037)
townofficials1670	0.367	0.316	-0.052
	(0.483)	(0.478)	(0.114)
hasmps1670	0.346	0.421	0.075
	(0.477)	(0.507)	(0.113)
marketdays1670	1.108	1.105	-0.003

	(0.555)	(0.567)	(0.131)
largemarket1670	0.343	0.211	-0.133
	(0.476)	(0.419)	(0.112)
smallmarket1670	0.096	0.211	0.114
	(0.296)	(0.419)	(0.072)
mordenroad1700	0.723	0.474	-0.249**
	(0.448)	(0.513)	(0.107)
		geographic vars. In historic controls	
rivernav1670	0.247	0.105	-0.142
	(0.432)	(0.315)	(0.101)
stream1670	0.527	0.684	0.157
	(0.500)	(0.478)	(0.118)
coastal1670	0.157	0.000	-0.157*
	(0.364)	(0.000)	(0.084)
Observations	332	19	351

Note: No target towns means endpoints and through towns identified on 1779 canal plan are excluded from (2).

VI. Summary statistics

Summary statistics for the main variables are shown in table A.6.1. The mean difference in log population (1.682) implies an annual growth rate of 1.05% between 1680 and 1841 or 437% increase. The mean difference in the baseline log MA_i (1.635) implies a 413% increase in market access from 1680 to 1830. The means for these $\Delta lnMA_i$ using simplified market formulas are generally larger. The exceptions are those which use 1680 population or 1680 networks in calculating 1830 MA_i. Part of the increase in market access is removed in these two measures.

Table A.6.1: Descriptive Statistics for urban population growth and market access change variables

Variable	Obs.	Mean	Std. Dev.	Min	Max
(1) $\Delta \ln pop_i$, between years 1680 and 1841	448	1.682	0.817	-0.306	5.467
(2) $\Delta lnMA_i$ baseline, calculated from equation (1)	448	1.635	0.659	0.549	3.775
(3) $\Delta lnMA_i$, Simplified	448	3.174	0.890	1.659	5.770
(4) $\Delta lnMA_i$, Simplified, omit towns within 50 km	448	3.135	0.773	1.706	5.701
(5) $\Delta lnMA_i$, Simplified, use 1680 pop. in 1830 MA	448	1.201	0.808	-0.169	3.743
(6) $\Delta lnMA_i$, Simplified, use 1680 pop. and $\tau_{ij1830\ w/1680\ net,}$ in 1830 MA	448	0.603	0.364	-0.267	1.221

Notes: For definitions of variables see text.

Table A.6.2 reports correlation coefficients between the main variables. The difference in log town population is positively correlated with all the market access variables. The market access variables are all correlated with each other, although the baseline less.

Table A.6.2: Correlations urban population growth and market access change variables

	Correlation coefficient with				
	(1)	(2)	(3)	(4)	(5)
(1) $\Delta_{1841,1680} \ln pop_i$	1.00				
(2) $\Delta lnMA_i$ baseline derived from model	0.19	1.00			
(3) $\Delta lnMA_i$, Simplified MA_i	0.19	0.64	1.00		
(4) $\Delta lnMA_i$, Simplified MA_i , omit towns within 50 km	0.18	0.53	0.90	1.00	
(5) $\Delta lnMA_i$, Simplified MA_i, fix 1680 population	0.13	0.62	0.99	0.89	1.00

Notes: For definitions of variables see text.

Descriptive statistics for the control variables are given in table A.6.3 and A.6.4

Table A.6.3: Descriptive Statistics: geographic controls and Blome missing or no summary dummy variables

Variable	Obs	Mean	Std. Dev.	Min	Max
logdistcoastkm	448	-4.069	1.588	-9.596	-2.335
exposedcoal	448	.221	.415	0	1
averagerain	448	787.22	188.825	558	1372.5
averagetemp	448	8.949	.707	5.5	10
elevation mean	448	83.854	65.445	.326	401.49
elevation sd	448	29.713	27.454	.5	166.016
Lat.	448	52.26	1.18	50.1	55.7
Lon.	448	-1.56	1.52	-5.53	1.75
Lat.*Lon.	448	-81.72	78.9	-277.5	92.01
Lon.*Lon.	448	4.77	5.91	0.00002	30.65
Lat.*Lat.	448	2733.1	124.8	2510.1	3110.2
regionfe1	448	.203	.403	0	1
regionfe2	448	.188	.391	0	1
regionfe3	448	.132	.339	0	1
regionfe4	448	.112	.315	0	1
regionfe5	448	.096	.295	0	1
regionfe6	448	.098	.298	0	1
regionfe7	448	.076	.265	0	1
regionfe8	448	.036	.186	0	1
regionfe9	448	.06	.238	0	1
Blome nosummary	448	.074	.262	0	1
Blome missing	448	.089	.285	0	1

Table A.6.4: Descriptive Statistics historic controls, when Blome missing or no summary dummy variables are zero

Variable	Obs	Mean	Std. Dev.	Min	Max
harbour1670	375	.101	.302	0	1
mining1670	375	.051	.22	0	1
cloth1670	375	.144	.352	0	1
brewing1670	375	.035	.183	0	1
othermanuf1670	375	.093	.291	0	1
freeschool1670	375	.096	.295	0	1
alms1670	375	.029	.169	0	1
townofficials1670	375	.368	.483	0	1
hasmps1670	375	.352	.478	0	1
marketdays1670	375	1.131	.655	0	8
largemarket1670	375	.339	.474	0	1
smallmarket1670	375	.107	.309	0	1
mordenroad1700	375	.707	.456	0	1
rivernav1670	375	.235	.424	0	1
stream1670	375	.547	.498	0	1
coastal1670	375	.144	.352	0	1

VII. Additional estimates on effect of changes in market access

Appendix table 7.1 repeats the estimates in table 2 using various Conley standard errors. We estimate Conley S.E.'s for spatial kernal cutoffs of 50km, 100km, and 150km using the STATA command ols_spatial_HAC.

Table A.7.1: Effect of market access on town population change: baseline OLS estimates with Conley standard errors compared to clustered standard errors.

	1	2	3	4
Dep. Var.		ln1841pop-ln1680pop		
	Coeff. (st. err.)	Coeff. (st. err.)	Coeff. (st. err.)	Coeff. (st. err.)
$\Delta lnMA_{it}$	0.101	0.179	0.234	0.169
Standard errors				
Clustered on county	(0.059)*	(0.062)***	(0.062)***	(0.079)**
Conley kernal cutoff 50km	(0.067)	(0.064)***	(0.069)***	(0.067)**
Conley kernal cutoff 100km	(0.064)*	(0.054)***	(0.055)***	(0.061)***
Conley kernal cutoff 150km	(0.036)***	(0.035)***	(0.030)***	(0.032)***
Region FEs	Y	Y	Y	N
Geo. Controls	N	Y	Y	Y
Pre-IR controls	N	N	Y	Y
County FEs	N	N	N	Y
N	451	448	448	448
R-squared	0.234	0.310	0.366	0.454

Notes: All regressions include a 2nd order polynomial in latitude and longitude. For definitions of Geographic (Geo.) and pre-industrial revolution (Pre-IR) controls see text and appendix. *, **, and *** represent statistical significance at the 10, 5, and 1% levels.

Table A.7.2 provides coefficient estimates for all variables in table 3.

Table A.7.2 Coefficient estimates for models in table 3

Dependent variable	ln1841pop-ln1680pop				ln1680pop-ln1563pop
VARIABLES	(1) Model 1	(2) Model 2	(3) Model 3	(4) Model 4	(5) Model 5
$\Delta lnMA_{it}$	0.101*	0.179***	0.234***	0.170**	-0.134
	(0.0594)	(0.0624)	(0.0627)	(0.0787)	(0.203)
logdistcoastkm		-0.106***	-0.0603*	-0.0400	-0.0966
		(0.0278)	(0.0335)	(0.0338)	(0.143)
exposedcoal		0.528***	0.422***	0.290*	-0.165
		(0.144)	(0.146)	(0.170)	(0.225)

averagerain		0.000524	0.000554	0.00119	-0.00113
		(0.000668)	(0.000657)	(0.000787)	(0.00121)
averagetemp		0.175	0.0746	0.0112	0.373
		(0.106)	(0.107)	(0.125)	(0.293)
elevation_mean		0.000578	-0.000176	-0.000563	0.00478**
		(0.00109)	(0.00116)	(0.00134)	(0.00226)
elevation_sd		-0.00250	-0.00212	-0.00246	0.00261
		(0.00195)	(0.00197)	(0.00238)	(0.00497)
Lat.	4.484	5.935	6.106	9.504	13.11
	(5.852)	(4.599)	(4.459)	(6.183)	(32.26)
Lon.	2.928	1.360	1.230	-8.746	-5.586
	(2.210)	(1.794)	(1.947)	(5.454)	(16.98)
Lat.*Lon.	-0.0563	-0.0273	-0.0249	0.165	0.117
	(0.0424)	(0.0342)	(0.0373)	(0.103)	(0.330)
Lon.*Lon.	0.0206	-0.00851	-0.0163	-0.000336	0.0344
	(0.0146)	(0.0179)	(0.0189)	(0.0421)	(0.180)
Lat.*Lat.	-0.0447	-0.0564	-0.0583	-0.0891	-0.119
	(0.0561)	(0.0441)	(0.0429)	(0.0581)	(0.307)
harbour1670			-0.107	-0.112	
			(0.170)	(0.173)	
mining1670			0.542**	0.531*	
			(0.259)	(0.277)	
cloth1670			0.216	0.268*	
			(0.150)	(0.159)	
brewing1670			0.239	0.229	
			(0.173)	(0.196)	
othermanuf1670			0.136	0.253	
			(0.160)	(0.165)	
freeschool1670			-0.188	-0.0395	
			(0.121)	(0.134)	
alms1670			-0.330	-0.389	
			(0.250)	(0.300)	
townofficials1670			0.127*	0.115	
			(0.0748)	(0.0839)	
hasmps1670			-0.128	-0.155	
			(0.102)	(0.108)	
marketdays1670			-0.0235	-0.0782	
			(0.0560)	(0.0639)	
largemarket1670			-0.0202	-0.0802	
			(0.0698)	(0.112)	
smallmarket1670			0.0861	-0.0496	
			(0.155)	(0.178)	
mordenroad1700			-0.0469	0.0585	
			(0.0898)	(0.101)	
rivernav1670			0.0532	-0.00492	0.563*
			(0.156)	(0.160)	(0.280)
stream1670			-0.0919	-0.0678	0.190*
			(0.111)	(0.113)	(0.0952)

coastal1670			0.398*	0.513**	0.0633
			(0.222)	(0.223)	(0.427)
Blome_nosummary			17.48	20.11*	16.47
			(10.55)	(10.88)	(11.36)
Blome_missing			26.03	29.90*	25.44
			(15.75)	(16.26)	(17.22)
Region FEs	Y	Y	Y	N	N
County FEs	N	N	N	Y	Y
Observations	448	448	448	448	145
R-squared	0.234	0.310	0.366	0.455	0.421

Notes: Standard errors clustered on the county are reported. *, **, and *** represent statistical significance at the 10, 5, and 1% levels.

Table A.7.2 shows the full first stage estimates for the IV specifications in table 5.

Table A.7.3: first stage estimates for market access in table 5.

Dep. var.	$\Delta lnMA_{it}$	$\Delta lnMA_{it}$
	(1)	(2)
VARIABLES		
$\Delta lnMA_i$ to far towns incidentally connected to Plan	0.658***	
	(0.0395)	
ln dist. to 1680 inland waterways		0.245***
		(0.0209)
logdistcoastkm	0.0192	-0.0323
	(0.0163)	(0.0204)
exposedcoal	0.000716	-0.0482
	(0.0286)	(0.0745)
averagerain	0.000563*	0.00119***
	(0.000299)	(0.000420)
averagetemp	0.0521	0.0252
	(0.0768)	(0.0841)
elevation_mean	-0.000175	0.000427
	(0.000499)	(0.000789)
elevation_sd	2.68e-05	-0.000810
	(0.00101)	(0.00202)
Lat.	-1.080	-0.416
	(3.500)	(6.399)
Lon.	-4.608**	-2.258
	(2.167)	(2.779)
Lat.*Lon.	0.0861**	0.0424
	(0.0410)	(0.0535)
Lon.*Lon.	-0.0376*	0.00885
	(0.0223)	(0.0195)
Lat.*Lat.	0.0122	0.00560

	(0.0325)	(0.0614)
harbour1670	0.0467	0.125
	(0.0596)	(0.0872)
mining1670	0.0287	-0.0449
	(0.0497)	(0.111)
cloth1670	-0.0555	-0.0397
	(0.0404)	(0.0742)
brewing1670	-0.163	-0.0715
	(0.103)	(0.129)
othermanuf1670	-0.00531	0.0328
	(0.0516)	(0.0806)
freeschool1670	0.0202	0.00427
	(0.0563)	(0.107)
alms1670	0.113	0.117
	(0.127)	(0.163)
townofficials1670	-0.0135	-0.0321
	(0.0423)	(0.0610)
hasmps1670	-0.0425	-0.0243
	(0.0320)	(0.0533)
marketdays1670	-0.0796*	-0.0623
	(0.0441)	(0.0425)
largemarket1670	0.0860**	0.0705
	(0.0374)	(0.0669)
smallmarket1670	-0.00453	-0.0574
	(0.0468)	(0.0753)
mordenroad1700	-0.0203	-0.00542
	(0.0310)	(0.0440)
rivernav1670	-0.0194	-0.0848
	(0.0633)	(0.0725)
stream1670	0.00900	0.0428
	(0.0371)	(0.0647)
coastal1670	0.0394	0.0309
	(0.0561)	(0.0868)
Blome_nosummary	-1.298	-0.0346
	(4.296)	(6.404)
Blome_missing	-1.873	-0.00572
	(6.407)	(9.618)
County FEs	Y	Y
Observations	448	448
R-squared	0.893	0.729

Notes: The instrument in col. 1 is $\ln\left[\sum_j^J D_{ij}^{far} D_j^{inc} pop_{j1680}\, \tau_{ij1830}{}^{-2}\right] - \ln\left(\sum_j^J pop_{j1680} \tau_{ij1680}{}^{-2}\right)$. The instrument in 2 is ln distance to 1680 inland waterways. Standard errors are clustered on counties. *, **, and *** indicates statistical significance at the 10, 5, and 1% levels.

VIII. Details on registration Sub-district town linking and outcomes

Data on sub-registration districts (RSDs) come from the 'Atlas of Victorian Fertility Decline' Project (see Reid et al. 2018). We link our 563 sample towns to 769 English and Welsh RSDs following the procedures explained in the text. The 769 linked RSDs mainly include urbanized and semi-urbanized RSDS. To illustrate, table A.8.1 summarizes the population density of RSDs in our linked sample and in all of England and Wales.

Table A.8.1: Descriptive Statistics of population density in our RSD linked and non-linked sample.

Variable	Obs	Mean	Std. Dev.	Min	Max
If linked to our town sample					
Population density	769	32.177	71.21	0.092	518.9
If not linked to our town sample					
Population density	1428	1.369	7.163	0.014	167.5

RSD-town outcome variables are defined as follows. If a town is uniquely linked to a single RSD, the RSD-town outcome is equal to the RSD outcome. Here we interpret the RSD as the town plus its immediate hinterland, which applies to 511 of our 563 town-RSDs. If a town is linked with more than 1 RSD (52 cases), we aggregate the 1851 population of all associated RSDs. For outcomes that are defined as rates or percentages of the population, we calculate the population weighted average across all linked RSDs. Reassuringly the town-RSD populations are highly correlated (rho=0.99) with 1841 town populations used in our earlier analysis. Note that all findings are robust to dropping the cities of London, Manchester, Plymouth, and Lambeth, which are sprawling urban areas and linked differently.

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