

Transport and urban growth in the First Industrial Revolution

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Abstract⁵

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 early transport improvements, like improving rivers and roads, building canals, and reducing sailing costs. We estimate how much inter-urban freight transport costs declined from all such innovations between 1680 and 1830 using a new multi-modal transport model. We find that relative to producer prices, transport costs declined by nearly 75%. We then estimate how lower trade costs led to significantly higher urban population through increased market access. Our empirical strategy addresses confounding factors and potential endogeneity. A counterfactual suggests that without any change in the ratio of transport costs to producer prices between 1680 and 1830, the population in 1841 would have been more coastal and inland towns would have been 20 to 25% smaller. In extensions, we show that levels of market access in 1830 had persistent, positive effects on urban population up to 1911. It also led to significantly higher property income, more migration, and fewer unskilled occupations by the mid-nineteenth century. Broadly, early transport improvements significantly shaped the spatial structure of urban economies during the First Industrial Revolution and beyond.

Keywords: Urbanization, transport improvement, market access, Industrial Revolution.

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The Industrial Revolution led to major changes in the spatial organization of economies. One striking feature was the growth of urban areas. In England, London was always the largest city, but industrial centers, like Manchester, Leeds, and Birmingham, grew more rapidly in the late 1700s and early 1800s. Several English towns also grew into major service or commercial centers (Berg, 2005; Shaw-Taylor and Wrigley, 2014). Broadly, there was a process of population convergence across urban areas from the late 1600s to the early 1800s. By contrast, in the decades leading up to World War I, there was little or no convergence across urban areas. As a result, many emerging towns around 1840 continued to be larger by 1911, and even today many remain large urban centers.

The forces shaping the spatial dimensions of the First Industrial Revolution (from the mid-18th to the mid-19th centuries) 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 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 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 transport costs in 1680 before the Industrial Revolution and after 150 years of infrastructure improvement and innovation (1830). Transport costs are measured relative to producer prices to create a measure of trade costs. We also use a theoretical framework, featuring market access, to estimate how trade costs affected urban population. We

use our estimates to quantify how urban populations would have been different if trade costs did not change from 1680 to 1830, ultimately explaining how urban development during the Industrial Revolution would have been more limited and redistributed in space without transport improvement and innovation. We go further in showing effects on urban populations up to 1911, indicating a persistent effect of early transport improvements, before railways and steamships.

Our first main contribution is to estimate transport costs in 1680 and 1830 using new, detailed multi-modal models of the English and Welsh transport system. The models identify the lowest freight transport cost between 590 notable 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 historical transport model includes such details. Building on these new data, trade costs between town i and j are defined as one plus the ratio of their transport costs to a weighted average of coal and grain prices, the two commodities which account for most tonnage shipped. We estimate that trade costs declined substantially between 1680 and 1830. On average, the ratio of transport costs to coal/grain prices declined by nearly 75%. As we show, there were two different trends at work. Prices of coal and grain rose in nominal terms, while transport costs fell. Lower transport costs account for just under half of the overall decline.

Our second main contribution is to estimate how lower trade costs increased town populations. We use a new urban-town dataset, which includes estimated populations in 1680, along with census populations in 1801, 1841, and every decade from 1851 to 1911. For a sub-sample, there are population estimates dating to 1560. Beyond population, there is town-level assessed property income in 1843, including housing. The dataset also links towns to registration sub-districts with urban settlements in 1851, giving migration and socioeconomic-status outcomes. Finally, the dataset also has town-level geographic, economic, and institutional characteristics dating to the late 1600s.

As a preliminary step, we measure market access for town i as a sum over the population of other town's j , divided by a power function of trade costs from i to j . We show that the growth in town population from 1680 to 1841 is positively and significantly correlated with the growth

in town market access from 1680 to 1830. Also, town population in 1911 is positively and significantly correlated with town market access in 1830, pointing to a persistent effect.

We go further using a trade model, which specifies a theoretically based form of market access, estimating equations for outcomes, like population and land values, and a structure for conducting counterfactuals. The model comes from Donaldson and Hornbeck (2016) and derives from several foundational works like Redding and Venables (2004) and Eaton and Kortum (2002). It captures 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. 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. The class of models we use have proven to be a powerful tool for identifying how transportation improvements throughout the network change the distribution of population.⁶ To date, we are the first to apply them to the First Industrial Revolution, especially at a granular spatial level.

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, along with a rich set of town-level controls and fixed effects. Our preferred ordinary least squares (OLS) estimate shows that a 10% increase in market access would increase its town population by approximately 2.0%. 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 feature 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 addition to market access from incidentally connected towns more than 50 km away, holding

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

their population fixed at 1680. Another instrument is the distance to 1680 inland waterways. The estimates in various robustness checks and using instrumental variables are similar in magnitude.

Building on our estimates and the theoretical model we consider several counterfactuals. The main one quantifies how all English and Welsh urban populations in 1841 would have changed if the trade costs of 1830 were replaced with those of 1680. The estimates imply that the total urban population would have been 11% lower in 1841, with substantial 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 been more similar.

Our extensions show that the level of market access in 1830 had further important implications. Using specifications that address endogeneity, we estimate that greater market access in 1830 contributed to significantly higher town populations by 1911. The effects are also present for town populations in 1861 and 1891 and confirm a persistent effect of the early transport improvements we highlight in this paper. We also estimate that greater market access in 1830 led to significantly higher town property income in 1843, especially housing income. We use the coefficients to demonstrate that had trade costs in 1830 been higher, and equal to 1680, there would have been large income losses for urban property owners. Another extension analyzes outcomes for the distance to place of birth for residents of urban registration subdistricts (RSDs) in 1851. We estimate that greater 1830 market access significantly increased the population percentage born more than 50 km from their residence, and reduced the percentage born less than 10km from their residence. These findings suggest that market access affected urban population through migration. We close by estimating effects for the socio-economic status (SES) of men in urban RSDs. By 1851 greater market access significantly reduced the population with the lowest SES, unskilled manual occupations, and significantly increased population with the second highest SES, lower skilled non-manual. As there were zero or minor changes in other SES groups, these two findings indicate that greater market access generally increased the SES of its male workforce. It also affected the male occupational structure, shifting it away from agriculture and more to services, which is a noted feature of England during the Industrial Revolution (Shaw-Taylor and Wrigley, 2014).

Our paper contributes to many literatures. The first uses history to study transport improvement and economic development.⁷ The most related examine economy-wide effects of improving networks using a market access approach.⁸ Many studies analyze domestic and international connections expanded by railways, highways, and steamships. This paper is one of the first to analyze market access impacts for earlier infrastructural and technological innovations and one of the few to show they had persistent effects.⁹ Also related, there are several studies highlighting new shipping technologies related to sailing.¹⁰ Others focus on internal improvements, such as canals, and innovation in freight services.¹¹ 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.¹² 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 generally.¹³

Third, our paper contributes to the literature on the Industrial Revolution, especially its geographic location within England. One view is that endowments were a major factor, especially being on the coalfields since they gave energy cost advantages.¹⁴ Another view is that economic

⁷ See Atack *et al.* (2010), Tang (2017), Garcia-López (2015), Hornung (2015), Berger and Enflo (2017), Jedwab (2017), Bogart *et al.* (2022) as examples.

⁸ See Donaldson and Hornbeck (2016), Donaldson (2018), Jaworski and Kitchens (2019), Jacks and Novy (2018), Heblich *et al.* (2020), Jaworski, Kitchens, and Nigai (2022), Fajgelbaum and Redding (2024) as examples.

⁹ To our knowledge only Zimran (2020), Trew (2020), and Flückiger *et al.* (2022) study access in the pre-steam era.

¹⁰ See Ville (1986), Harley (1988), Armstrong (1991), Solar (2013), Pascali (2017), Kelly and Ó Gráda (2019), Bogart *et al.* (2020), Kelly *et al.* (2021).

¹¹ See Gerhold (1996, 2014), Bogart (2005), Maw (2011), Bogart, Lefors, and Satchell (2019), Allen (2023).

¹² See Dittmar (2011), Bosker *et al.* (2013), Cantoni and Yuchtman (2014), Dittmar and Meisenzahl (2020).

¹³ See Redding and Venables (2004), Redding and Sturm (2008), Duranton and Turner (2012), Fabor (2014), Allen and Arkolakis (2022).

¹⁴ See Allen (2009), Wrigley (2010), Crafts and Wolf (2014), Stuetzer *et al.* (2016), Warde (2018), Hanlon (2020), Fernihough and Hjortshøj O'Rourke (2021).

specialties in the past had persistent effects.¹⁵ We provide the first rigorous estimates on effects of reduced trade costs and increased market access in this important historical context.

The following section describes the early transport revolution. It also introduces the new data on inter-urban freight rates and trade costs. Section 2 describes urban growth, including preliminary correlations followed by a theoretical framework. Section 3 describes our estimation strategy and main results for population change from 1680 to 1841, including counterfactuals. The extensions in sections 4, 5, and 6 estimate the effects of 1830 market access on 1911 population, 1843 property income, and migration or SES outcomes in 1851. Section 7 concludes.

1. The early transportation revolution

Transportation improved significantly in England prior to the rise of railways and steamships.¹⁶ This sector evolved from the mid-1600s as more of the river network was 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 town 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 the needed capital. Central Government 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 1750.¹⁷ 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 increased accessibility to the coast. Canals were the next phase of inland waterway development. Canals were like a straightened

¹⁵ See Heblich and Trew (2019), Kelly *et al.* (2023), Mokyr *et al.* (2022).

¹⁶ For an overview, see Dyos and Aldcroft (1969), Aldcroft and Freeman (1983), Bagwell (1988).

¹⁷ For more on river navigations see Willan (1964) and Bogart (2018).

river with artificial cuts, and made more use of locks, tunnels, and reservoirs.¹⁸ The first was promoted and financed by the Duke of Bridgewater, linking his coal mines with the emerging industrial town of Manchester in 1762 and later with Liverpool. 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 generated interest in Brindley's proposal for a 'Grand' cross-shaped network, linking the four major river basins of England (the Thames, Mersey, Severn, and Trent) with two continuous lines of canal, and thereby connecting the coastal centers of Hull, Bristol, Liverpool, and London. The Grand Cross was made by several joint stock companies from the 1770s to the early 1800s, each using local sources of capital. The companies would connect their canal lines with one another and with rivers (Figure 5 shows a map of the Cross Plan).

Canal building continued through the 1820s, addressing some 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. With time, canals were more widely used by private shippers and scheduled-public freight services (Maw, 2013; Bogart, Lefors, and Satchell, 2019). Canals were often used in conjunction with roads and coastal ships. The famous Pickford's firm provides a good illustration as it used roads and canals to ship between Manchester and London (Turnbull, 1979). Generally, canals linked with rivers or major ports, relying on network effects to increase their reach. We now briefly explain improvements in other transport modes.

1.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 increased in the 1700s when turnpike trusts began improving roads.¹⁹ Turnpike trusts were given statutory powers to improve individual roads and to levy tolls on users. They were like canal companies in relying on local planning and financing, but they were non-profit. By 1830, there were close to

¹⁸ For more on canal development see Hadfield (1968), Ward (1974), and Maw (2014).

¹⁹ For the literature on turnpikes and their effects, see Bogart (2005) and Rosevear *et al.* (2023).

1000 trusts managing different sections of the main network. They were generally successful in building new roads and raising their quality. Trust improvements were greatest near the industrial north and southern coast. Trusts in these areas recruited better engineers and investors took more risks in lending on the security of future toll revenues (Rosevear *et al.*, 2023).

Improvements in sea transport were also significant 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 improved rigging, which increased speed and reliability.²⁰ 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 docks, which shut water in and kept it at a fixed level to facilitate loading (Pope and Swann, 1960). Port Improvements were also initiated through special acts empowering trusts or joint-stock companies (Jackson, 1983). Lighthouses also evolved 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.²¹

Of course, transport would change even more dramatically with the application of steam power in the nineteenth century. The first steam powered passenger railway service started operating in 1830. Around the same time, steamships were introduced in coastal shipping. Both would revolutionize transport and have large impacts as much research has shown. Our aim in this paper is to understand how transport changed before steam power and its implications.

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

There are no detailed, spatially granular estimates of how early transport costs changed throughout the economy. As a result, we don't know how the totality of transport improvements affected development during the Industrial Revolution.²² In this sub-section, we describe a new multi-modal model of the English and Welsh transport system, used to address this limitation.

²⁰ For the literature on speeds and shipping innovation, see Armstrong (1991), Solar (2015), Kelly and O'Grada (2019), Bogart *et al.* (2020), Kelly, O'Grada, and Solar (2021).

²¹ For the literature on lighthouses, see Coase (1974), Candela and Geloso (2018), Bogart *et al.* (2022).

²² We know that markets became more integrated (Brunt and Cannon 2014), but transport's role is unclear. We also have studies that mainly focus on canals or roads (e.g., Bogart 2005, Allen 2023), but not all transport.

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 mainly after 1689. 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 next section and Online Appendix A have more details on the 590 towns.

The freight transport model combines several modes to identify the cheapest route between points representing the 590 towns. Polylines represent networks of roads, waterways, and coastal routes and together they form a transport 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 . The output is an estimated transport cost between all towns i and j , which we call tc_{ij} .²³

Our networks are derived from historical maps and other sources explained in Online Appendix B. The definition of a port is broad and includes 479 loading/unloading places. Coastal routes between ports were digitized according to the navigation charts of the era and physical geography. There is one coastal network for long-distance shipping, and a second serving short-distance shipping in estuaries and tidal rivers. In 1680, inland navigation consisted of the network of navigable rivers. In 1830, it also included canals and river navigations made since 1680. The 1830 inland navigation data also includes locks, which add to freight costs. The road network in 1680 includes the principal roads identified in John Ogilby's Atlas of 1675. It also includes important secondary roads identified from a military survey of 1686. Information on terrain slope and vehicle accessibility, either packhorse or wagon, are also added. The principle and secondary roads in 1830 are represented by a digitization of the turnpike trust road network. Along with slope, several classes of road quality are incorporated. Bridges and ferries are added too.

Figure 1 shows the full picture of transport networks. Ports, roads, and waterways are shown individually in Online Appendix B, along with descriptions of their attributes which we use.

²³ Online Appendix C gives a brief description of our multi-modal model. More details are found in our replication folder, see data\raw\GIS\Multimodal model 1680 and 1830 EJ replication.docx.

Aside from important coastal routes, in 1680 there are many roads but few inland waterways beyond the major rivers. In 1830, by contrast, several canals linked distant rivers. 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.

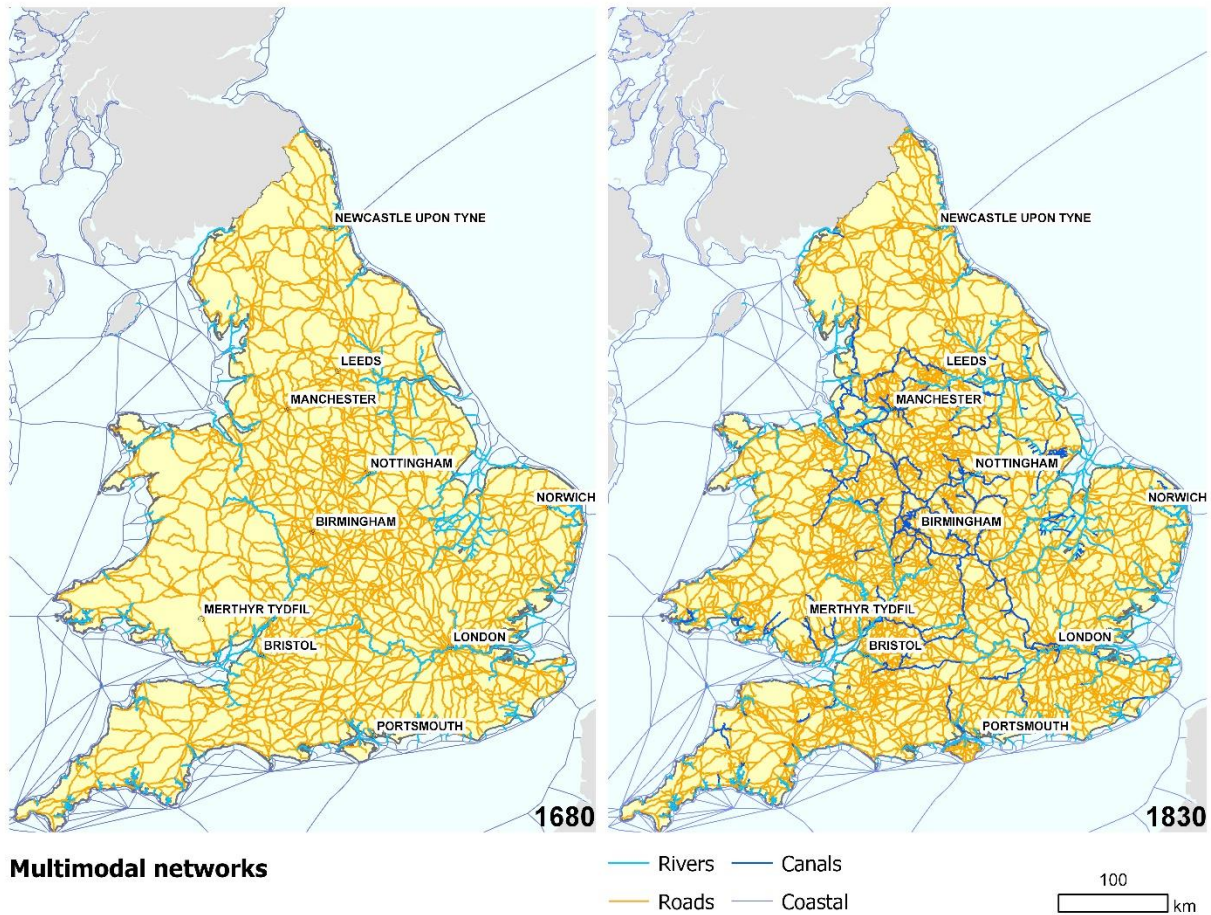


Fig. 1. *Transport networks in 1680 and 1830.*

Notes: Made by authors drawn from sources described in text. See Online Appendix B for more description.

Our multi-modal model integrates the networks, providing connections between coastal, inland waterways, and roads. Each network in the model has been assigned a ton per mile rate and some have fixed fees along the route or varying rates due to terrain and quality. We call these freight rates. Table 1 summarizes the main freight rates for 1680 and 1830. The figures come from various sources which are explained in Online Appendix C. The freight rates generally apply to heavy low-value goods, like coal, or heavy medium-value goods, like grain. Road and

inland water rates are generally inclusive of tolls paid by shippers. Road freight rates are expressed for the lowest and highest quality roads and for different slopes (height/length). We derive them from the calculations of a civil engineer in the 1830s and other sources. The trans-shipment fee captures the monetary cost associated with transferring cargo at intersections of roads, waterways, and seaports. It omits the time cost, say related to financing inventories, which is defensible for low value goods. Lastly, the freight rates are in nominal terms. The next section considers transport cost changes relative to coal and grain prices, similar to a real cost.

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

| | 1680 cost | 1830 cost |
|--|-----------------------|-----------------------|
| Coastal 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 |
| lock fee in pence per ton | NA | 1 |
| Trans-shipment fee for changing at road, water, or seaports in pence per ton | 17.14 | 13.9 |
| Lowest quality road, pence per ton mile as function of height/length | $11.2+(h/l)*(298.67)$ | $9.87+(h/l)*(238.93)$ |
| Highest quality road pence per ton mile as function of height/length | $9.97+(h/l)*(298.67)$ | $7.5+(h/l)*(238.93)$ |
| Ferry pence per ton | 1 | 2 |

Notes: (h/l) means height gain divided by length of segment. For more details and sources see Online Appendix C.

There are several features worth noting. First, inland waterway freight rates were 4.7 times more than sea transport freight rates in 1680. Inland waterways become relatively more expensive by 1830, mainly because canals charged tolls. Second, seaport fees declined reflecting improvements to ports. Nevertheless, they were non-trivial. In 1830, seaport fees equaled about 10 miles of inland waterway freight costs. Third, absent locks and at zero slope, freight rates for roads were 3.75 to 4.9 times more than inland waterways in 1830. Consequently, the arrival of a canal near an inland town could lower its local freight rates by 80%. Fourth, assuming zero slope, differences in quality can change road freight rates by approximately 30% in 1830. Fifth, road rates with the best quality and no slope were between 44 and 47 times more expensive than sea transport rates. Not surprisingly, it was more economical to ship by sea. Last, but not least, sea transport freight rates fell significantly from 1680 to 1830. This reflects better technology and nautical skills, but also less naval warfare by 1830, which previously raised shipping costs.²⁴

²⁴ Solar (2013), Kelly and Ó Gráda (2019), Bogart *et al.* (2020), Kelly *et al.* (2021).

We emphasize that historical inter-urban freight costs are generally unobserved and so the model outputs, tc_{ij} represent new data based on detailed network, geographic, and logistic information.²⁵ We now summarize the model outputs between 461 towns that are the focus of our later specifications. The average transport cost between all 461 towns i and j , tc_{ij} , decreased from 762 pence per ton in 1680 to 413 pence per ton in 1830, or a 46% decrease. Much of the reduction in average tc_{ij} came from the different transport networks in 1830. As an illustration, we calculate transport costs with a hypothetical model that keeps networks fixed at 1680 and uses 1830 freight rate parameters shown in Table 1. In this latter case, the average tc_{ij} is 692 pence, which is a far smaller reduction from the 762 average tc_{ij} , prevailing in 1680.²⁶

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

We follow the trade literature in studying a proportional cost applied to each unit of a good shipped (see Redding and Venables, 2004). Let $\tau_{ij} = tc_{ij}/P + 1$, where tc_{ij} is our multi-modal model's nominal freight transport cost per ton between the location pair i and j , and P is the average per ton price paid to producers around the same year. The expression τ_{ij} can be interpreted as the price mark-up of j 's product when sold in any other location i if goods in j had the average producer price. Henceforth we call τ_{ij} the trade cost, recognizing that it could be called a 'gross trade cost' bounded below by 1. We call the ratio, tc_{ij}/P , the iceberg cost.

In our baseline, the producer price is a weighted average of coal and grain prices. We lack data on the composition of all transported goods. However, we know the relative shares of the top two goods in terms of coastal shipping tonnage: coal and grain (See Online Appendix C). In our preferred specification, the weights are 0.92 for coal and 0.08 for grain, yielding a producer price P of 115 pence per ton in 1680 and 233 pence in 1830. An extension uses price weights of 0.6 for coal and 0.4 for grain, based on an estimate that coal represented 60% of all coastal shipping tonnage and all other goods had the same price per ton as grain. The extension

²⁵ Of course, there are limitations. The assigned modal freight rates per mile could vary. The quality of infrastructure might be greater or less than is accounted for. Geography could have further effects than just slope.

²⁶ Replication files in the folder data\processed\trade_costs contain transport costs tc_{ij} between all 590 towns and for the 461 sub-sample. There are also files with hypothetical transport costs using 1680 networks with 1830 freight rate parameters and 1830 networks with 1680 freight rate parameters.

may over-state the producer price based on case studies of canals, which detail shipments of other low value goods, like timber and stone (Maw, 2013). With P and tc_{ij} defined, we construct a symmetric matrix τ with elements $\tau_{ij} = tc_{ij}/P + 1$. One matrix uses tc_{ij} and P from 1680, yielding τ_{1680} , and the other uses tc_{ij} and P from 1830, yielding τ_{1830} .²⁷

Starting with our baseline producer price, we calculate the average trade cost for each town i to all other towns j labelled as $\tau_i = \sum_j \tau_{ij} / n$. The average across 461 towns i , or $\bar{\tau} = \sum_i \tau_i / n$, was 7.63 in 1680. For interpretation, this means the price of a good produced in i would be marked up 7.63 times on average when it was shipped to any other town (assuming i had the average producer price). In 1830, we find that $\bar{\tau}$ was 2.77, or a 64% decrease from 1680. Focusing on the iceberg cost tc_{ij}/P , which is $\tau_{ij} - 1$, we find that average transport costs relative to producer prices decreased from 6.63 to 1.77 or a 73% decrease.

It is useful to recognize there were two different trends: transport costs decreased, on average from 762 to 413, and producer prices increased from 115 to 233. To illustrate each, we first calculate a hypothetical iceberg cost tc_{ij1680}/P_{1830} , which uses 1680 transport costs and 1830 producer prices. The average is 3.27, which means increasing the producer price can account for a 51% decline $(3.27-6.63)/6.63$ relative to the average iceberg cost from 1680. Second, we calculate the hypothetical cost tc_{ij1830}/P_{1680} , which uses 1830 transport costs and 1680 producer prices. The average is 3.59, which means the reduction in transport costs can account for a 46% decline $(3.59-6.63)/6.63$ relative to the 1680 iceberg average.

In the extension, using producer price weights of 0.6 for coal and 0.4 for grain, we find the average trade cost $\bar{\tau}$ falls from 3.2 in 1680 to 1.5 in 1830, or a 53% decrease. One takeaway is that trade cost levels are much lower when grain has greater weight in the price, but the percentage point decline over time is broadly similar as our baseline has $\bar{\tau}$ declining by 64%.²⁸

The average baseline trade costs for each town, τ_i , are mapped in Figure 2 to show the spatial aspects. We see that in 1680, inland towns faced very high average trade costs, generally

²⁷ Replication files in the folder data\processed\trade_costs contain matrices of various estimated trade costs and iceberg costs. We refer the reader to this data for the summary statistics discussed in the text.

²⁸ In the extreme case where grain is the only traded good $\bar{\tau}$ is 1.97 in 1680 and 1.21 in 1830, 38.4% decrease.

above 10, which means their inhabitants faced prices at least 10 times higher than the average producer price. Towns near the coast or navigable rivers often had average trade costs of less than 5. There is much more uniformity in 1830. Of course, trade costs continued to be lower near the coast in 1830, but the difference was much less dramatic than 1680.

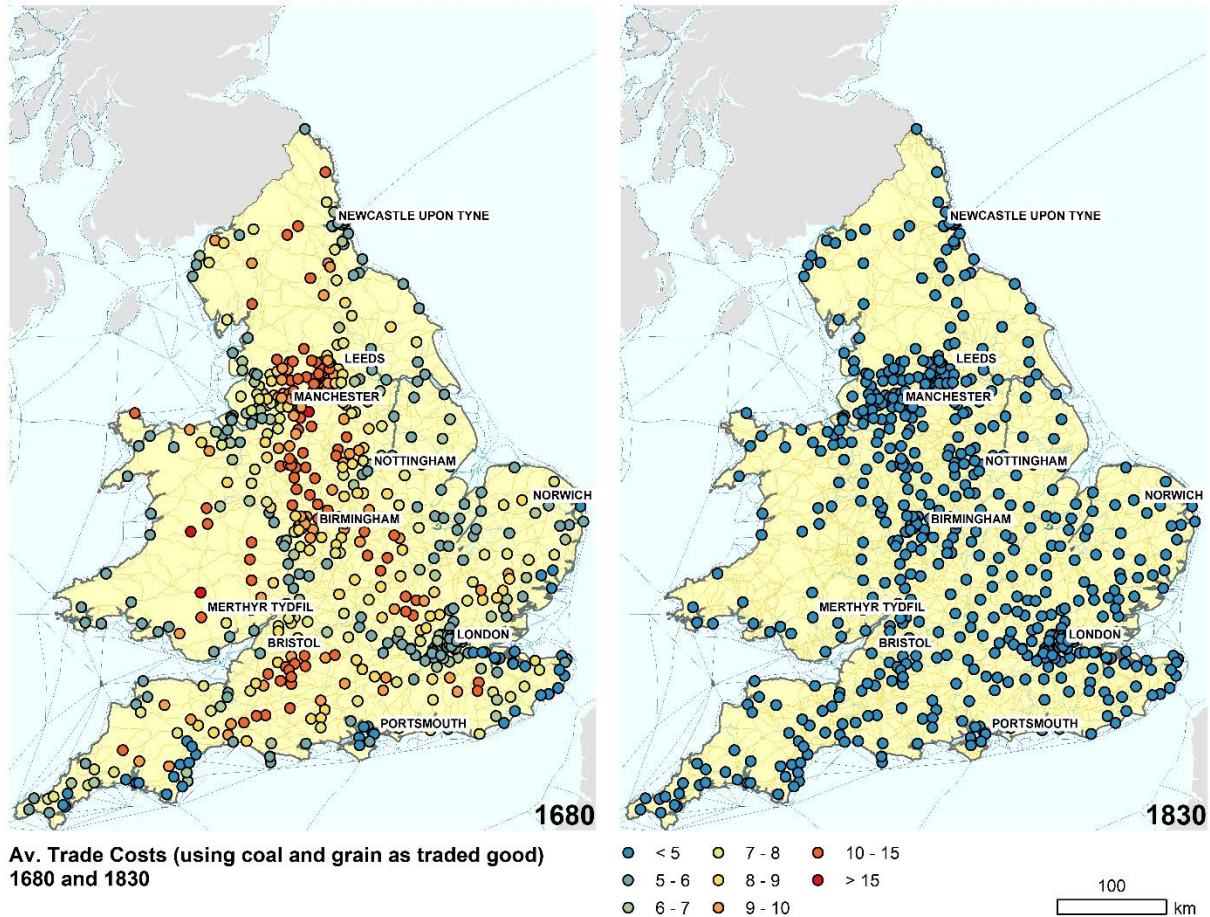


Fig. 2: Average trade costs for each town to all other towns in the sample

Notes: The maps show $\bar{\tau}_i$, averaging τ_{ij} across all towns j , where $\tau_{ij} = tc_{ij}/P + 1$ and tc_{ij} is the nominal freight transport cost per ton between the location pair i and j , and P is the average per ton price paid to producers of coal and grain around the same year. See replication files in the folder `data\processed\trade_costs` for the trade cost data in each year.

As further evidence for significant change in trade costs, we use data on coal prices to show the market became more spatially integrated between 1680 and 1830.²⁹ In Online Appendix D, we use a sample of 35 towns to show that the coefficient of variation (CV) in coal

²⁹ Allen (2023) also provides evidence that the market for coal became more integrated as canals were built.

prices was lower in 1842 than around 1700. A lower CV is consistent with greater market integration. Moreover, we show the ratio of coal prices in London versus Newcastle declined. London was the main urban market for coal and Newcastle was the main northeastern port supplying coal. We also show that our trade cost measures for 1680 and 1830 are highly correlated with observed differences in coal prices along the coast around 1700 and in 1842.³⁰

2. From the transport revolution to urban growth

The dramatic reductions in trade costs had consequences for urban growth during the Industrial Revolution. We study the effects using a new urban dataset for England and Wales. The main features are: (1) Population estimates for 925 urban settlements around the year 1680 linked with their census populations in 1801 and 1841. For a sub-sample, there are additional population estimates around the year 1560. (2) Census population data in every decade between 1841 and 1911 for 567 major towns and cities, linked to (1). (3) Assessed property income in the year 1843 for 556 boroughs, parishes, and townships linked to urban settlements. (4) Economic, political, and infrastructure characteristics for 783 linked towns around 1673. (5) Settlement locations based on historical landmarks and public buildings. (6) Settlement natural resources, geographic, and climate features. (7) indicators for settlements serving as foreign trade ports by 1791. For brevity, we call all urban settlements ‘towns’, even though some were formally cities.³¹

The dataset builds on several works with respect to population, parts of which have been digitized and compiled by Bennet (2012). One of our main variables, town populations c.1680, comes from Langton (2000), who estimates populations from sources like the Hearth Tax. The populations of 567 major towns in every decade from 1841 to 1911 derive from Law (1967) and Robson (2012), and our digitization of populations for more than 100 towns. The latter require assumptions about which parishes and townships constitute towns, nevertheless they are based on accurate census sources.³² Populations from 1560 are drawn from Clark and Hosking (2005) and Wrigley (1985). They are available for a subset of towns. As we show in Online Appendix A,

³⁰ In Online Appendix D, we match towns with their closest coastal supplier and report their coal price ratios. We then compare the price ratios with 1680 and 1830 trade costs using coal as the producer price.

³¹ The new urban dataset is described in detail in Online Appendix A.

³² Law, Robson, and Langton make different assumptions on which parishes and townships should be combined in the census, and thus town populations in 1841 can differ between the sources (see Bennet 2012).

population levels in 1680 and population growth from 1680 to 1841 are similar in the sub-sample with 1560 population and the full sample.

In building our transport model, we selected 590 towns in this dataset whose population would at some point exceed 2,500 in either 1680, 1801, or 1841, according to Langton's data. Thus, we have trade costs between 590 sizable towns. One caveat is that 125 of these towns have no estimated population in 1680, while they have recorded population in 1841. In some estimations, we use the set of 461 towns with non-missing populations in both 1680 and 1841, and in others we use 586 towns with non-missing population in 1841.

The dataset establishes several facts about the population of towns in England around 1680. While London and 7 other towns had a population over 10,000, most had less than 2,500. The mean population was approximately 2,200. By 1841 many towns had grown much larger. The mean population was approximately 15,200 then. Figure 3 compares the geography of town populations in 1680 and 1841. Towns in the west midlands and northwest grew significantly by 1841. For example, Manchester and Liverpool's population grew from approximately 2,500 to 300,000. More generally, our data suggest there was population convergence from 1680 to 1841. The coefficient of variation (CV) in population across 461 towns was 6.49 in 1680. The CV falls to 6.16 for the same 461 towns in 1841. We also find a negative and significant correlation between town i 's 1680 population and its population growth from 1680 to 1841. Together these statistics indicate population convergence across towns, one outcome in urban growth (see Duranton and Puga, 2014).

Urban populations continued to grow up to 1911. With our dataset, we can quantify growth after 1841 for 568 towns. The mean population increased from around 14,600 in 1841 to 46,000 in 1911. We also find some population divergence in this later period. The coefficient of variation (CV) for town population was 6.21 in 1911, whereas the CV is 6.10 in 1841. There is also no evidence for beta convergence after 1841, where smaller towns grew faster than larger towns.

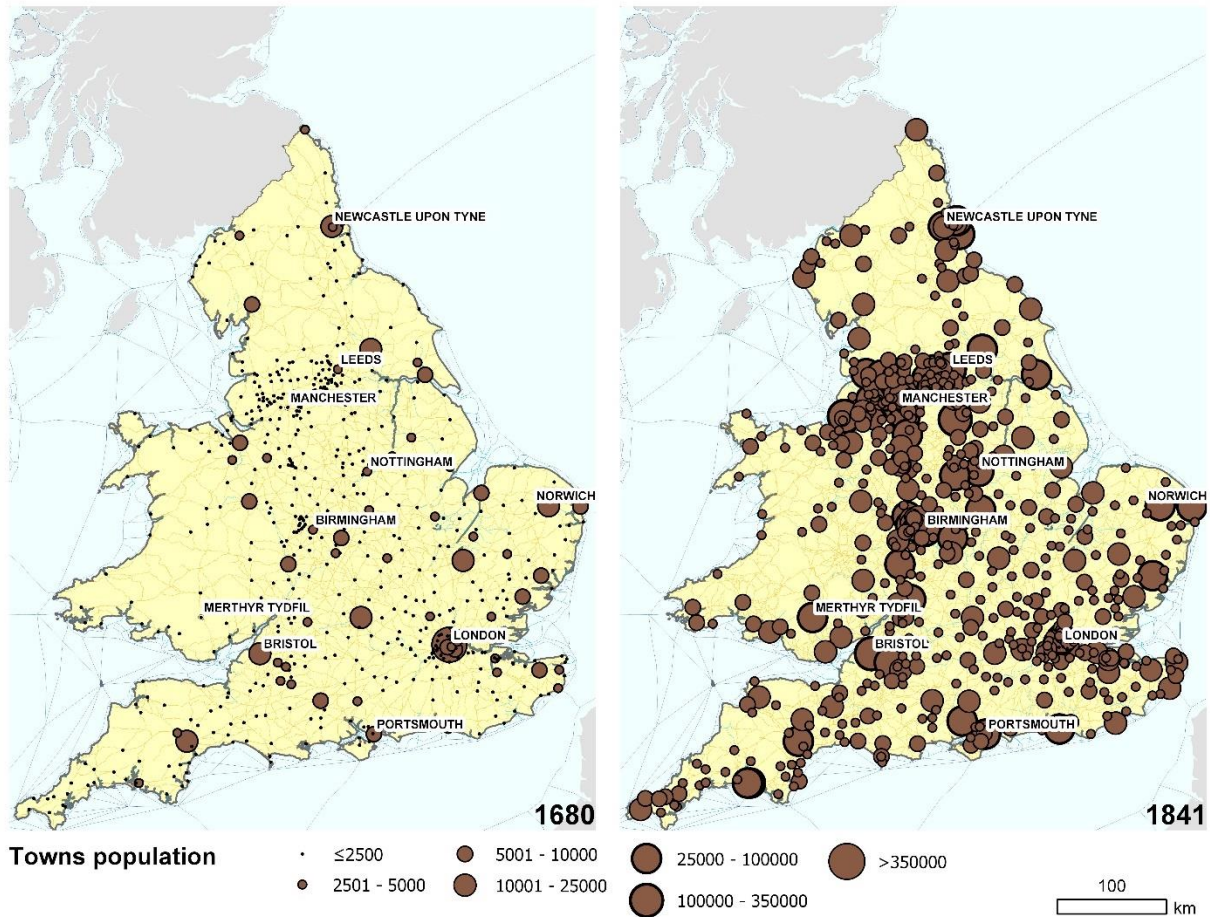


Fig. 3: English and Welsh town populations in 1680 and 1841

Notes: These maps show populations of 461 towns in our sample. See text and Online Appendix A for details.

In the literature, there are several explanations for varying urban growth up to 1841.³³ 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; Sugden *et al.*, 2023). Having access to water is another emphasized natural advantage as it provided sources of power. Another explanation is that some 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). There is another explanation for urban growth which we emphasize: well-developed transport connections. Towns were able to attract migrants if they had cheaper food and fuel, which

³³ Stobart (2000) provides a good overview of a large historical literature.

depended on transport connections. Towns were able to provide more employment if their firms could sell to more locations, which again depended on their transport connections.

Our data on trade costs illuminates the role of transport connections in urban growth. According to the trade literature, trade costs affect ‘market access,’ generally the distance-weighted sum of the market capacities of trading partners (Redding and Venables, 2004). We start with a common measure: $MA_i = \sum_j pop_j \tau_{ij}^{-\theta}$, where in our case i is a town, pop_j is the population of other towns j , indexed from $j = 1, \dots, n$, and τ_{ij} are trade costs between i and j , and θ is a scaling parameter greater than 1. Notice that low trade costs to larger towns increase market access more than low trade costs to small towns. A large θ reduces market access generally. Once θ is selected, market access for town i is calculated by multiplying the $1 \times n$ vector $pop = (pop_1, pop_2, \dots, pop_n)$ by the $n \times 1$ i 'th row of the trade cost matrix τ to the power $-\theta$. For 1680 MA_i , we use trade costs τ_{ij} and 461 town populations from that date. For 1830 we use trade costs and 461 populations in 1841.³⁴ Note, going forward we call $MA_i = \sum_j pop_j \tau_{ij}^{-\theta}$ the simplified formula for market access. Later, we use a more complex market access formula derived from a trade model.

As a preview of the data patterns, we show that changes in the simplified expression of town market access are statistically associated with increased town population from 1680 to 1841. Panel A of Table 2 reports the correlation between $\Delta \ln pop_i$, the difference between i 's natural log 1841 population and its natural log 1680 population, with $\Delta \ln MA_i$, the difference between i 's natural log 1830 market access and its natural log 1680 market access. Here, and throughout, we omit the own town population term $pop_i \tau_{ii}^{-\theta} = pop_i$ of market access to avoid a mechanical connection with i 's population. Also MA_i is calculated for four common values of $\theta = 1, 2, 4, \text{ and } 8$. The correlation between $\Delta \ln pop_i$ and $\Delta \ln MA_i$ is always positive and statistically significant, indicating that population growth and market access growth are correlated regardless of θ . In Online Appendix E, we also show that the mean for the variable

³⁴ Online Appendix E describes the calculations of market access. The eleven-year gap between trade costs and population will create some error, but it is unlikely to matter as railways had not yet penetrated the economy.

$\Delta \ln pop_i$ is 0.30 larger for towns with above median $\Delta \ln MA_i$, and the distribution is shifted to the right (higher population growth) for towns with above median market access growth.

Table 2: Correlation between simplified market access and important town variables

| Panel A: Correlation between $\Delta \ln pop_i$ and $\Delta \ln MA_i$ | | | | |
|---|----------|----------|----------|----------|
| Assumed θ for MA_i | 1 | 2 | 4 | 8 |
| Correlation coeff. ρ | 0.166*** | 0.171*** | 0.173*** | 0.154*** |
| Panel B: Correlation between $\ln pop_{i1911}$ and $\ln MA_{i1830}$ | | | | |
| Assumed θ for MA_i | 1 | 2 | 4 | 8 |
| Correlation coeff. ρ | 0.333*** | 0.362*** | 0.394*** | 0.425*** |
| Panel C: Correlation between natural log 1842 town property income and $\ln MA_{i1830}$ | | | | |
| Assumed θ for MA_i | 1 | 2 | 4 | 8 |
| Correlation coeff. ρ | 0.218*** | 0.240*** | 0.258*** | 0.279*** |

Notes: In this table, i refers to a town, $\Delta \ln pop_i$ refers to the difference in natural log 1841 and log 1680 population, $\ln pop_{i1911}$ refers to natural log 1911 town population, MA_i refers to market access calculated using the simplified formula, $MA_i = \sum_j pop_j \tau_{ij}^{-\theta}$ omitting own town i population, $\Delta \ln MA_i$ refers to the difference in natural log 1830 and log 1680 market access, and $\ln MA_{i1830}$ is log market access in 1830. See text for more details. When accounting for missing values, the sample size in panel A is 461, in panel B the sample size is 569, and in panel C it's 556. *, **, and *** represent statistical significance at the 10, 5, and 1% levels.

We also calculate market access for 586 towns in our sample using their observed 1841 population and our figures for 1830 trade costs. In panel B, we preview later findings in showing that log market access in 1830 is positively and significantly correlated with log 1911 population across all θ values 1, 2, 4, and 8. In Online Appendix E.1, we also show the average 1911 population is 71 log points (103% more) if towns have above median market access in 1830.

In Panel C, we preview results for property income. 1843 is one of the first years where property income was accurately assessed by fiscal authorities. The data are reported for each parish or borough and include total annual property income, and separately for 11 categories, including housing. We digitize these for our sample of towns with trade costs.³⁵ In panel C, we show there is a positive and significant correlation between 1843 property income and 1830

³⁵ We use the Total Annual Value of Real Property of each Parish of each county in England and Wales assessed to the Property and Income Tax for the year ending 1843 (see British Parliamentary Papers 1842-43). The 11 categories are land, housing, tithes, manors, fines, quarries, mines, ironworks, fisheries, canals, and railways.

market access (in logs). To our knowledge, this is one of the few correlations between market access and a measure of urban land values in a pre-railway economy (see Heblich *et al.*, 2020).³⁶

Besides establishing the effects of market access on individual towns, we are also interested in how changing trade costs affected the population distribution across all towns. Estimating such effects requires the use of general equilibrium trade models extended to economic geography settings. We now turn to such models to set up our empirical analysis.

2.A Theoretical framework

In the standard trade and geography model, households choose their location based on wages, prices for goods, and rents.³⁷ 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, which in turn raises house prices, generally until real wages are equalized. On the production side, firms rent land and hire labor to produce a unique product variety (greater variety is valued by consumers). 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. The fixed supply of land is a constraint on the concentration of production and population, and acts as a dispersion force.³⁸

For our analysis, we use Donaldson and Hornbeck's (2016) theoretical framework. It includes the main assumptions of the standard trade models, but keeps the framework simple, omitting intermediate goods and assuming symmetric trade costs between locations. It also arguably fits our early industrial setting. Summarizing, they derive an expression for equilibrium population and market access in each location $i = 1, \dots, n$. The first equation is

$$\ln pop_i = \kappa_1 + \kappa_2 \ln MA_i + \kappa_3 \ln A_i + \kappa_4 \ln L_i \quad (1)$$

³⁶ In Appendix E.1, we show 1843 property income is 31% higher for towns with above median 1830 market access.

³⁷ We refer the reader to Helpman (1998), Eaton and Kortum (2002), Redding and Venables (2004), Redding and Sturm (2008) for some foundational works.

³⁸ There are extensions of the standard model as in Allen and 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 applicable for an early industrial England and Wales.

where $\ln pop_i$ is natural log population in i , κ_j 's are collections of the model's parameters, $\ln MA_i$ is log market access for i , $\ln A_i$ is log productivity (generally unobserved), and $\ln L_i$ is log land area, assumed to be fixed.³⁹ The parameter of interest is κ_2 , empirically it is the elasticity between market access and population. The second equation gives market access for each i :

$$MA_i = \kappa \sum_j^J (\tau_{ij}^{-\theta} pop_j) * MA_j^{-(1+\theta)/\theta} \quad (2)$$

where κ is a parameter, pop_j is the population of location j , indexed from $j = 1, \dots, n$, τ_{ij} are trade costs between i and j , and θ is a parameter greater than 1 measuring the inverse variation in productivity across locations.⁴⁰ In (2), the first summation term $\tau_{ij}^{-\theta} pop_j$ is the same as the simplified market access. It implies that market access for i is higher when it has low trade costs to more populated locations all else equal. The second term $MA_j^{-(1+\theta)/\theta}$ implies that as the market access of other locations j increases, then MA_i decreases, which is due to the higher competition in j . It allows for reallocation effects from different trade costs.

Observe that population and market access in the whole economy are defined by the system of equations (1) and (2) for every location $i = 1, \dots, n$. One implication is that any change in trade costs will result in a new equilibrium distribution of population. For example, a reduction in trade costs between locations i and j will increase their populations as they are able to trade more, making them attractive locations for consumers and firms. The lower trade costs between i and j also affects populations of locations that previously traded more with i and j . The direction and degree of change depends on the strength of agglomeration and dispersion forces.

We apply this theoretical framework to estimate how changes in trade costs from 1680 to 1830 affected urban population across the entire English and Welsh economy. First, we estimate a coefficient like κ_2 in equation (1), giving the elasticity between market access and population. We focus on a specification where the outcome is the difference in town 1841 and 1680 population (in logs) and the key explanatory variable is the difference in town 1830 and 1680 MA_i (in logs). Second, in a counterfactual we quantify how the spatial structure of the

³⁹ In related theoretical models, A_i could be interpreted as a city specific amenity (see Redding and Sturm 2008).

⁴⁰ As explained by Donaldson and Hornbeck (2016), the parameter θ captures the scope for comparative advantage. A low θ means productivity draws are dispersed, creating larger incentives to trade.

1841 urban economy would change if 1830 trade costs were replaced with 1680 trade costs, and all else was the same.

In practice, we calculate MA_i in 1680 and 1830 by solving a system of n non-linear equations specified by (2), after choosing $\theta = 2$ and $\kappa = 1$. In both years, we use the sub-sample of 461 towns with non-missing populations and baseline trade costs in 1680 and 1830. As above, own town population i is omitted from i 's market access. $\kappa = 1$ is a normalization. For θ we calculate simplified market access for different values and estimate our preferred specification in section 3 using maximum likelihood. $\theta = 2$ had the highest log likelihood value, and therefore it is our baseline (see Online Appendix E for more details).

The values of MA_i , derived from the model equation (2), are mapped in Figure 4 for each town and year. In 1680 MA_i was relatively high near London and along the east coast. Elsewhere, it was much lower, often less than 20% of the east coast. By 1830, the level and distribution of MA_i changed dramatically, increasing the most inland and in the northwest. On average, market access increased by 461% from 1680 to 1830. In Appendix E, we show MA_i growth from 1680 to 1830 is positively and significantly correlated with town population growth, 1680 to 1841. We also show MA_i from (2) is highly correlated with values from the simplified access formula $\sum_j^J pop_j \tau_{ij}^{-\theta}$, which is reassuring. Yet, it is lower on average, as MA_i is decreasing in other towns' MA_j , a key feature in our context. We prefer using the theoretically derived MA_i in our estimation and counterfactual, but the simplified formula is useful for robustness checks and in constructing our instrument explained in the next section.

Two final remarks on the theory. First, market access should also affect land rents in towns. Donaldson and Hornbeck (2016) give the following expression for rents q_i at location i

$$\ln q_i = \kappa_4 + \kappa_5 \ln(A_i/L_i) + \kappa_6 \ln MA_i \quad (3)$$

where (A_i/L_i) captures land productivity and MA_i is market access as in equation (2). We apply this expression to estimate the effect of 1830 market access on town property or housing income in 1843. The magnitude of this estimate is important as it captures income effects. Second, the theoretical expressions for population (1) reflect equilibriums, however, some

urban models assume populations in year t are still adjusting to fundamental factors from previous years (Duranton and Puga, 2014). In extensions, we build on this and estimate effects of 1830 market access on town populations up to 1911, while controlling for other factors.

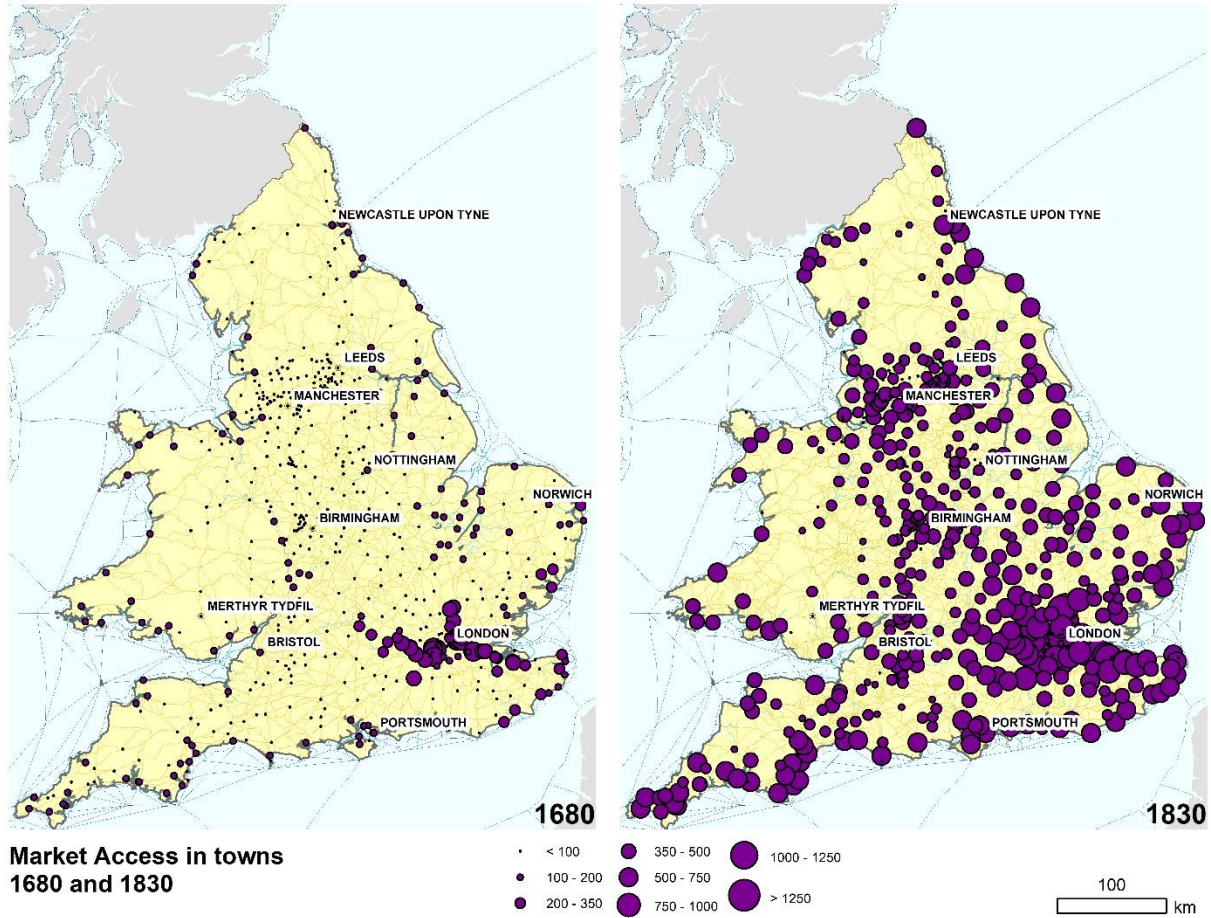


Fig. 4: Estimated market access for towns in 1680 and 1830.

Notes: Market access for 461 towns derived from model equation (2) with $\theta = 2$, omitting own town population. Note 1830 uses 1841 town population.

3. Estimated effects of market access on town population, 1680 to 1841

We start with a specification given by equation (4):

$$\Delta \ln pop_i = \beta \Delta \ln MA_i + \gamma \cdot x_i + \varepsilon_i \quad (4)$$

where i are towns, $\Delta \ln pop_i = \ln pop_{i1841} - \ln pop_{i1680}$, $\Delta \ln MA_i = \ln MA_{i1830} - \ln MA_{i1680}$, and x_i is a vector of controls. Equation (4) is equivalent to a two-period, fixed effects panel regression with $\ln pop_{it}$ and $\ln MA_{it}$ being the variables for town i in period t and the controls

x_i interacted with the single time-period fixed effect. (4) is also analogous to the theoretical equation for population (1), where the time-invariant aspects are eliminated by differencing.

The controls x_i address potential confounders. We always include a 2nd order polynomial in town latitude and longitude coordinates to flexibly address the spatial patterns of population growth. We further 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. These variables are made from linking towns to a database of 9700 spatial units, comprised of parishes and townships.⁴¹ This linked dataset also gives us distance to local infrastructure like inland waterways, turnpike roads, railways stations, and steamship ports.

We further address confounders by including 16 controls drawn from Richard Blome's *Britannia*, originally published in 1673 (see Blome 1962 reprint). 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, was a port of significance, or was on a main road. Some are also political, like whether the town was represented in parliament. We call them 'pre-industrial revolution' controls as they date from 1673. One limitation is that 73 sample towns are absent in Blome's individual town summaries, from which the variables are made, or missing altogether. Rather than omit them, we create dummy variables for missing summary and missing altogether. We then give the same arbitrary values for all Blome variables to each missing type. Online Appendix A and E gives more details on these controls.

Finally, in our preferred specifications we add fixed effects for the 54 counties in England and Wales where each town was located. They address unobserved heterogeneity across counties. We also cluster on counties to address within-county correlation in the standard errors. Before turning to the results, we should add that additional variables which

⁴¹ See Bogart, You, Alvarez, Satchell, and Shaw-Taylor (2022) for details on spatial units and their variables. The Exposed coalfields come from Satchell and Shaw-Taylor (2013). Rainfall and temperature come from the FAO and are averaged from 1961 to 1990. While they are recent, variation in rainfall and temperature across English and Welsh towns was likely to have been similar in the late 18th century as 1961 to 1990.

change after 1680 are not included as they could be the result of market access. However, our rich set of geographic and pre-industrial controls should capture some determinants of endogenous structural changes, for example the creation of banks.⁴²

Table 3 reports ordinary least squares (OLS) regression estimates for β in equation (4) using MA_i calculated from (2) in the theoretical framework. The baseline estimating sample has 448 towns, which have unique values for all the geographic controls.⁴³ The estimates imply a significant effect of market access on town population. In column (col.) 1, we report a bivariate regression. In col. 2, we add the 2nd degree polynomial in latitude and longitude and 6 other geographic variables. The coefficient is nearly the same as col. 1 (see Online Appendix Table G1 for all estimates). In col. 3, pre-industrial revolution controls are added. The coefficient for $\Delta \ln MA_i$ gets larger, and the standard errors remain similar. Our interpretation is that pre-industrial characteristics 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 includes county fixed effects. The coefficient is smaller than in col. 3, but it remains statistically significant at the 5% level. In col. 5, we weight observations by log 1680 population. The estimates are little changed. In Online Appendix Table G2, we report Conley Standard Errors addressing spatial correlation within various distances. They are close to our standard errors clustered on counties, mostly smaller. In Appendix Table G3, we replicate Table 3 using the simplified formula: $MA_i = \sum_j^J pop_{jt} \tau_{ijt}^{-2}$. The coefficients are very similar.

Table 3: Effect of market access on town population change: baseline OLS estimates

| VARIABLES | (1) | (2) | (3) | (4) | (5) |
|---------------------------|--------------------|---------------------|----------------------|---------------------|---------------------|
| $\Delta \ln MA_i$ | 0.173* (0.0926) | 0.180** (0.0772) | 0.240*** (0.0755) | 0.205** (0.0920) | 0.189** (0.0912) |
| Observations | 448 | 448 | 448 | 448 | 448 |
| R-squared | 0.015 | 0.269 | 0.321 | 0.456 | 0.454 |
| Lat. Lon. & Geo. Controls | NO | YES | YES | YES | YES |
| Pre-IR controls | NO | NO | YES | YES | YES |

⁴² For example, Heblich and Trew (2019) use postal roads to instrument for c.1820 financial employment or banks.

⁴³ We drop from our main estimation 13 towns which shared a linked spatial unit with a town that had a larger 1680 population. Thus, they will have the same geographic variables as the larger town, which we want to avoid. As we show in Table H4, Online Appendix H, our results are similar if we include these 13 towns.

| | | | | | |
|---------------------------|----|----|----|-----|-----|
| County FEs | NO | NO | NO | YES | YES |
| Weight obs. by lnpop_1680 | NO | NO | NO | NO | YES |

Notes: The dependent variable is natural log 1841 pop. minus log 1680 pop. $\Delta \ln MA_i$ refers to the difference in natural log 1830 and log 1680 market access. MA_i is calculated using model equation 2 with $\theta=2$, omitting own town population. Latitude and longitude enter as a 2nd order polynomial. For description of Geo. and Pre-IR controls see text and Online appendix A and E. Standard errors clustered on the county are reported. *, **, and *** represent statistical significance at the 10, 5, and 1% levels.

There may be a concern that estimates in Table 3 are biased, even with the rich controls. Specifically, the selection of infrastructure connections throughout the network for town i might be correlated with the unobservable factors affecting the population growth of town i , which are contained in the error term ε_i . The direction of this potential bias is unclear. Towns which shared positive unobserved productivity changes, increasing their population, might be more likely to get connections with one another (positive network selection). On the other hand, towns which had no unobserved productivity change might have been more attractive in route selection as their land was cheaper for infrastructure builders.

Three alternative market access variables help address concerns about bias. For ease of calculation, all modify the simplified formula to calculate $\Delta \ln MA_i$. 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 that $\Delta \ln MA_i$ now captures the effects of reducing trade costs to towns that were populous in 1680. The second alternative restricts the accessed towns j to be more than 50 km from 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. The third alternative is similar to the second but also restricts the accessed towns j to be one of 72 custom ports with at least 1 entering ship involved in foreign trade in 1791.⁴⁴ The formula is $MA_{it} = \sum_j^J D_{ij}^{far} D_{ij}^{port} pop_{jt} \tau_{ijt}^{-2}$, where D_{ij}^{port} is an indicator if town j was linked to one of 72 custom ports. As these towns were international, it is unlikely they had common unobserved productivity changes with far towns in England. In addition to using these

⁴⁴ We identified these ports using the National archive records. For linking to towns see Online Appendix A.4.

alternative market access variables, we also estimate specifications adding controls for local infrastructure, like distance to inland waterways, turnpike roads, and railway stations in 1831.

The estimates for alternative market access variables are reported in Table 4. All specifications include geographic, pre-industrial characteristics, and county fixed effects as controls. Briefly stated, the coefficients are quite similar to Table 3. For example, including local infrastructure connections, like log distance to 1831 railway stations, does not alter the estimate (col. 2 and 3). The same when the market access formula fixes population at 1680 levels (col. 4). There is a slightly larger effect when the access formula restricts to towns that were more than 50 km away or to towns that were foreign shipping ports (see col. 5 and 6.) The latter makes sense as such towns were connections to the international economy. Moreover, the largest ports for foreign shipping were generally the most populous cities, making them large domestic markets.⁴⁵

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

| VARIABLES | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---------------------|----------------------|----------------------|----------------------|----------------------|----------------------|
| $\Delta \ln MA_i$, simple | 0.194** (0.0735) | 0.213*** (0.0754) | 0.212*** (0.0764) | | | |
| $\Delta \ln MA_i$, fix 1680 pop. | | | | 0.209*** (0.0758) | | |
| $\Delta \ln MA_i$, towns > 50 km. | | | | | 0.245*** (0.0752) | |
| $\Delta \ln MA_i$, foreign ports > 50 km | | | | | | 0.228*** (0.0705) |
| Observations | 448 | 444 | 444 | 448 | 448 | 448 |
| R-squared | 0.457 | 0.472 | 0.472 | 0.458 | 0.460 | 0.461 |
| New Controls | | | | | | |
| Log dist. 1830 roads and waterways | NO | YES | YES | NO | NO | NO |
| Log dist. 1831 rail stations | NO | NO | YES | NO | NO | NO |

Notes: The dependent variable is natural log 1841 pop. minus log 1680 pop. $\Delta \ln MA_i$ refers to the difference in natural log 1830 and log 1680 market access. In columns 1 to 3 we use the simplified formula for MA_i with $\theta=2$. In column 4 we again use simple MA_i with $\theta=2$, but fix population at 1680 levels for 1830 MA_i . In column 5 we again use simple MA_i with $\theta=2$, but restrict the access formula to the population of towns j more than 50 km from town i . In column 6 we again use simple MA_i with $\theta=2$, but restrict the access formula to population for towns j that have foreign ships entering their ports and are more than 50 km from i . See text for more description of alternative MA_i . All regressions include a 2nd order polynomial in latitude and longitude, geographic controls, pre-industrial revolution controls, and county fixed effects. Standard errors are clustered on

⁴⁵ Fajgelbaum and Redding (2024) have a related finding for Argentina that locations closer to international markets have higher population densities and experience structural change.

county. *, **, and *** indicates statistical significance at the 10, 5, and 1% levels.

We further address endogeneity using two instrumental variables. The first is the added market access to towns more than 50 km away and incidentally connected to the 1779 Grand Cross Plan.⁴⁶ To illustrate, the 17 canals and river navigations in the 1779 Plan that were built or completed by 1830 are shown in Figure 5, along with all towns in our data. It is based on a map by Hugh Henshall and John Cary, shown in Online Appendix B.⁴⁷ The history suggests that some towns along the routes were targeted for their use of the canal, but for many it was due to engineering and construction. Some towns were on the flattest or shortest route between the major river basins and centers. Land costs were a factor in canal route selection, as canal companies avoided houses and valuable buildings. A town might be near the route because neighboring villages had more available land or resources for water reservoirs (Hadfield, 1968; Harvey-Fishenden and Macdonald, 2021).

For the instrument, we developed a strategy to identify towns near the waterways in the Plan that were not targeted to directly use them. We define ‘incidentally connected’ towns as having two characteristics. (i) They were within 2.5km distance of the built version of the 17 waterways depicted in the 1779 Henshall and Cary Map. (ii) Either towns were not named on the 1779 Map, or they were named but not depicted as being directly on the route in the Map. We assume either feature in (ii) meant the town was not targeted. In Online Appendix F, we list the 17 incidental towns with non-missing 1680 population. All but one had a population of less than 2,000. Appendix F also reports balance tests showing incidental towns were statistically no different from others in their 1680 population and all pre-industrial revolution controls except one. Their geography controls are more different, as expected if they were selected due to engineering and construction.

The instrument based on the Plan uses simplified market access and is defined by (5)

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.

⁴⁷ The engineer Brinley provided the conceptual framework for the Grand Cross, and various engineers connected with Brindley did the work, while being hired by several canal companies (Hadfield 1968, p. 50).

$$IV_i = \ln [\sum_j^J D_j^{far} D_j^{inc} pop_{j1680} \tau_{ij1830}^{-2}] - \ln (\sum_j^J pop_{j1680} \tau_{ij1680}^{-2}). \quad (5)$$

where D_j^{inc} is an incidental indicator equal to 1 for town j if characteristics (i) and (ii) above are met, D_j^{far} is an indicator if town j was more than 50 km from i , τ_{ij1830} and τ_{ij1680} are trade costs in 1830 and 1680. 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 log term is simplified market access in 1680, which is why we say (5) gives added market access from far, incidentally connected towns. We expect the instrument to have high relevance for $\Delta \ln MA_i$ as incidental towns got an extra reduction in trade costs being near Cross Plan canals. Exclusion of the instrument is defensible as there is no reason to think connections between incidental towns and any town i more than 50 km away were selected.

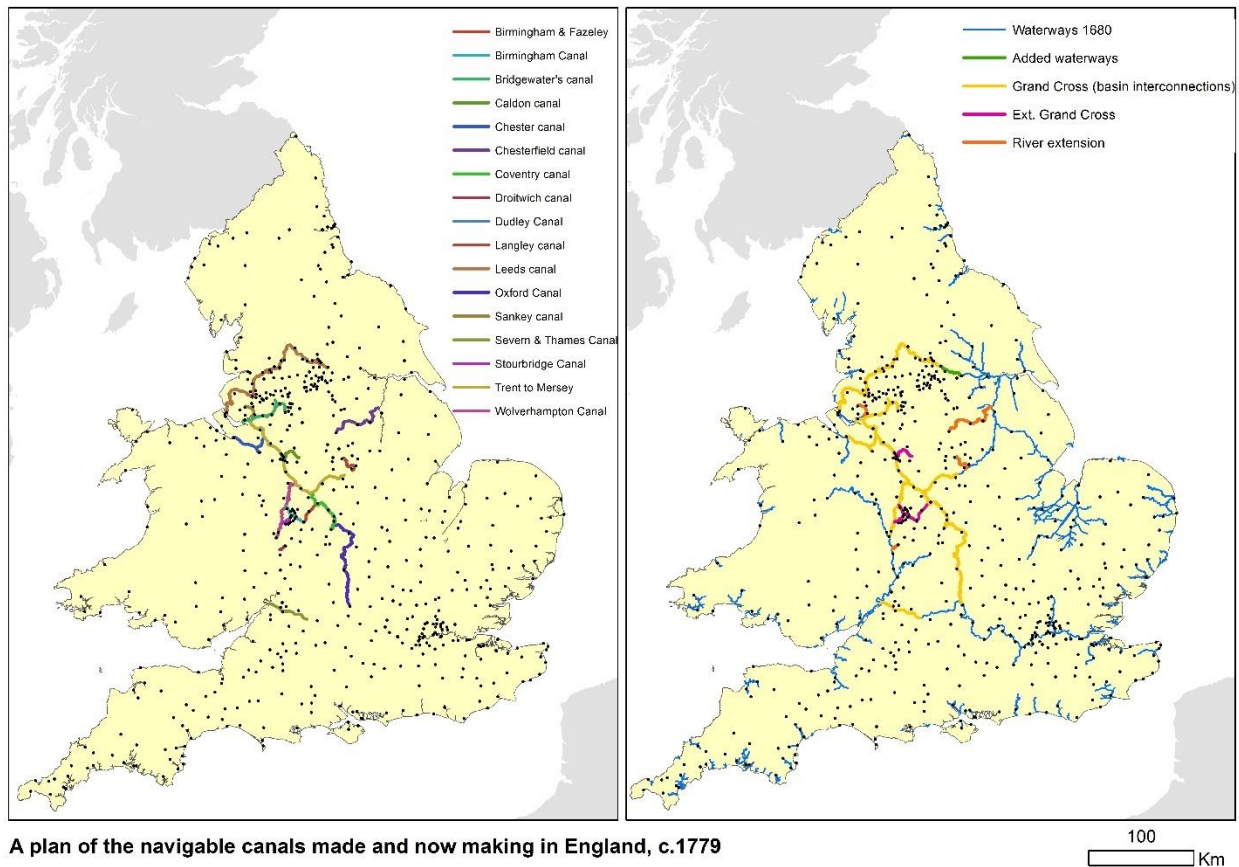


Fig. 5: Representation of inland waterways built in Grand Cross Plan 1779 (left), with classification and waterway connections (right)

Notes: This map is the authors' representation of canals made by 1830, which are described in Henshall and Cary's 1779 Map. The latter can be seen in Appendix B and at: <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 log distance to the main 1680 inland waterways, shown in blue in the right panel of 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).⁴⁸ Exclusion is defensible on the grounds that distance to 1680 waterways is determined by geography and in our baseline we control for whether a town is directly next to a navigable river by 1673 (one of our pre-industrial revolution variables).

Table 5 shows the second stage IV estimates, where the endogenous variable is the log change in market access derived from model equation (2). First stage estimates are shown in Online Appendix Table G4. Col. 1 uses the 1779 Canal Plan instrument in (5). It is a strong positive predictor of $\Delta \ln MA_i$, and the Kleibergen-Paap F-stat is very large. The IV coefficient for $\Delta \ln MA_i$ is a little smaller than our preferred OLS in col. 4 of Table 3, but the endogeneity test statistic implies no statistical difference. In col. 2 we use log distance to 1680 inland waterways as the instrument, which is a strong negative predictor of $\Delta \ln MA_i$. The second stage IV estimate is much larger in col. 2 at 0.330. It points to a downward bias in OLS, but the endogeneity test again implies no statistical difference. In col. 3, we use both instruments and find a broadly similar estimate. Additionally, the over-identification test indicates we cannot reject the null hypothesis that the instruments are valid and excluded from the second stage.⁴⁹ Overall, the IV results in Table 5 suggest there is no significant downward bias to our OLS estimates of equation (4).

Table 5: Effect of market access on town population change: instrumental variable estimates

| VARIABLES | (1) | (2) | (3) |
|-------------------|---|--|------------------------------|
| | Instrument: added market access from far incidentally connected towns | Instrument: log distance to 1680 waterways | Instruments: both 1 and 2 |
| $\Delta \ln MA_i$ | 0.194** (0.0832) | 0.330** (0.132) | 0.201** (0.0841) |

⁴⁸ Donaldson and Hornbeck (2016) using a similar instrument based on distance to Great Lakes and rivers.

⁴⁹ Anderson-Rubin weak instr. test stats. have p-values of 0.021, 0.014, and 0.031 in col. 1, 2, and 3 respectively.

| | | | |
|--------------------------------|-------|-------|-------|
| Observations | 448 | 448 | 448 |
| R-squared | 0.183 | 0.179 | 0.183 |
| Lat. Lon. & Geo. Controls | YES | YES | YES |
| Pre-IR controls | YES | YES | YES |
| County FEs | YES | YES | YES |
| Kleibergen-Paap F statistic | 600.1 | 177.5 | 492.4 |
| Endogeneity test stat. p-value | 0.803 | 0.261 | 0.691 |
| Over-id test, p-value | | | 0.166 |

Notes: The dependent variable is log 1841 pop. minus log 1680 pop. $\Delta \ln MA_i$ refers to the difference in log 1830 and log 1680 market access. MA_i is calculated using model equation 2 with $\theta=2$, omitting own town population. The instrument in col. 1 is added market access from far towns incidentally connected to 1779 Canal Plan as expressed in equation 5. The instrument in 2 is log distance to main 1680 inland waterways shown in Figure 5. In col. 3 both instruments from col. 1 and 2 are used. Definitions of controls in text and Table 3. Standard errors are clustered on counties. *, **, and *** indicates statistical significance at the 10, 5, and 1% levels.

We perform several additional robustness checks, which are reported in Online Appendix H and briefly described here. First, we make estimates identical to col. 4 of Table 3, but with simplified MA_i calculated for different values of $\theta=1, 2, 4,$ and 8 . All yield the same qualitative conclusion, while $\theta = 2$ gives the highest R-square (Table H1). Second, we use the difference in 1680 and 1560 population (in logs) as the dependent variable. The results, available for 155 towns, show no precisely estimated effect of market access with all our controls (Table H2). Third, we calculate trade costs based on a producer price that weighs coal prices at 0.6 and grain prices at 0.4. The estimates for the resulting $\Delta \ln MA_i$ are similar (Table H3). Fourth, we omit from the sample (1) towns with population below 500 or above 5000 in 1680, (2) towns in the top 1% or bottom 1% of population growth from 1680 to 1841, or (3) towns with missing summaries in Blome or missing altogether. The estimates are generally similar (Table H4). Fifth, we find little change when including town i 's population in MA_i (Table H5).

In a sixth robustness check, we consider the role of changes in transport costs, while holding populations and producer prices at 1680 levels. Here we calculate "1830" trade costs as $\tau_{ij1} = tc_{ij1830}/P_{1680} + 1$. Then we estimate the effect of increasing market access through τ_{ij1} compared to our simplified baseline using 1680 trade costs, meaning $\Delta \ln MA_i = \ln(\sum_j^J pop_{j1680} \tau_{ij1}^{-2}) - \ln(\sum_j^J pop_{j1680} \tau_{ij1680}^{-2})$. Online Appendix Table H7 shows there is a

positive and significant effect of this $\Delta \ln MA_i$ on population growth, with a similar coefficient to Table 3.⁵⁰ Thus, transport cost changes were central to the market access effects we identify.

Based on all these specifications, we believe 0.193 is a reasonable lower bound estimate for the elasticity of market access with respect to population. This coefficient implies that a town experiencing the average change in $\Delta \ln MA_i$, 1.724, would increase its population by 33.2 log points, or a 39.4% increase in population from 1680 to 1841. However, this estimate is larger than the impact of experiencing the average reduction in trade costs, all else equal, because populations of other towns are also changing due to other factors, which enter $\Delta \ln MA_i$ as well. The effect of lower trade costs requires a clearly specified counterfactual, to which we now turn.

3.A Counterfactual with different trade costs

We begin by defining non-market access determinants of town population in 1841, which are fixed in the counterfactual. Applying equation (1) of the model gives us an expression for log town i 1841 population as $\ln pop_{i1841} = \kappa_2 \ln MA_{i1841} + \ln E_{i1841}$, where MA_{i1841} is market access from (2), κ_2 is an elasticity, and $\ln E_{i1841} = \kappa_3 \ln A_{i1841} + \kappa_4 \ln L_{i1841} + \kappa_1$, or the effects of town productivity, land area, and other factors. In the counterfactual, we assume $\ln E_{i1841} = \ln pop_{i1841} - 0.193 \ln MA_{i1830}$, where MA_{i1830} is our measure of market access, derived from equation 2 (using $\theta = 2$), and $\kappa_2 = 0.193$, which is our summary elasticity estimate. We think this ‘residual’ $\ln E_{i1841}$ provides a reasonable approximation to the many factors which determined 1841 population besides market access.

Next, we propose two sets of counterfactual trade costs τ_{ij}^C . First, we assume trade costs do not change at all from 1680 to 1830. In other words, $\tau_{ij}^C = \tau_{ij}^{1680}$ for all pairs i and j , which implies a 178% increase over the baseline 1830 average trade cost $\bar{\tau}$. Second, we use 1680 networks with the 1830 freight rates in Table 1 to calculate counterfactual transport costs tc_{ij}^C . In section 2, we reported that after removing all network changes the average tc_{ij} in 1830

⁵⁰ Online Appendix Table H6 makes the same estimate holding population and transport costs at 1680 levels but allowing producer prices to change by 1830. The effect of market access is generally positive, but less precise.

would be 693 pence instead of 413. Assuming producer prices remained the same in 1830, the resulting counterfactual average trade cost becomes 43% higher than our baseline in 1830.⁵¹

The last step is to express town i 's counterfactual 1841 population, pop_{i1841}^C , and town i 's counterfactual market access, MA_{i1841}^C , with two equations:

$$(i) \text{ } pop_{i1841}^C = MA_{i1841}^C \text{ }^{0.193} E_{i1841} \text{ and (ii) } MA_{i1841}^C = \sum_j^J (\tau_{ij}^C \text{ }^{C-2} pop_{i1841}^C) * MA_{i1841}^C \text{ }^{-3/2}.$$

We solve (i) and (ii) for all $i = 1, \dots, n$, using E_{i1841} and τ_{ij}^C as inputs. Note we should not solve the system of counterfactual market access equations (ii) using pop_{i1841}^C for all j . We should use pop_{i1841}^C , which is a function of MA_{j1841}^C through (i). The procedure for solving these systems is detailed in Online Appendix K. Note in the counterfactual, we choose to calculate pop_{i1841}^C and MA_{j1841}^C for 586 towns where there is observed population in 1841.⁵² Using the full set of towns, we get a more complete picture of urban population change.

Our calculations show some striking differences. We first summarize the counterfactual where it is assumed 1680 trade costs prevailed in the economy of 1841. The average MA_{i1841}^C is 226.7 compared to the average of 398.1 for our baseline MA_{i1830} , indicating an average loss in market access of 43%. We also find the total town population in the economy would be 11.6% lower in 1841 or 0.89 million less from a base of 7.6 million. These former town-dwellers would have presumably stayed in rural areas, as happened in other economies without an early transport revolution. A summary of actual and counterfactual populations in 1841 for the top 20 towns are shown in Table 6. Some lose significant population. For example, industrial Sheffield loses 25%. Others, like London, are similar. Broadly, there is a population redistribution from inland to the coast (see I. vs. C. in Table 6). Bristol and Liverpool, two major ports, would have 8 to 10% lower population. Inland towns like Manchester, Birmingham, and Leeds would have 20 to 25% less. In other words, the large inland towns of 1841 would have been much smaller had trade costs not changed from 1680 to 1830. Online Appendix K gives statistics for all other towns.

⁵¹ There is an implicit assumption here that network size and freight rates are independent, with the latter being driven by other factors, including 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, instead it was mainly technology, see Solar (2013), Kelly and Ó Gráda (2019), Bogart *et al.* (2020), Kelly *et al.* (2021).

⁵² Online Appendix E explains how we estimate market access for 586 towns using model equation (2).

Table 6: Counterfactual populations for top 20 towns if trade costs or networks did not change

| Description of counterfactual | (1) | (2) | (3) | (4) | (5) |
|---|------------------|--|------------------------|--|------------------------|
| | Actual pop. 1841 | No change in trade costs from 1680 to 1830 | | Extension where 1680 networks are kept fixed in calculation of trade costs | |
| Town, (I. for inland, C. for coastal or on 1680 rivers) | Actual pop. 1841 | Counterfactual pop. 1841 | ratio col. 2 to col. 1 | Counterfactual pop. 1841 | ratio col. 4 to col. 1 |
| LONDON, C. | 1,948,417 | 1,896,503 | 0.973 | 1,995,341 | 1.024 |
| MANCHESTER, I. | 311,269 | 248,800 | 0.799 | 280,450 | 0.900 |
| LIVERPOOL, C. | 286,487 | 259,886 | 0.907 | 280,038 | 0.977 |
| BIRMINGHAM, I. | 182,922 | 138,388 | 0.756 | 156,458 | 0.855 |
| LEEDS, I. | 152,074 | 118,442 | 0.778 | 133,187 | 0.875 |
| BRISTOL, C. | 125,146 | 115,486 | 0.922 | 122,921 | 0.982 |
| SHEFFIELD, I. | 111,091 | 83,582 | 0.752 | 95,933 | 0.863 |
| WOLVERHAMPTON, I. | 93,245 | 75,073 | 0.805 | 82,827 | 0.888 |
| NEWCASTLE U. TYNE, C. | 70,337 | 66,354 | 0.943 | 69,744 | 0.991 |
| HULL, C. | 67,308 | 64,186 | 0.953 | 66,285 | 0.984 |
| BRADFORD, I. | 66,715 | 50,536 | 0.757 | 57,593 | 0.863 |
| NORWICH, C. | 61,846 | 60,033 | 0.970 | 61,328 | 0.991 |
| NEWINGTON, C. | 54,606 | 52,525 | 0.961 | 53,688 | 0.983 |
| SUNDERLAND, C. | 53,335 | 50,009 | 0.937 | 52,837 | 0.990 |
| BATH, I. | 53,196 | 40,283 | 0.757 | 46,587 | 0.875 |
| PORTSMOUTH, C. | 53,032 | 50,532 | 0.952 | 52,547 | 0.990 |
| NOTTINGHAM, C. | 52,360 | 49,606 | 0.947 | 50,458 | 0.963 |
| BOLTON, I. | 51,029 | 41,008 | 0.803 | 46,521 | 0.911 |
| PRESTON, I. | 50,887 | 46,771 | 0.919 | 49,980 | 0.982 |
| LEICESTER, I. | 50,806 | 37,809 | 0.744 | 43,165 | 0.849 |

Notes: Authors' calculations from counterfactual models. See text and Online Appendix K for details.

The second counterfactual is designed to quantify the impact of not changing networks, specifically not adding inland waterways and not building new roads. We estimate the total town population would have been 4.6% lower in 1841 had networks remained fixed at 1680, and all else was the same. Col. 4 in Table 6 shows populations for the top 20 towns as a result. Inland towns, like Birmingham, Wolverhampton, and Sheffield, lose the most as they were especially dependent on the canal network. Coastal towns generally lose less population, and some—like London—are even larger. Thus, without network change, the redistribution of population from inland to the coast continues to be significant.

For robustness, we also repeat the counterfactual using a simplified access formula,

$MA_{i1841}^C = \sum_j^J (\tau_{ij}^{C-2} pop_{i1841}^C)$ in (ii). As discussed in Online Appendix K, the counterfactual

1841 populations with 1680 trade costs are even lower. However, the simplified formulation of market access could overstate the impact, and therefore we emphasize the estimates above.

In summary, we find that without any change in trade costs from 1680 to 1830 there would have been an 11.6% reduction in the total population of towns in 1841, along with substantial redistribution from inland to the coast. Just under half of the effect is associated with network change. It is worth stating that our 586 towns constitute a total population of 7.75 million in 1841, while the total population of England and Wales (E&W) was 18.55 million in that year. It is likely that with higher trade costs, equal to 1680 levels, the total population of E&W would have been lower too, but we think the primary effect would be to make the economy more rural and less urban.

4. Effect of 1830 market access on town population decades after 1841

In our first extension, we demonstrate that urban market access in 1830 contributed to town population growth decades after 1841, indicating a persistent effect. We use the sample of more than 500 towns with population data from 1841 to 1911 and estimate the following:

$$\ln pop_{i1911} = \lambda \ln pop_{i1841} + \beta \ln MA_{i1830} + \gamma \cdot x_i + \varepsilon_i \quad (6)$$

where the dependent variable is $\ln pop_{i1911}$, the natural log of 1911 town population, and MA_{i1830} is market access derived from model equation (2) using the 1841 population of 586 towns, 1830 trade costs, and $\theta = 2$.⁵³ In this specification, market access in 1830 is treated as one factor which determines population size in the long-run, but which has not fully impacted town population by 1841, which serves as a control.⁵⁴ The β coefficient on $\ln MA_{i1830}$ would be the same if we subtracted $\ln pop_{i1841}$ from both sides of (6) and estimate $\ln pop_{i1911} - \ln pop_{i1841}$ as the dependent variable. The only coefficient that would change is on $\ln pop_{i1841}$, which becomes $(\lambda - 1)$. The variables x_i capture other factors, which can influence the long-run population size. As this period involved the transition to steam-powered transport, two natural variables are the distance to the nearest railway station in 1841 and distance to the nearest of

⁵³ Summary statistics for these variables are provided in Online Appendix E.

⁵⁴ Similar specifications have been used to estimate effects of infrastructure levels on subsequent urban growth, see Duranton and Turner (2012) as an example.

the 5 major steamship ports in 1841 (Bristol, Hull, Liverpool, London, or Southampton). They are added to town geographic and pre-industrial controls, along with county fixed effects.

Identification in (6) requires that $\ln MA_{i1830}$ is uncorrelated with the error term conditional on $\ln pop_{i1841}$ and control variables x_i . As this is a strong assumption, we also use an instrumental variable similar to equation 5: $\ln[\sum_j D_{ij}^{far} D_j^{inc} pop_{j1680} \tau_{ij1830}^{-2}]$. We call this the Plan Levels instrument (IV). Note that it uses 1830 trade costs τ_{ij1830} with 1680 populations of incidentally connected towns that were far from i through the term $D_{ij}^{far} D_j^{inc} pop_{j1680}$.⁵⁵ Building on the findings in Table 5, the relevance of the Plan Levels IV for $\ln MA_{i1830}$ should be high. Likewise, it is arguably excludable as 1830 trade costs to far, incidentally connected towns should be independent of unobservable factors influencing town i 's population in 1911 conditional on $\ln pop_{i1841}$ and control variables x_i .

The estimates of specification (6) are shown in Table 7.⁵⁶ In col. 1, without any controls, the coefficient on $\ln MA_{i1830}$ is positive and significant. Col. 2 gives a noteworthy finding. Even when conditioning on 1841 population, the coefficient continues to be positive and significant, which points to a persistent effect of 1830 market access on 1911 population. In col. 3, we add town geographic and pre-industrial controls identical to Table 3. The coefficient for $\ln MA_{i1830}$ is little changed. In col. 4, we add county fixed effects. The coefficient gets smaller, but again is still significant. Col. 5 adds the distance to rail stations and steamship ports in 1841. Those variables have a negative and significant effect as expected, but when included in the specification they diminish the market access coefficient only by a slight amount.

Table 7: Estimates for the effect of 1830 market access on 1911 town population

| VARIABLES | (1) | (2) | (3) | (4) | (5) | (6) |
|------------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|
| $\ln MA_{i1830}$ | 0.894*** (0.1160) | 0.758*** (0.141) | 0.702*** (0.131) | 0.580*** (0.196) | 0.530*** (0.164) | 0.328* (0.172) |
| log pop. 1841 | | 1.146*** (0.0242) | 1.139*** (0.0259) | 1.128*** (0.0307) | 1.077*** (0.0325) | 1.144*** (0.0293) |

⁵⁵ Recall D_{ij}^{far} is an indicator for j being more than 50km from i and D_j^{inc} is an indicator for j being an incidentally connected town. See Appendix F for more details.

⁵⁶ Our sample size is no smaller than 528 after omitting towns with missing variables, or which share a spatial unit with a larger 1680 population town, and hence have the same geo. controls. Recall we drop such towns in Table 3.

| | | | | | | |
|--------------------------------|-------|-------|-------|-------|-----------|--------|
| log dist. station 1841 | | | | | -0.0567* | |
| | | | | | (0.0288) | |
| log dist. steamship port 1843 | | | | | -0.256*** | |
| | | | | | (0.0721) | |
| Observations | 537 | 532 | 528 | 528 | 528 | 528 |
| R-squared | 0.084 | 0.723 | 0.792 | 0.829 | 0.839 | 0.776 |
| Lat. Lon. & Geo. Controls | NO | NO | YES | YES | YES | YES |
| Pre-IR controls | NO | NO | YES | YES | YES | YES |
| County FEs | NO | NO | NO | YES | YES | YES |
| Kleibergen-Paap F statistic | | | | | | 97.01 |
| Endogeneity test stat. p-value | | | | | | 0.0942 |

Notes: The dependent variable is log 1911 pop. MA_{i1830} is market access calculated using model equation 2 with $\theta=2$ using 1830 trade costs and 586 towns with non-zero population in 1841. The instrument in col. 6 is the Plan Levels IV explained in the text. Standard errors are clustered on counties. Anderson-Rubin weak instr. test stat. has a p-value of 0.054 in col. 6. *, **, and *** indicates statistical significance at the 10, 5, and 1% levels.

The estimates in col. 6 of Table 7 are the most credible as they address the likely endogeneity of 1830 market access. The Plan Levels IV is shown to be a strong positive predictor of $\ln MA_{i1830}$, and gives a large Kleibergen-Paap F-stat of 97. The resulting IV coefficient in Table 7 is smaller than OLS and is significant only at the 10% level. Yet, we stress that the IV coefficient is still economically significant. As an illustration, we consider a -0.56 change in $\ln MA_{i1830}$, which is equivalent to the average decline in 1830 market access associated with our counterfactual using 1680 trade costs. The estimate in col. 6 implies this would reduce 1911 population by -18.3 log points or -16.7%.

Further robustness checks are in Online Appendix I. We repeat the specification of col. 5 in Table 7 using either distance to nearest railway station in 1851 or 1871 as a control (Table I3). The main coefficient is similar, and thus the OLS estimate for $\ln MA_{i1830}$ is not confounding the effects of future railway development. Also, the estimate is similar adding log 1680 town population. Moreover, the standard errors are similar if we use Conley with a 100km cutoff.

In Online Appendix I we also examine the effects of $\ln MA_{i1830}$ before 1911. We estimate the same regressions as Table 7 but use log 1861 or 1891 town population as the dependent variable. The market access coefficients are generally smaller in magnitude for 1861 or 1891 population, but they are more precisely estimated (Table I1 and I2). For example, with respect to explaining 1891 population, the IV specification identical to col. 6 of Table 7 gives a coefficient

for $\ln MA_{i1830}$ of 0.248 (s.e. 0.127). Our takeaway is that the effect of 1830 market access on population increased over time.

It is striking that market access in 1830 had lasting and large impacts on town population as late as 1911. The Second Industrial Revolution, starting around 1850, would change the economy substantially, yet the market access established by 1830 continued to influence urban populations for many decades after.

5. Effect of 1830 market access on town property values in 1843

In the second extension, we establish an important addition to our results for population: market access increased property income. We have collected data on the total property income of 556 towns in 1843, drawn from the first accurate assessment by fiscal authorities in England. As discussed earlier, we match our towns to the parishes and boroughs, for which property income is reported, including several categories, like housing. In our data, property income totaled 34.62 million pounds, with housing income totaling 25.59 million pounds. In all of England and Wales assessed property income equaled 85.8 million pounds.⁵⁷

We estimate equation (7), which is analogous to equation (3) in the theory framework:

$$\ln \text{property}_{i1843} = \beta \ln MA_{i1830} + \gamma \cdot x_i + \varepsilon_i \quad (7)$$

where property_{i1843} is total property income or housing income. In some specifications, we also divide property_{i1843} by total land area in acres, an approximation as jurisdictional areas are not always clear in census records. MA_{i1830} is the same as section 4, where we use 586 towns with 1841 population and 1830 trade costs. The controls x_i are also the same, except we include log 1680 town population to address longer term drivers of property income, and an indicator equal to 1 if this variable is missing. We also use the same Plan Level IV to address endogeneity.

The results are reported in Table 8. In col. 1, OLS estimates show a positive and significant effect of $\ln MA_{i1830}$ on property income, even after controlling for 1680 population. In col. 2 the Plan Level IV yields a strong first stage just like in Table 7. The IV estimates are close to OLS, indicating little endogeneity bias. The latter coefficient implies that a -0.56 change in $\ln MA_{i1830}$,

⁵⁷ The total value in England and Wales is taken from British Parliamentary Papers (1842-43 Vol. XXXVIII, p. 3).

equivalent to what we estimated in our counterfactual with 1680 trade costs, would reduce 1843 property income by -31.8 log points or -27.2%, a large effect. Continuing with the estimates in Table 8, col. 3 and 4 show larger effects on property income per acre. In col. 5 and 6 we find that market access has a large and significant effect on housing income, the major component of property income in our town sample. The IV estimate is smaller in col. 6, but it is still large and precisely estimated.

Table 8: Estimates for the effect of 1830 market access on 1843 property income

| VARIABLES | (1) | (2) | (3) | (4) | (5) | (6) |
|------------------------------------|---------------------------|--------------------------|---------------------------------------|--------------------------------------|--------------------------|-------------------------|
| | OLS property income | IV property income | OLS property income per acre | IV property income per acre | OLS housing income | IV housing income |
| $\ln MA_{i1830}$ | 0.519*** (0.1472) | 0.569*** (0.178) | 1.018*** (0.227) | 0.941*** (0.261) | 0.733*** (0.160) | 0.538*** (0.179) |
| Observations | 523 | 523 | 518 | 518 | 520 | 520 |
| R-squared | 0.541 | 0.475 | 0.498 | 0.415 | 0.586 | 0.536 |
| Lat. Lon. & Geo. Controls | YES | YES | YES | YES | YES | YES |
| Pre-IR controls | YES | YES | YES | YES | YES | YES |
| County FEs | YES | YES | YES | YES | YES | YES |
| Kleibergen-Paap F statistic | | 115.2 | | 115.3 | | 116.7 |
| Endogeneity test stat. p- value | | 0.689 | | 0.619 | | 0.167 |

Notes: The dependent variable is log 1842 town property income, either all property or housing, and in col. 3 and 4, property income divided by land area. MA_{i1830} is market access calculated using model equation 2 with $\theta=2$ using 1830 trade costs and 586 towns with non-zero population in 1841. The instrument in col. 2, 4, and 6 is from Table 7 or what we call the Plan Levels IV in the text. All specifications include a 2nd order polynomial in latitude and longitude, along with stated controls. All specifications also include a variable for log 1680 population and an indicator for missing 1680 populations. An arbitrary constant value is given for 1680 population when it is missing. Standard errors are clustered on counties. *, **, and *** indicates statistical significance at the 10, 5, and 1% levels.

Broadly, these results confirm that market access increased the rental value of housing, a key prediction of many theoretical models. In this context, the results imply the level of 1830 market access had a large impact on the incomes of urban property owners, generally the most prosperous group in England. While the evidence applies to a single year, 1843, it suggests that the transport improvements which reduced trade costs from 1680 to 1830 also had large effects

on urban property owners. In the next section, we provide evidence on migration and socio-economic status, which suggests workers were also affected by market access.

6. Effect of 1830 market access on migration outcomes and socio-economic status in 1851

In our last extension, we estimate the effects of market access levels on proxies for migration and outcomes related to occupational-based status in 1851. The theoretical frameworks in section 2 posit that higher market access for location i increases its in-migration and reduces its out-migration. Therefore, results on migration can be viewed as evidence concerning mechanisms. Data limitations prevent us from studying migration prior to the mid-19th century. Nevertheless, there is data on birth distance-residency outcomes at the sub-registration district level (RSDs) provided in the 1851 census.⁵⁸ The Victorian Fertility Decline Project gives the percentage of the RSD male and female population who was born in England and Wales and was either (1) born within 10 km from where they resided in 1851, (2) born 10-49 km from where they resided, or (3) born more than 50km from where they resided. Variable (1) could be interpreted as the % of non-migrants using 10km as the threshold for the birth-residency distance. If so, market access should be negatively related to (1) and positively related to variables (2) and (3) if it increased town in-migration. The Victorian Fertility Decline Project also gives the population percent residing in each English and Welsh RSD born in other parts of Great Britain, most of which were likely from Scotland. It is a useful variable as it certainly includes only migrants in 1851.

Estimating the effect of market access on birth distance-residency variables in urban settlements requires that we link 563 of our sample towns 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. The remaining 52 towns 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 (London, Manchester, Plymouth, and Lambeth) were

⁵⁸ Data on RSDs come from the 'Atlas of Victorian Fertility Decline' Project (see Reid *et al.* 2018).

linked with additional RSDs that approximate urban boundaries in 1851.⁵⁹ As RSD birth residency variables are reported separately for men and women, we calculate a weighted average using the share of men and women in the RSD population as weights. More details on our town-RSD units are given in Online Appendix J.

We estimate specifications like equation (8):

$$y_{i1851} = \beta \ln MA_{i1830/50} + \gamma \cdot x_i + \varepsilon_i \quad (8)$$

where y_{i1851} are various town-RSD birth-distance residency outcomes in 1851, and $MA_{i1830/50}$ is a new market access variable calculated using model equation (2), RSD-town populations in 1851, trade costs in 1830 (calculated with our baseline producer price of 233), and $\theta = 2$.⁶⁰ We call this variable town-RSD market access. The control variables x_i are the same as sections 3, 4, and 5, along with latitude and longitude of RSD coordinates and land area. We also use the same Plan Level instrument in Table 7 & 8 to address endogeneity of $MA_{i1830/50}$. Here we study outcomes beyond population, but in Online Appendix Table J3, the natural log of town-RSD population in 1851 is used as the outcome in equation (8). Our preferred specification shows that a 10% increase in market access raises town-RSD population by 4.7%. This market access-population elasticity is larger than what we found in Section 3, but it is reassuringly similar.

Turning to birth distance-residence outcomes in Table 9, we generally find evidence that town-RSD market access increased the population % of migrants. We report OLS and IV using our most demanding specification with town controls and county fixed effects. The means for each birth-residency variable are reported in the notes. Our first stage F-stat is strong and is the same for all specifications. In col. 1 the estimate implies town-RSD market access negatively and significantly affected the % born within 10km from where they resided in 1851. The IV estimate in col. 2 implies a smaller effect, but it is still significant. The signs on the coefficients in col. 3 and 4 are positive as we expect, but the IV estimate is smaller and imprecise. Nevertheless, we can reject the null hypothesis that the coefficient in (4), 1.322, is the same as our coefficient in (2) -

⁵⁹ 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.

⁶⁰ Online Appendix J summarizes the town RSD market access variables.

4.123. This indicates different effects of town-RSD market access on the % born less than 10 km and the % born 10-49 km away. The more conclusive findings apply for the % born greater than 50km from where they reside and the % born elsewhere in Great Britain, most likely Scotland (see col. 5, 6, 7, and 8). Here we find that town-RSD market access has positive and significant coefficients in both OLS and IV. For example, a one-SD increase in $\ln MA_{i1830/50}$ would raise the % born more than 50km away by 0.729, or 7.5% of the mean.

Table 9: Effect of market access on birth distance-residency outcomes in 1851

| Panel A | (1) | (2) | (3) | (4) |
|--------------------------------|-----------------------------|-----------------------------|--|--|
| | OLS | IV | OLS | IV |
| | % born < 10 km of residence | % born < 10 km of residence | % born 10-49 km of residence | % born 10-49 km of residence |
| VARIABLES | | | | |
| $\ln MA_{i1830/50}$ | -6.692*** (2.3289) | -4.123* (2.3630) | 2.633* (1.4663) | 1.322 (1.3310) |
| Observations | 538 | 538 | 538 | 538 |
| R-squared | 0.471 | 0.235 | 0.375 | 0.186 |
| Kleibergen-Paap F statistic | | 118.5 | | 118.5 |
| Endogeneity test stat. p-value | | 0.0835 | | 0.161 |
| Panel B | (5) | (6) | (7) | (8) |
| | OLS | IV | OLS | IV |
| | % born >50 km of residence | % born >50 km of residence | % born in GB not E&W and residing in E&W | % born in GB not E&W and residing in E&W |
| VARIABLES | | | | |
| $\ln MA_{i1830/50}$ | 3.029** (1.2078) | 2.323* (1.2200) | 0.426** (0.1703) | 0.299** (0.1389) |
| Observations | 538 | 538 | 538 | 538 |
| R-squared | 0.573 | 0.266 | 0.597 | 0.228 |
| Kleibergen-Paap F statistic | | 118.5 | | 118.5 |
| Endogeneity test stat. p-value | | 0.348 | | 0.142 |

Notes: The dependent variables are various birth-distance residency percentages for town-RSDs. The mean for % born < 10 km of residence is 69.9. The mean for % born 10-49 km of residence is 18.35. The mean for % born >50 km of residence is 9.68. The mean for % born in GB not E&W and residing in E&W is 0.51. $MA_{i1830/50}$ is market access calculated using model equation 2 with $\theta=2$ using 1830 trade costs and 538 town-RSDs with population in 1851. All regressions include latitude, longitude, RSD land area, county fixed effects, town geographic controls, and town pre-industrial revolution controls. See text for definitions. The instrument is the same as Table 7 in all columns, the Plan Levels IV. Standard errors clustered on the county are reported. *, **, and *** represent statistical significance at the 10, 5, and 1% levels.

Besides increasing in-migration, market access could have also affected urban populations through fertility and mortality, but we expect these channels to be weaker or to go against increasing urban populations. England was undergoing the demographic transition during the nineteenth century, which would weaken the market access-income-fertility link. Market access could reduce mortality through higher wages, but it could also raise mortality through pollution, or by increasing the density of housing which led to the spread of contagious disease (Davenport, 2020; Hanlon 2020). In Online Appendix Table J4, we report estimates that show greater market access had no significant effect on fertility. We do find that market access significantly increased early childhood mortality, which on its own, would reduce populations in town-RSDs.

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

We finish by analyzing the effects of 1830 market access levels on socio-economic status (SES) outcomes associated with occupation in 1851. The Victorian Fertility Decline Project reports percentages of men in 5 SES categories using the Historical International Social Class Scheme (HISCLASS) for occupations. As explained by Reid *et al.* (2018), the top class, SES 1, is high-skilled non-manual, such as managers and professionals. SES class 2 is lower skilled non-manual, like clerks and sales personnel. SES 3 is higher skill manual, such as plasterers, blacksmiths, and farmers. SES 4 is lower skill manual, such as factory workers and miners. The lowest SES class 5 is unskilled manual, which captures farm laborers and general laborers. HISCLASS has some limitations when applied to the English context, but it is useful for our purposes because it points to effects of market access on the SES of urban workers and the occupational structure of urban RSDs.

Table 10 reports OLS and IV estimates using the same specification as (8) with outcomes being the % in SES class 2, 3, 4, and 5. SES class 1, higher skill non-manual, is small on average and we choose to omit it from the analysis. The first stage is the same as Table 9, which means the instrument is strong in all specifications. Briefly summarizing, town-RSD market access has a positive and significant effect on SES 2, lower skilled non-manual, and a negative and significant effect on SES 5, unskilled manual. The coefficients are similar in OLS and IV, indicating no endogeneity bias. There are imprecisely estimated effects on SES 3 and SES 4.

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

| Panel A | (1) | (2) | (3) | (4) |
|--------------------------------|--------------------------------|--------------------------------|-----------------------------|-----------------------------|
| | OLS | IV | OLS | IV |
| VARIABLES | SES 2 lower skilled non-manual | SES 2 lower skilled non-manual | SES 3 higher skilled manual | SES 3 higher skilled manual |
| $\ln MA_{i1830/50}$ | 3.667*** (1.0621) | 3.979*** (1.2839) | 0.262 (1.0806) | -1.056 (1.3956) |
| Observations | 538 | 538 | 538 | 538 |
| R-squared | 0.570 | 0.448 | 0.433 | 0.228 |
| Kleibergen-Paap F statistic | | 118.5 | | 118.5 |
| Endogeneity test stat. p-value | | 0.589 | | 0.228 |
| Panel B | (5) | (6) | (7) | (8) |
| | OLS | IV | OLS | IV |
| VARIABLES | SES 4 lower skilled manual | SES 4 lower skilled manual | SES 5 unskilled manual | SES 5 unskilled manual |
| $\ln MA_{i1830/50}$ | 2.396 (3.2212) | 4.276 (2.8721) | -6.749** (2.5535) | -7.687*** (2.8581) |
| Observations | 538 | 538 | 538 | 538 |
| R-squared | 0.718 | 0.453 | 0.713 | 0.520 |
| Kleibergen-Paap F statistic | | 118.5 | | 118.5 |
| Endogeneity test stat. p-value | | 0.245 | | 0.546 |

Notes: The dependent variables are various SES percentages for town-RSDs. The mean values of SES 2, 3, 4, and 5 are 11.32, 26.14, 24.61, and 34.28, respectively. $MA_{i1830/50}$ is market access calculated using model equation 2 with $\theta=2$ using 1830 trade costs and 538 town-RSDs with population in 1851. All regressions include latitude, longitude, RSD land area, county fixed effects, town geographic controls, and town pre-industrial revolution controls. See text for definitions. The instrument is the same as Table 7, the plan levels IV. Standard errors clustered on the county are reported. *, **, and *** represent statistical significance at the 10, 5, and 1% levels.

The results in Table 10 have several implications concerning the role of market access in the English economy towards the end of the First Industrial Revolution between 1830 and 1850. First, we learn that greater market access levels for a town-RSD generally increased the SES of its male workforce. It resulted in a lower percentage of males in SES 5, the lowest class, and the most numerous, averaging 34.28%. Greater market access also resulted in a higher percentage of males in SES 2, the second highest class. If we regard the effects on SES 3 and 4 as zero, which they are statistically, then greater market access increased the percentage of males in a higher SES class, through less males in lower class 5 and more in higher class 2.

Second, we learn there were effects on the occupational structure of town-RSDs. The finding that greater market access reduced SES 5, which has farm laborers, fits with our earlier results as greater access meant higher population density, which should have contributed to less agricultural production, even if it encouraged some higher value gardening activities near towns. The finding that market access increased lower skilled, non-manual occupations, implies that it contributed to a larger service sector. This is noteworthy since tertiary (i.e., services) occupations grew rapidly in England since at least the 1700s (Shaw-Taylor and Wrigley, 2014). It is also noteworthy that we find an imprecise effect on lower skilled manual, including factory work. In these occupations, the literature generally emphasizes the importance of endowments and clusters of skill, especially in textiles (e.g., Crafts and Wolf, 2014). Perhaps market access was a less important factor in determining the location of such occupations.

7. Conclusion

This paper offers new insights on the role of early transport improvements in altering the spatial structure of the economy during the first Industrial Revolution in England and Wales. We emphasize the extensive network of improved rivers, canals, high quality roads, and capable ports made in the 1700s and up to 1830. We also emphasize technological advances, 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 transportation system to calculate freight transport costs between 590 towns in 1680 and 1830. Strikingly, we estimate that the average transport cost relative to producer prices declined by 75% between 1680 and 1830. In other words, trade costs between towns dramatically declined in England and Wales even before the widespread application of steam power through railways and steamships.

Our second main contribution estimates how lower trade costs affected town populations through greater market access, which is generally the inverse trade cost weighted sum of the market capacities of trading partners. We make use of a new urban dataset with population estimates in 1680 linked to populations in the census of 1841. The dataset also has rich information on many geographic and pre-industrial characteristics of towns. We calculate a standard measure of market access, and another that is defined by a trade-geography model. Both access measures increased substantially from 1680 to 1830, especially for inland towns and

in the northwest. Using econometric specifications, which address confounding factors and endogeneity, we estimate that greater market access significantly increased town populations from 1680 to 1841. We then use the estimates to make a new counterfactual calculation assuming trade costs did not change from 1680 to 1830. It is meant to capture a hypothetical scenario where the various transport improvements did not happen. We estimate that the total urban population in England and Wales in 1841 would have been 11.6% lower if trade costs remained unchanged from 1680. We also argue there would have been large impacts on the spatial distribution of urban populations. Inland towns are estimated to have been 20 to 25% smaller in 1841 without changes in trade costs. Others, mainly on the coast, would have seen less population loss. London for example loses only 3% of its population.

Extensions show more striking implications from town market access levels by 1830. We estimate that greater market access had a large, positive effect on 1911 town populations even after addressing endogeneity. Among other factors, this points to a persistent effect of the early transport improvements which reduced trade costs. In another extension, we estimate that 1830 market access increased 1843 property income substantially. Effects are even larger for housing income. These results are predicted by many theoretical models which see market access as affecting both population and housing rents. In our context, they also imply that urban property owners benefited greatly from the reduced trade costs we highlight here. We also estimate that greater market access increased the percentage of a town-RSD population born more than 50km from their residence or who were born in other parts of Great Britain. This suggests that greater market access increased urban populations through greater in-migration, another prediction of the theoretical models we feature. We also estimate that market access decreased the percentage of men with the lowest socio-economic status (SES) group and increased the percent in the second highest SES group. Besides pointing to a positive effect on the social status of the male workforce, it also shows that market access contributed to occupational structural change. To conclude, we argue that 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 were quantitatively large and persisted for decades after.

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Online Appendix for

Transport and urban growth in the First Industrial Revolution

A. A new historical urban dataset for England and Wales

In this paper, we make a new historical urban dataset for England and Wales (E&W) by combining data from different historical and secondary sources. We begin with a list of places considered to be a town at some point between c. 1500 to c. 1900. The list comes from a database made by Shaw-Taylor, Satchell, Newton, Terki-Mignot, Bogart, and McKenzie (2024). A place is on the list if they are identified in at least one of 25 primary and secondary sources which describe towns. The list provides all distinct spellings in the sources. Each entry is given an ID number, `alltowndictID`, and a standardized name, `newstandard`. The standardized name is shared by some places judged to be the same town, but with different spellings (see the replication files `data\raw\towns\alltownsdict.xlsx` and Bogart (n.d.) for description). We consider the list of unique standardized names as a list of ‘candidate’ towns, which are used to link with other databases.

Our dataset includes the populations of many towns by drawing on several sources. Our first source is Langton (2000), who uses counts of enumerated households in the hearth tax and Bishop Compton’s count of Anglicans and other religious households to estimate populations for 925 urban settlements in E&W in the 1660s and 1670s, which we generally date as c.1680.⁶¹ Langton also gives population and 950 E&W settlements in 1801 and 1039 in 1841 using censuses.⁶² We use Bennet (2012) who has digitized Langton’s data (see the replication files `data\raw\towns\langton_bennet.xlsx` and `data\raw\townsguide_bennet.pdf` as a guide). The Langton towns in Bennet have been linked to the list of candidate towns and are given a standardized town name and county, `newstandard` (see the replication files `data\processed\towns_langtonpop\langton_linked_sample.xlsx`).

⁶¹ Langton (2000 pp. 460, 462 463, 486, 489). Fifty-six population estimates derive from the Compton Census in the 1670s. Fourteen towns, for which data were not available, are reasoned guesswork based on nearby towns. Ibid, p.460 and fn. 39.

⁶² Langton’s data are digitized and available through Bennet (2012), who also summarizes Langton’s methods.

Regarding accuracy, Langton expressed doubts about his c.1680 estimates for the largest towns and noted they could be 30 percent below the true value.⁶³ Since we know there is some error, the question is how much. As a check, the sum of Langton town populations in a county divided by land area is highly correlated (0.98) with independent estimates of county population density.⁶⁴ Langton's 1680 estimates are thus very accurate in comparing town populations across counties.

One important feature is that several settlements in Langton have no population recorded, mainly for the year c.1680. For our analysis, we selected 590 towns that have a population of 2,500 or more, either in 1680, 1801, or 1841. We choose 2,500 as it is often the lowest standard for urban in historical studies (e.g. DeVries 2013).⁶⁵ Thus, the settlements include what were populous towns around 1680 or what would become populous towns by 1801 or 1841. For the details on the selection of 590 towns, see the replication file `data\processed\towns_langtonpop\langton_linked_sample.xlsx`.

We also link the 590 towns selected from Langton to a dataset which identifies the British National Grid coordinates (easting and northing) for 1,711 candidate towns. The town coordinates data were made by Shaw-Taylor, Satchell, Potter, and Bogart (2017). See the replication files `data\raw\GIS\CandidateTownsofEnglandandWalesc1563-1911.shp` and Satchell (n.d.) for a description. This dataset first assigns the coordinates of a town's market. In its absence, parish church coordinates were assigned. If no parish church was found, then inns, post offices, public houses, and high streets were used in that order. We link our 590 towns to their list of 1,711 towns using town name variable, `newstandard`. Nine of the 590 towns were unlinked and for these we added coordinates. We make a new variable for town name, `newstandar`, which we use in our datafiles for analysis.

As an illustration of the Langton population data, Table A1 shows the population of the largest 20 towns in 1680 along with their population levels and ranking in 1841. London is at the

⁶³ See Langton (2000, p. 461, especially footnote 46). London's population was 66 per cent of Wrigley's estimate for 1670 and 65 per cent of that by Gregory King (a statistically literate contemporary for 1695). Norwich's estimate, then the second city, is only 70% of the most widely cited estimate, *Ibid*, p 461 and fn. 48.

⁶⁴ County populations in 1680 are estimated by the weighted average of Wrigley (2009)'s figures in 1600 and 1700.

⁶⁵ Bairoch et al. (1988) use a threshold of 5000 and Buringh (2020) uses a modern threshold of 10,000.

top of the list, naturally. London grows from 1680 to 1841, but many others do not. For example, Salisbury falls out of the top 20 in 1841. Also, several other large towns in 1680 are not as exceptionally high ranked in population by 1841.

Table A1. Population of the largest 20 towns in 1680 in comparison with level and ranking in 1841

| Town Name.County | Pop 1680 | Pop 1841 | Rank 1841 |
|------------------------------------|----------|-----------|-----------|
| LONDON.MIDDLESEX | 310,941 | 1,948,417 | 1 |
| NORWICH.NORFOLK | 14,216 | 61,846 | 12 |
| YORK.YORKSHIRE NORTH RIDING | 14,201 | 28,842 | 34 |
| BRISTOL.GLOUCESTERSHIRE | 13,482 | 125,146 | 6 |
| NEWCASTLE UPON TYNE.NORTHUMBERLAND | 11,617 | 70,337 | 9 |
| OXFORD.OXFORDSHIRE | 11,065 | 24,258 | 47 |
| CAMBRIDGE.CAMBRIDGESHIRE | 10,574 | 24,453 | 45 |
| EXETER.DEVONSHIRE | 10,307 | 37,231 | 25 |
| IPSWICH.SUFFOLK | 9774 | 25,384 | 41 |
| GREAT YARMOUTH.NORFOLK | 9248 | 27,865 | 35 |
| CANTERBURY.KENT | 7671 | 15,435 | 72 |
| WORCESTER.WORCESTERSHIRE | 7046 | 27,004 | 38 |
| SHREWSBURY.SHROPSHIRE | 6867 | 18,285 | 63 |
| SALISBURY.WILTSHIRE | 6811 | 10,086 | 105 |
| COLCHESTER.ESSEX | 6647 | 17,790 | 66 |
| HULL.YORKSHIRE EAST RIDING | 6600 | 67,308 | 10 |
| COVENTRY.WARWICKSHIRE | 6427 | 31,032 | 33 |
| CHESTER.CHESHIRE | 5849 | 23,866 | 48 |
| KENDAL.WESTMORELAND | 5730 | 11,770 | 85 |

Notes: Authors' calculations from town population in Langton (2000), digitized by Bennet (2012).

Table A2 shows the population of the largest 20 towns in 1841 and their population levels and ranking in 1680. London is again at the top. Interestingly the next two, Manchester and Liverpool, are not large towns in 1680. Liverpool is not even in the top 100 in 1680. Bradford is another example of a town that grows significantly by 1841.

Table A2. Population of the largest 20 towns in 1841 in comparison with level and ranking in 1680

| Town Name.County | Pop 1680 | Pop 1841 | 1680 |
|------------------------------------|----------|----------|-------|
| LONDON.MIDDLESEX | 310941 | 1948417 | 1 |
| MANCHESTER.LANCASHIRE | 2356 | 311269 | 64 |
| LIVERPOOL.LANCASHIRE | 1210 | 286487 | 198.5 |
| BIRMINGHAM.WARWICKSHIRE | 2745 | 182922 | 49 |
| LEEDS.YORKSHIRE WEST RIDING | 3501 | 152074 | 37 |
| BRISTOL.GLOUCESTERSHIRE | 13482 | 125146 | 4 |
| SHEFFIELD.YORKSHIRE WEST RIDING | 2050 | 111091 | 84.5 |
| WOLVERHAMPTON.STAFFORDSHIRE | 2010 | 93245 | 88 |
| NEWCASTLE UPON TYNE.NORTHUMBERLAND | 11617 | 70337 | 5 |
| HULL.YORKSHIRE EAST RIDING | 6600 | 67308 | 17 |
| BRADFORD.YORKSHIRE WEST RIDING | 940 | 66715 | 282 |
| NORWICH.NORFOLK | 14216 | 61846 | 2 |
| NEWINGTON.MIDDLESEX | 1406 | 54606 | 158 |
| SUNDERLAND.DURHAM | 1147 | 53335 | 214 |
| BATH.SOMERSETSHIRE | 2652 | 53196 | 56 |
| PORTSMOUTH.HAMPSHIRE | 5007 | 53032 | 22.5 |
| NOTTINGHAM.NOTTINGHAMSHIRE | 4264 | 52360 | 29.5 |
| BOLTON.LANCASHIRE | 1830 | 51029 | 106 |
| PRESTON.LANCASHIRE | 1700 | 50887 | 120 |
| LEICESTER.LEICESTERSHIRE | 3014 | 50806 | 42 |

Notes: Authors' calculations from town population in Langton (2000), digitized by Bennet (2012).

Our second source is Clark and Hosking (2005), who give population estimates for small and medium sized towns based on the 1563 Diocesan returns, and later years. We have digitized their data and standardized the town name and county through the variable, `newstandard`, which is linked to the candidate town list (see the replication files `data\raw\towns\clark_hosking_linkalltowns.xlsx`). One issue is that Clark and Hosking often give two population estimates for 1563, separately for the township (t) and parish (p). We choose the township following Langton, or the designation which most closely matches other Clark and Hosking's population estimates in the early 1600s. We then link Clark and Hosking town populations for 1563 to the 590 towns we selected from Langton's data. The linking was made for 151 towns, see the replication files `data\processed\towns_c16thpop\ClarkHoskings_linked_sample.xlsx`. As Clark and Hosking focus on small and medium towns, their estimates are supplemented with Wrigley's (1985) top 10 city populations c.1520, including London.

It is useful to describe the properties of various samples. The left panel in Appendix figure A1 shows a kernel density estimate of log 1680 population in what we call the 1680-1801-1841 baseline estimating sample with 448 towns described in the main text. The left panel also shows a kernel density estimate of log 1680 population for the subsample that also has observed 1563 population plus Wrigley’s 10 towns. The distributions are similar, including having a long right tail for larger towns. The right panel of Appendix figure A1 shows the kernel density estimate for the difference in log 1841 and log 1680 population in the baseline estimating sample and sub-sample with 1563 populations. The distributions for growth are broadly similar.

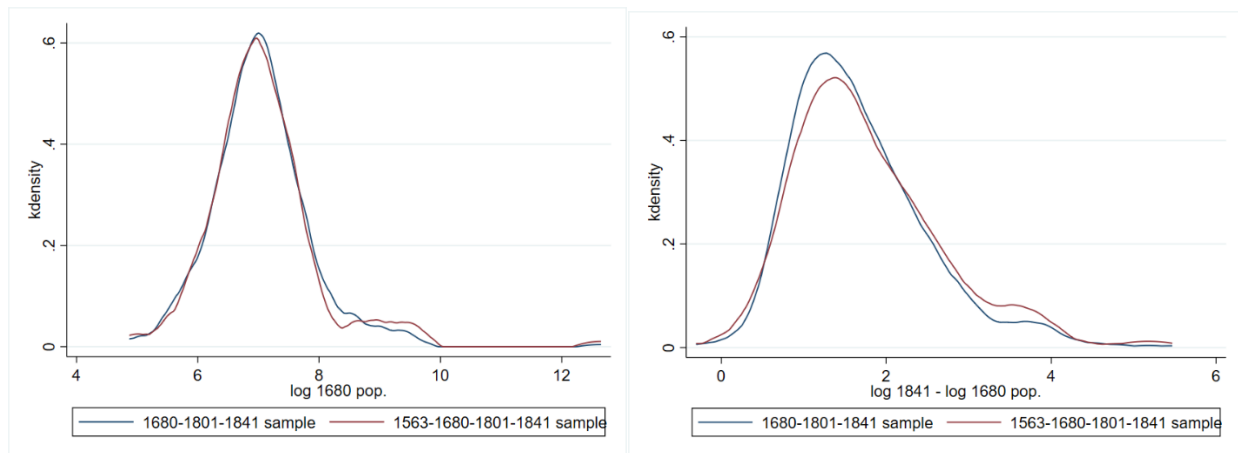


Fig. A1: kernel density estimates of log 1680 town population and the difference in log 1841 and log 1680 town populations for the baseline estimating sample (blue) and subset with 1560 populations (red).

Notes: Author’s calculations, see text.

Our third and fourth sources are Law (1967) and Robson (2012), who provide population estimates for 934 medium and large towns in 1801, and every ten years up to 1911. Their data has been digitized by Bennet (2012), which we use (see the replication files `data\raw\towns\law_robson_bennet.xlsx` and `data\raw\towns\guide_bennet.pdf` for a guide). We standardize the town name and county in Bennet and link to the candidate town list through `newtandard` and `alltownsdictID`. Then we link to the 590 towns we selected from Langton’s data. We find that only 326 of our selected 590 were directly linked to Law and Robson’s list digitized

by Bennet. Therefore, we entered population data for most of the remaining towns using three sources: (1) Southall, A Vision of Britain through Time, Find a historical place, <https://www.visionofbritain.org.uk/>, (2) the 1851 population census, and (3) Langton 1841 when possible. We end with population estimates in every decade from 1841 to 1911 for 568 of our selected 590 towns. (see the replication files `data\processed\towns_c19thpop\lawrobson_linked_sample.xlsx`).

A.1 Town economic, political, and infrastructure characteristics from Blome

Our new urban dataset includes variables drawn from town summaries in Richard Blome's *Britannia* published in 1673 (for a reprint see Blome 1962). Blome's town summaries describe their economic, political, and infrastructure characteristics. These summaries were digitized and converted into variables by Bogart (2018). (see the replication file `data\raw\towns\Blome_Britannia_data_linkalltowns.xlsx`). There are 782 towns with summaries, each of which has a standardized town name `NEWSTANDARD_Blome`.

We use 16 variables based on Blome's town description, which we call pre-industrial controls in the text. 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 a port for sea trade; 0 otherwise. Blome also described the town's market including the number of days, which we use to create the variable (12) the number of market days for the town. 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 favorable words like very good, good, well served, well provisioned, considerable; and zero otherwise. Variable (14) is an indicator equal to 1 if the market was described with unfavorable words like indifferent, small, mean, little, inconsiderable; and zero otherwise. The omitted group are markets, which are described neither favorably, nor unfavorably, or where no market days are given. 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, the Bogart (2018) dataset supplements Blome with Robert

Morden's, *The New Description of the State of England*. Morden (1701) provides maps of the main roads in each county in the late 17th century before turnpikes. Variable (16) is an indicator equal to 1 if the town was on the 1700 main road network and 0 otherwise.

We link 386 towns in the Blome dataset to our 590 towns selected from Langton (see the replication file `data\processed\towns_blome\blome_linked_sample.xlsx`). We do not want to drop the unlinked towns and therefore we give three types of arbitrary values to replace the missing values for the 16 variables. First, we give the value -20 if the town is mentioned in Blome's description of a county, but without a main entry, which is used to create the main variables. We define the dummy variable `Blomenomainentrybutnoted=1` in these cases, which enters as an additional variable in our pre-industrial controls. Second, we give the value -30 if the town is not mentioned in Blome at all and it has non-zero population in `lang_c17` and `lang_1841`, Langton's population variables. Here we define the additional dummy variable `Blomenomainentrynotnoted=1` in these cases. Third, we give the value -10 if the town is not mentioned in Blome at all and it has zero population, either in `lang_c17` or `lang_1841`. Again, we define the dummy variable `blomenomainentrynotnoted_zeropop=1` in these cases, which enters as an additional pre-industrial control variable in some specifications. More discussion of the sample properties is given Online Appendix E.

As an illustration of Blome variables, Figure A2 shows towns identified by Blome as having cloth manufacturing and mining.

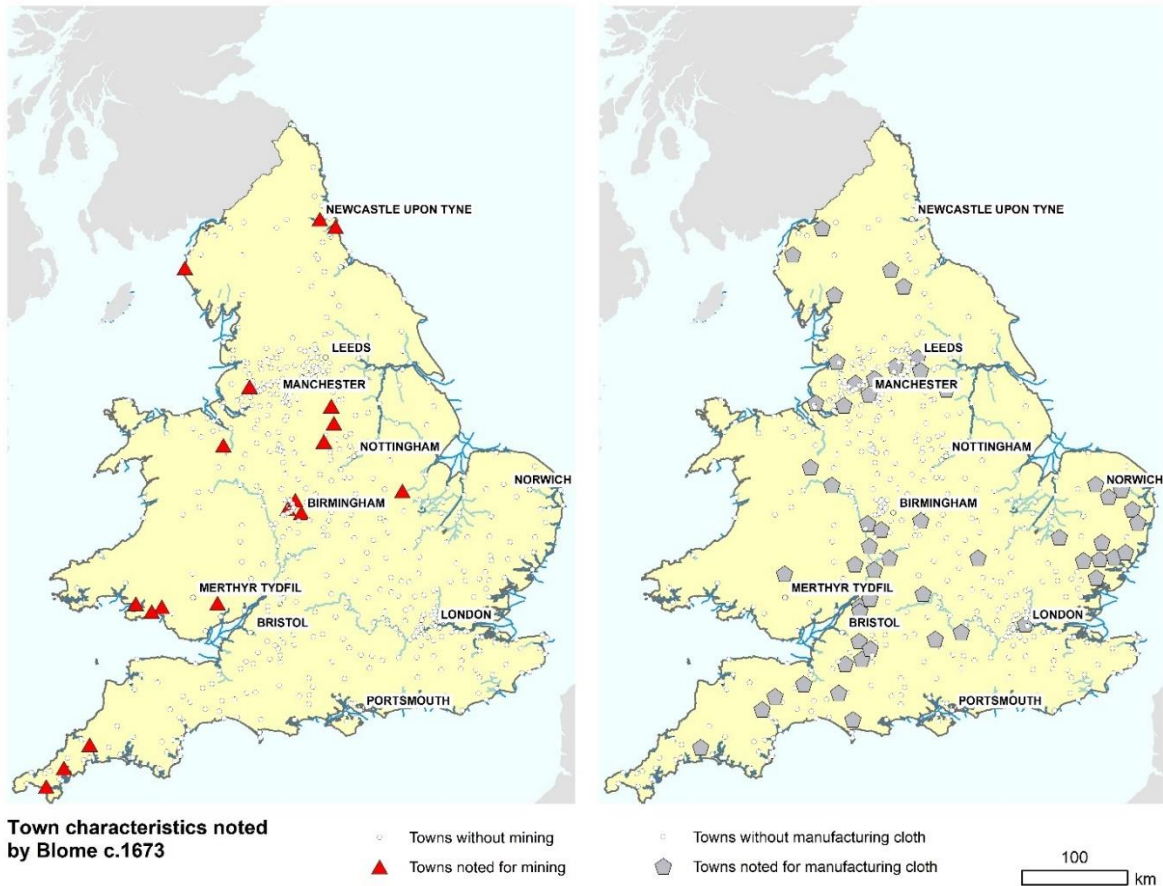


Figure A2: Main sample towns noted for mining and cloth manufacturing specialties by Blome’s *Britannia* in 1673

Notes: The main sample towns are those with non-missing populations in 1680 and 1841. Digitization of Blome variables drawn from Bogart (2018).

A.2 Town geographic characteristics from mappable units

Our new urban dataset also includes variables for geography. They are drawn from a rich database of 9700 spatial units in E&W, comprised of parishes and townships, which are called mappable units. The mappable unit data was made by Bogart, You, Alvarez, Satchell, and Shaw-Taylor (2022) to study impacts of railways. We use 15 of their variables for mappable units, see the replication file `data\raw\towns\bogartetalJUE_unitsdata_towns.xlsx`. We link the 590 towns selected from Langton to a single mappable based on their latitude and longitude coordinates lying within the mappable unit. We use the shapefiles `1801x1817x1851x1881MappableUnits.shp` and `CandidateTownsofEnglandandWalesc1563-1911.shp` in `data\raw\GIS` for the linking. We also use our added coordinates for nine Langton

towns missing in the Candidate towns coordinates. We then assign the linked mappable unit's geographic variables to our 590 towns through the linked variable: unit. See the replication file `data\processed\towns_mappableunits\bogartetalJUE_unit_townlink.xlsx`. Some towns are linked to the same spatial unit and are identified as not having a unique unit linkage. See the dummy variable `twoparishlink=1` if a town shares a mappable unit link with another town. As explained in the text, we identify the town which has a larger 1680 population and keep that town in our main sample to avoid repeated values of the geographic variables. The dummy variable `keeplargetwoparishlink=1`, which indicates which towns have a unique match to a mappable unit and the ones we select for our main sample. This step led to 13 towns being omitted from the main sample.

The town link to mappable units gives 5 geographic variables: an indicator for being on an exposed coalfield, average elevation, the standard deviation of elevation, average rainfall, and average temperature. The 'Exposed Coalfields' were areas with more easily exploited coal compared to concealed coal (see Satchell and Shaw-Taylor 2013). As this is an important predictor of population growth, Figure A3 shows the towns on the coalfield. Rainfall and temperature come from the FAO and are averaged from 1961 to 1990. While the climate data is more recent, the variation in rainfall and temperature across English and Welsh towns is likely to have been similar in the late 18th century. The link to mappable units also gives latitude and longitude coordinates using the World Geodetic System 1984 (WGS 84), which we use in our empirical analysis. Town links to units also give distance to the nearest port in 1565, distance to the nearest inland waterway in 1827, distance to the nearest turnpike road in 1830, distance to the nearest steamship port in 1843, and distance to the nearest railway stations in 1831, 1841, 1851, and 1871.

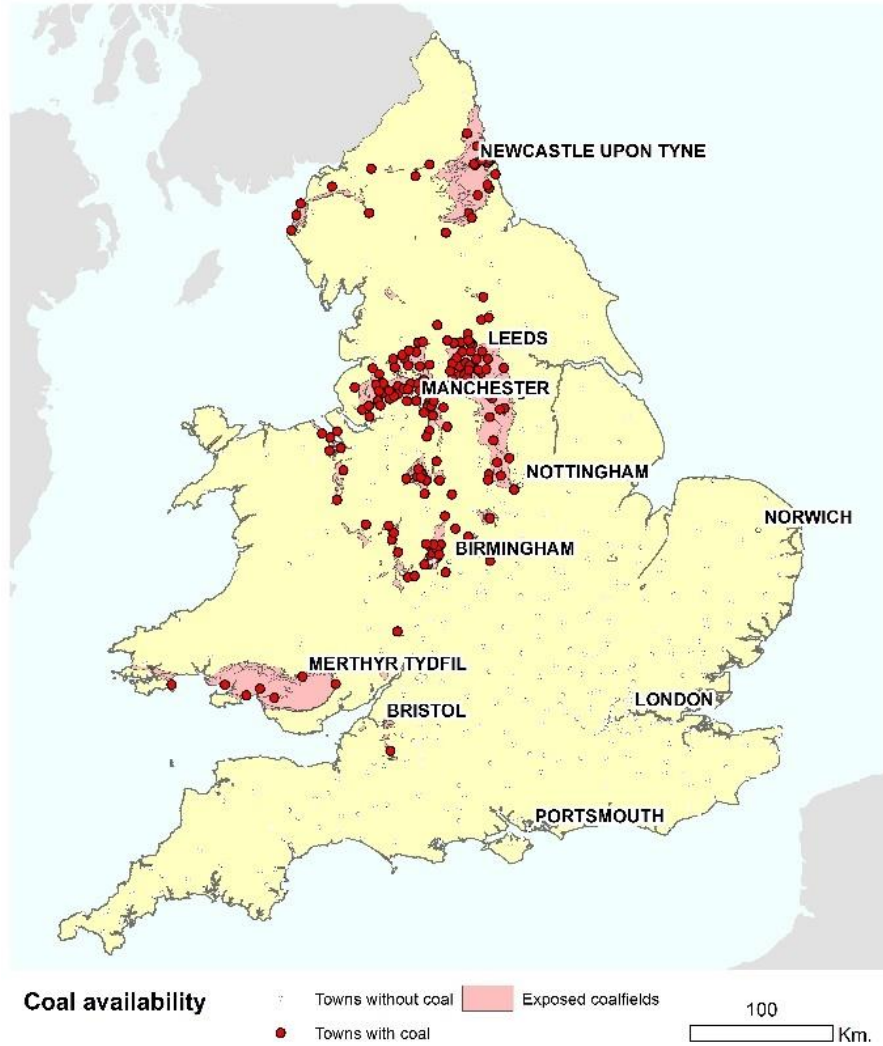


Figure A3: *Towns on the exposed coalfield along with major towns*

Notes: Author's creation based on exposed coal data from Satchell and Shaw-Taylor (2013).

A.3 *Town property income in 1843*

Our new urban dataset also includes property income. The year 1843 is one of the first where property income was accurately assessed by fiscal authorities in England and Wales. The data are reported for each parish or borough and include total annual property income, and separately for 11 categories, including housing. We digitize these for a subset of our 590 towns selected from Langton. We use the report, *Total Annual Value of Real Property of each Parish of each county in England and Wales assessed to the Property and Income Tax for the year*

ending 1843, British Parliamentary Papers (1842-43 Vol. XXXVIII). The 11 categories are housing, tithes, manors, fines, quarries, mines, ironworks, fisheries, canals, and railways.

We start with a dataset of England and Welsh parishes provided by Greg Clark. It contains parish and township names, along with population in 1801 and 1841, along with land area (see the replication file `data\raw\towns\English_parish_dataset.xlsx`). We then link our selected 590 towns to these parishes and townships, noting that some towns get linked with multiple parishes and townships (see the replication file `data\processed\towns_property\towns_1842property_linked.xlsx`). We then digitize the property income in 11 categories for the linked parishes and townships. The last step is to aggregate the property income for multiple parishes and townships linked to a single town. In the end, we have property income for 556 of our 590 selected towns.

A.4 Towns linked with foreign trade ports 1791

Our urban dataset further identifies towns that were ports involved in foreign trade in 1791. We identify foreign trading ports using National Archive records Cust17/13, States of navigation, commerce and revenue, 1791. It lists ports and the tonnage of ships involved in foreign trade that entered the port or left the port, i.e., tons in and tons out. We digitized this data, see the replication file `data\raw\towns\portsforeigntradetons_1791.xlsx`. We then linked these ports to our towns. A handful of ports were not linked altogether. A few were linked to towns with a different name close by. The details on town-foreign trade port links are given in the replication file `data\processed\towns_foreignports1791\towns_foreignports_linked.xlsx`.

B. GIS representations of networks and maps of the Grand Cross canals

We start Appendix B by briefly summarizing each type of GIS transport network used in our multi-modal model. More details are given in Alvarez-Palau, Bogart, Satchell, and Shaw-Taylor (2024), see our replication file `data\raw\GIS\Multimodal model 1680 and 1830 EJ replication.docx`. The GIS data on ports and routes are provided by Alvarez-Palau, Dunn, Bogart, Satchell, and Shaw-Taylor (2019) and described further in Alvarez-Palau and Dunn (2019). Figure B1 shows the geographical distribution of all 479 ports with one or more appearances in our sources.

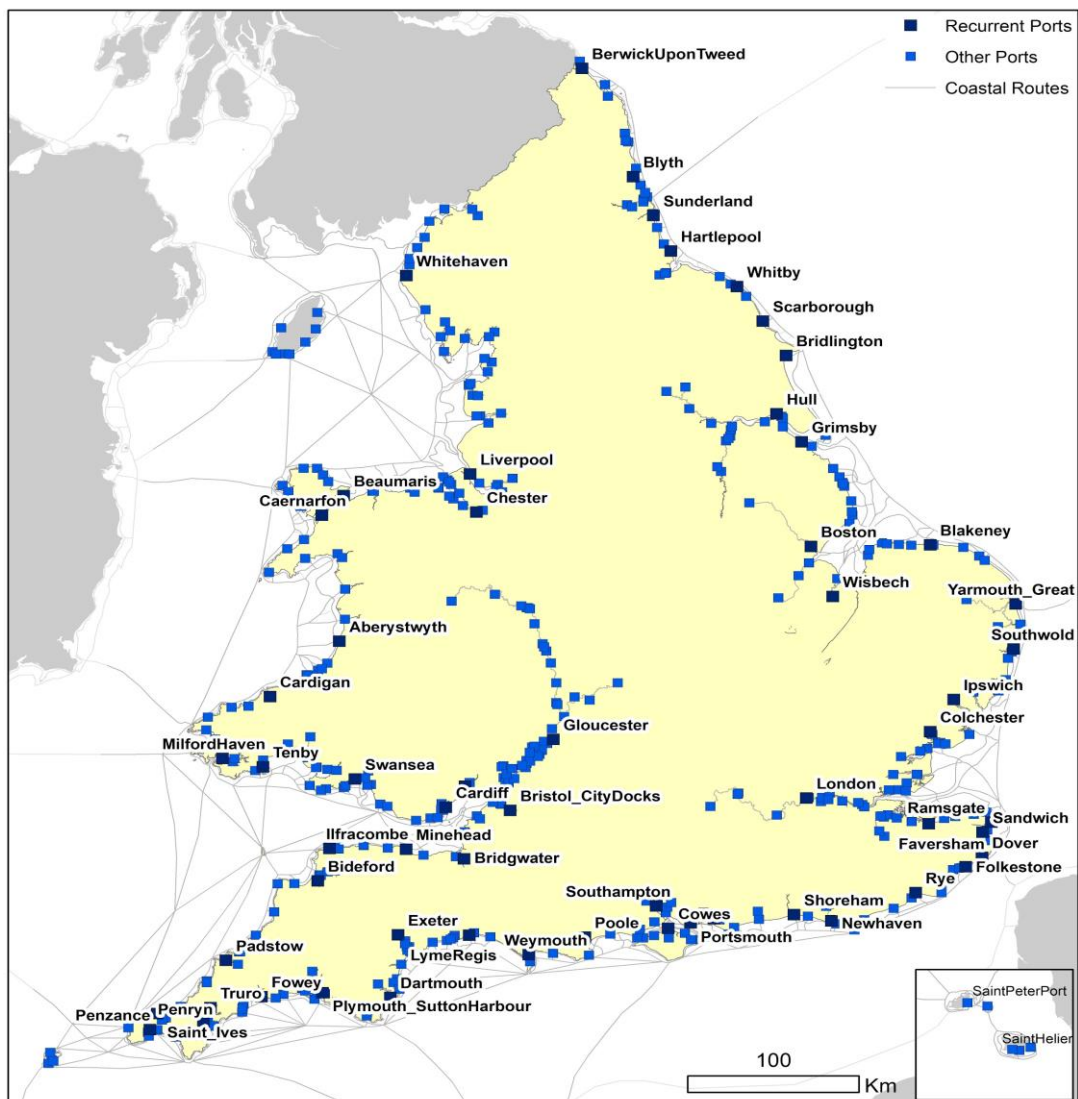


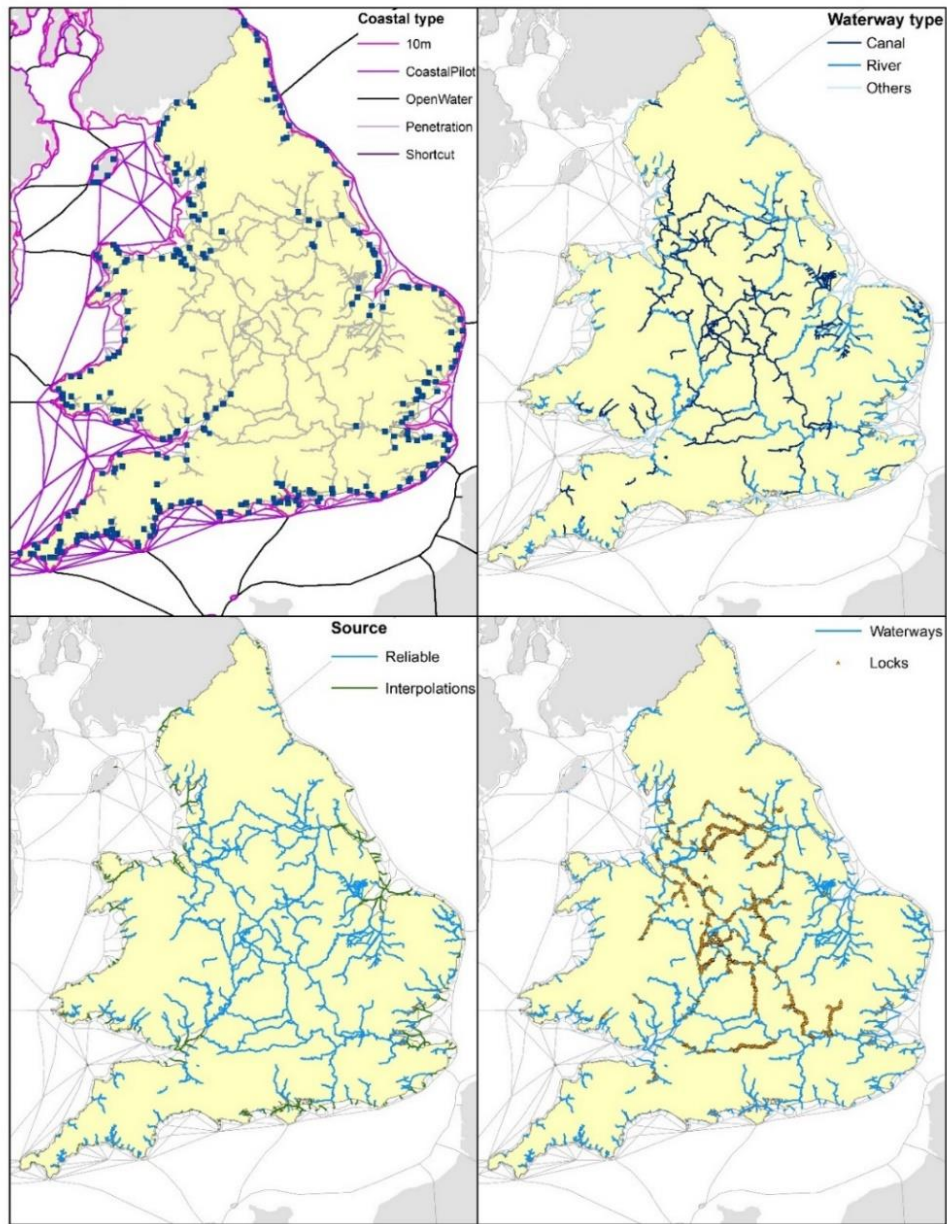
Figure B1: *Ports with one or more mentions within the sources used. Those places marked as dark blue (recurrent ports) are mentioned in at least nine out of eleven sources.*

Notes: Alvarez-Palau and Dunn (2019). Data derived from Alvarez-Palau, Dunn, Bogart, Satchell, Shaw-Taylor, L. (2019).

Various sources were used to identify the coastal routes mariners most likely followed. Specifically, Alvarez-Palau, Dunn, Bogart, Satchell, and Shaw-Taylor (2019) relied on historical coastal charts, bathymetric depth rasters, topographic elevation rasters, and parliamentary reports. They use these sources to create a coastal route intended for long-distance trade. We call this network: `coastal_1s`. It is shown in Figure B1. Further, they determine a line along the coast where the bathymetry is 10 meter deep. It is intended for short-distance trade along estuaries and tidal rivers. We define this network as `Coastal_2nd`. In Figure B1, `Coastal_2nd` is the circuitous coastal route closest to the coastland.

The GIS of inland waterways 1680 and 1830 come from Satchell, Shaw-Taylor, and Wrigley (2017a, b). The shapefiles are described in Satchell (n.d.), see the replication files `data\raw\GIS\waterwaysofenglandandwales1680.pdf` and `data\raw\GIS\waterwaysofenglandandwales1830.pdf`. Figure B2 shows (1) the coastal network, (2) the inland waterway network in 130, distinguishing rivers and canals, (3) interpolations that were made to connect the inland waterway and coastal networks, and (4) locks. We add surviving locks to our database using the River and Canal Trust Locks dataset.⁶⁶ From these, we make two inland waterway networks, `Waterway_1s` and `Waterways_2nd`. `Waterway_1s` is the main inland waterway network, which generally ends at the mouth of tidal rivers, where they meet the open sea. `Waterways_2nd` is created to connect inland waterways with the coastal shipping networks. Specifically, `Waterway_2nd` connects `Waterway_1s` with `Coastal_1s` and `Coastal_2nd`.

⁶⁶ See the River and Canal Trust, Locks, <http://data-canalrivertrust.opendata.arcgis.com/datasets/locks-public>. Accessed on 1 Aug. 2018. There is a potential survival bias here, but as locks were so important, they are added.



Coastal and waterway attributes in 1830



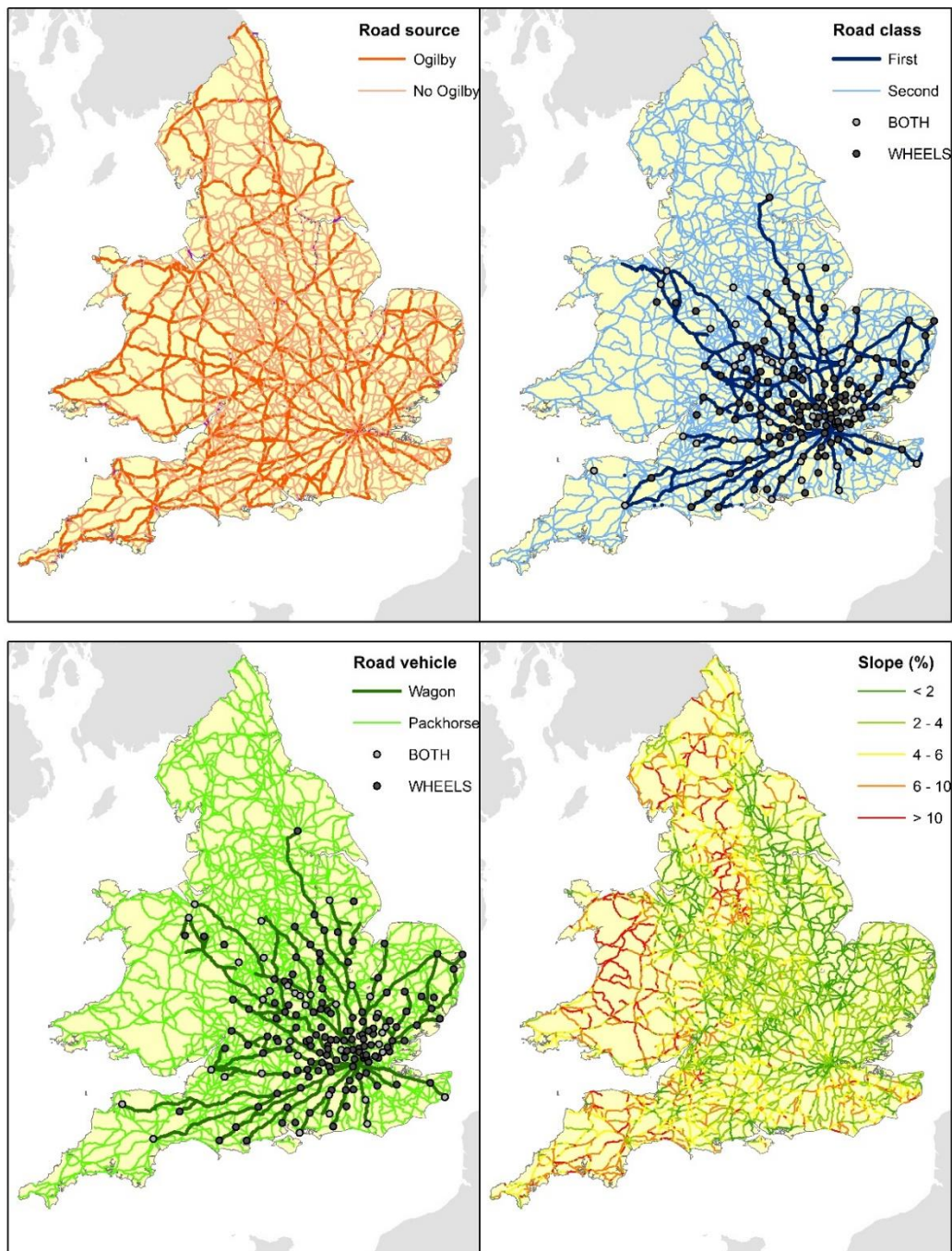
Figure B2: *Coastal and waterway networks and attributes in 1830*

Notes: authors creation using Satchell, Shaw-Taylor and Wrigley (2017 a, b) and locks from the River and Canal Trust.

The GIS data on 1680 roads derives from Satchell, Rosevear, Dickinson, Bogart, Alvarez, Shaw-Taylor (2017). They are described in Satchell and Rosevear (n.d.), see the replication file

data\raw\GIS\ candidatemainroadsofenglandandwalesc_1680.pdf. The 1680 roads GIS contains two distinct elements: a digitisation of 7,493 miles of road which derive from the strip maps of John Ogilby's Road Atlas and 13,439 miles of other roads which derive from a variety of other sources. A map of the main Ogilby roads and non-Ogilby roads is shown in the upper left box of Figure B3. We call the main Ogilby roads, Road_1s, and non-Ogilby roads, Road_2nd.

We have an attribute to determine whether wheeled transport or packhorses were used on 1680 roads. Our classification was derived from DeLaune (1681), which details whether packhorse (carrier) or wagon services were available from London to several towns. Sometimes both services were available to the same town. We have mapped towns with wheeled (i.e., wagon) or both using Delaune's data. It is shown in the upper right-hand box of Figure B3, along with all roads in 1680. Our interpretation is that wheeled transport was not available everywhere. Thus, we use this information to identify a first-class road network where only wheeled transport was used and a second-class network where packhorses or both were used. As wheeled vehicles and packhorses were both used in transport to some towns, we assume the 1680 road network where wheeled transport was available was larger than first class roads. The full network available for wheeled transport in 1680 is shown in the lower left-hand box of Figure B3. We overlay a raster file of elevation to calculate segments where the average slope was fit into different categories. These segments are shown in the lower right-hand box of Figure B3.



Road attributes in 1680

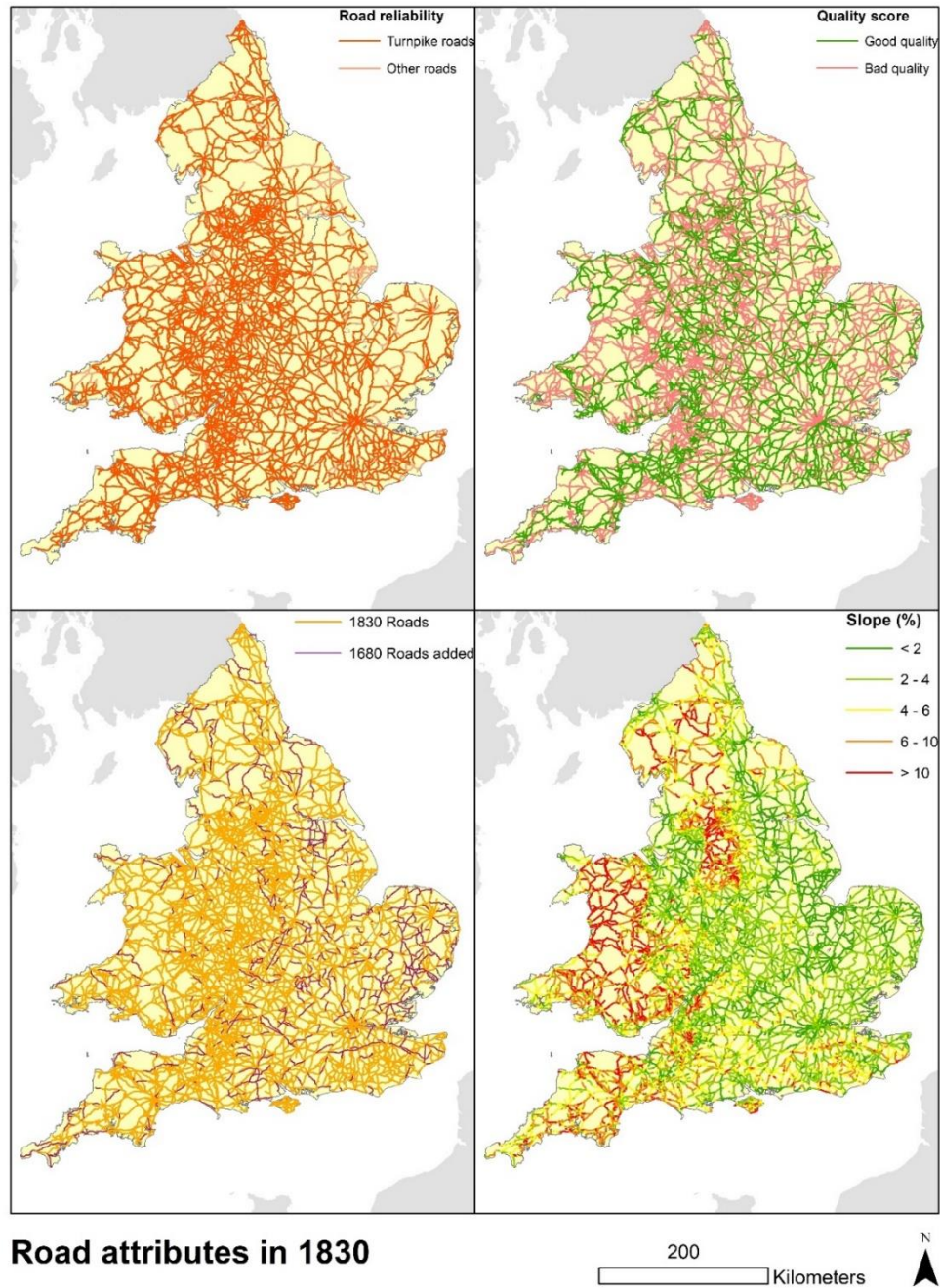


Figure B3: *Roads and attributes in 1680*

Notes: Author's creation using Satchell, Rosevear, Dickinson, Bogart, Alvarez, Shaw-Taylor (2017).

The GIS map of all turnpike trust roads was used as the starting point for selection in 1830 roads (see Rosevear *et al.* 2023). Polylines representing roads were selected first on the basis of the start date of the turnpike trust and all those with a date after 1830 are excluded. A map of turnpike roads in 1830 is shown in the upper left box of Figure B4. We add to the 1830 roads GIS. First, other main roads were added to link a small number of towns to the turnpike network, ensuring complete connection. Together they form our main road network for 1830, which we call Road_1s. Second, we add quality measures. The parliamentary report 'Appendix to the report of the commissioners for inquiring into the state of the roads in England and Wales,' British Parliamentary Papers' (BPP 1840 XXVII), includes an assessment of the road quality. Several classifications are given from poor, average, above average, good, very good, and excellent. From these we derive a road quality score of 1, 2, 3, 4, 5, and 6, where 6 is excellent and 1 is poor. For illustrative purposes, we create a simple quality classification 'Good' if the road was described as good, very good, and excellent, scores 4, 5, or 6. Otherwise, it is classified as 'Bad' (i.e., scores 1, 2, 3, or blank). The mapping of road quality is shown in the upper right box of Figure B4.

There were some 1680 roads that were not included in the 1830 turnpike network. However, we think it is likely those roads were used. Therefore, we include 1680 roads in the 1830 network and refer to them as secondary roads, Roads_2nd. The latter are shown in the lower left-hand box of Figure B4. Note they are classified as 'bad' on the quality metric. This assumption is reasonable as most were maintained by parishes and were generally of lower quality. Finally, as with 1680 roads we add slopes to each road segment. The slopes are shown in the bottom right box of figure B4.



Road attributes in 1830

Figure B4: *Roads and attribute data in 1830*

Notes: Author's creation using Rosevear *et al.* 2023 and other sources in text.

Bridges and Ferries were also added to the roads GIS files for 1680 and 1830. We identified four major categories of bridges in our sources. First, toll Bridges, which were generally new structures built during the period when roads were being turnpiked. Second,

county bridges, which were old bridges that by 1700, were already the responsibility of the county or counties on the river bank. Third, free bridges were built by a trust or a commission that did not levy a toll on users. Fourth, turnpike road bridges were new bridges built under the Act authorizing a new turnpike trust. In the roads GIS, bridges were plotted as polylines joining roads on the adjoining banks. The OS 6 inch first edition was used to locate the bridge alignment where possible. All bridges that were not part of a turnpike trust were added as discrete elements and associated data was that of the Bridge Trust or administrative unit. Bridges that were part of a turnpike trust were drawn as discrete polylines, but the associated data was that of the turnpike trust. Where several bridges or ferries were recorded at a location, the bridge in use in 1830 was given priority as the straight line joining the abutting roads. In our network, bridges are disconnected segments referred to as xRh_Ro_RoWa.

Ferries using boats were often the first major investment made at a river crossing (sometimes replacing fords which were dangerous and seasonal). Charges were made to use the ferry and could be lucrative. All instances where a bridge building Act mentions an earlier ferry were recorded and the date at which the ferry was replaced by the bridge noted. A sketch map of major Medieval Ferries was georeferenced and matched with potential ferry sites on Roads GIS. The OS 6 inch First series was inspected for all major rivers starting from the estuary and moving up stream along all significant tributaries. All ferries marked on this map were recorded. A google search for ferries on major rivers was used to confirm information on the possible earliest date and where applicable date of closure of ferries. In the Roads GIS, ferries were plotted as polylines joining roads on the adjoining banks. Where the ferry was replaced by a bridge, the most direct line was used for the bridge and the ferry was drawn displaced slightly from the bridge but with lines joining to the bank where bridge, road and ferry meet.

Many ferries (particularly those surviving into the 19th century) were not connected to the turnpike network. In order to incorporate these into the 1680 network, link roads to the nearest main road were drawn using the OS 6 inch First Series maps and these link roads to a ferry crossing designated (XLR).

B.1 The Grand Cross

The Grand Cross canals play a key role in our identification strategy. Figure B5 shows a conceptualization 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.

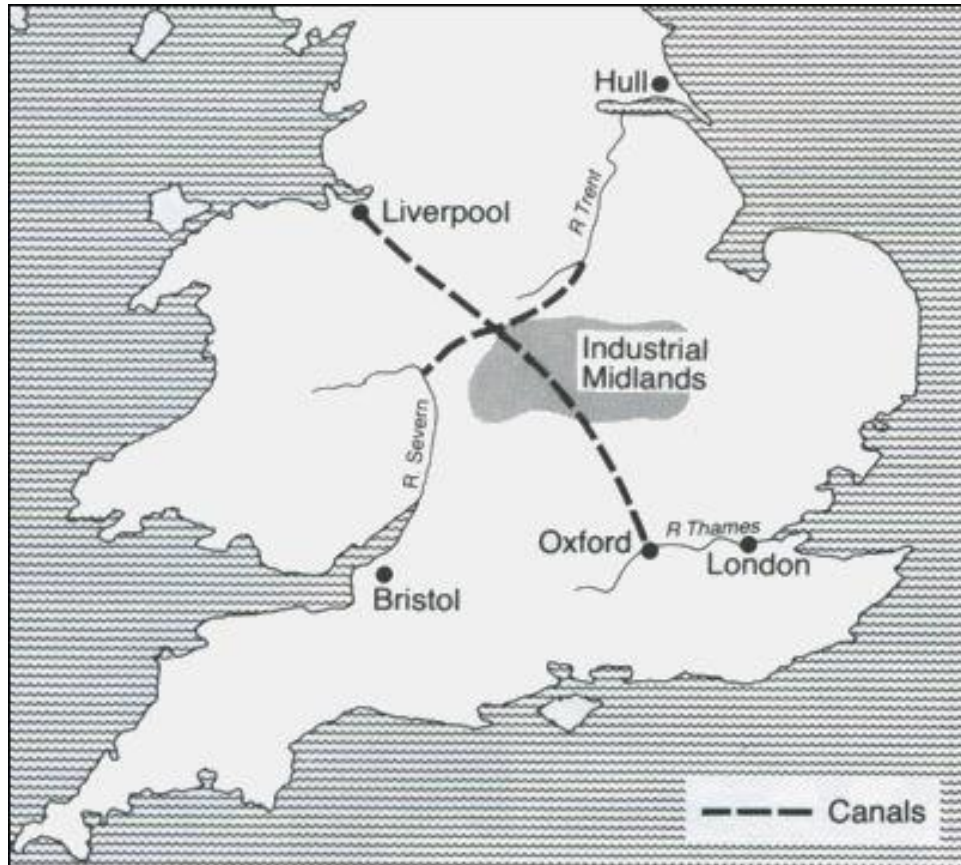


Figure B5: *Conceptual illustration of the Grand Cross Plan*

Notes: The "Grand Cross" of canals

<http://www.thepotteries.org/location/districts/boathorse2.htm>.

Accessed on 1 January 2023.

Figure B6 is a map of planned canals around 1779 by Hugh Henshall and John Cary. We use this map as the basis for identifying 17 built canals or river navigations that were described in the Plan. We also use it to identify 'incidentally connected' towns as explained in the text.

Chorley in Lancashire is an example of an incidental town named on the map but not depicted as being on the route of the canals or navigations.

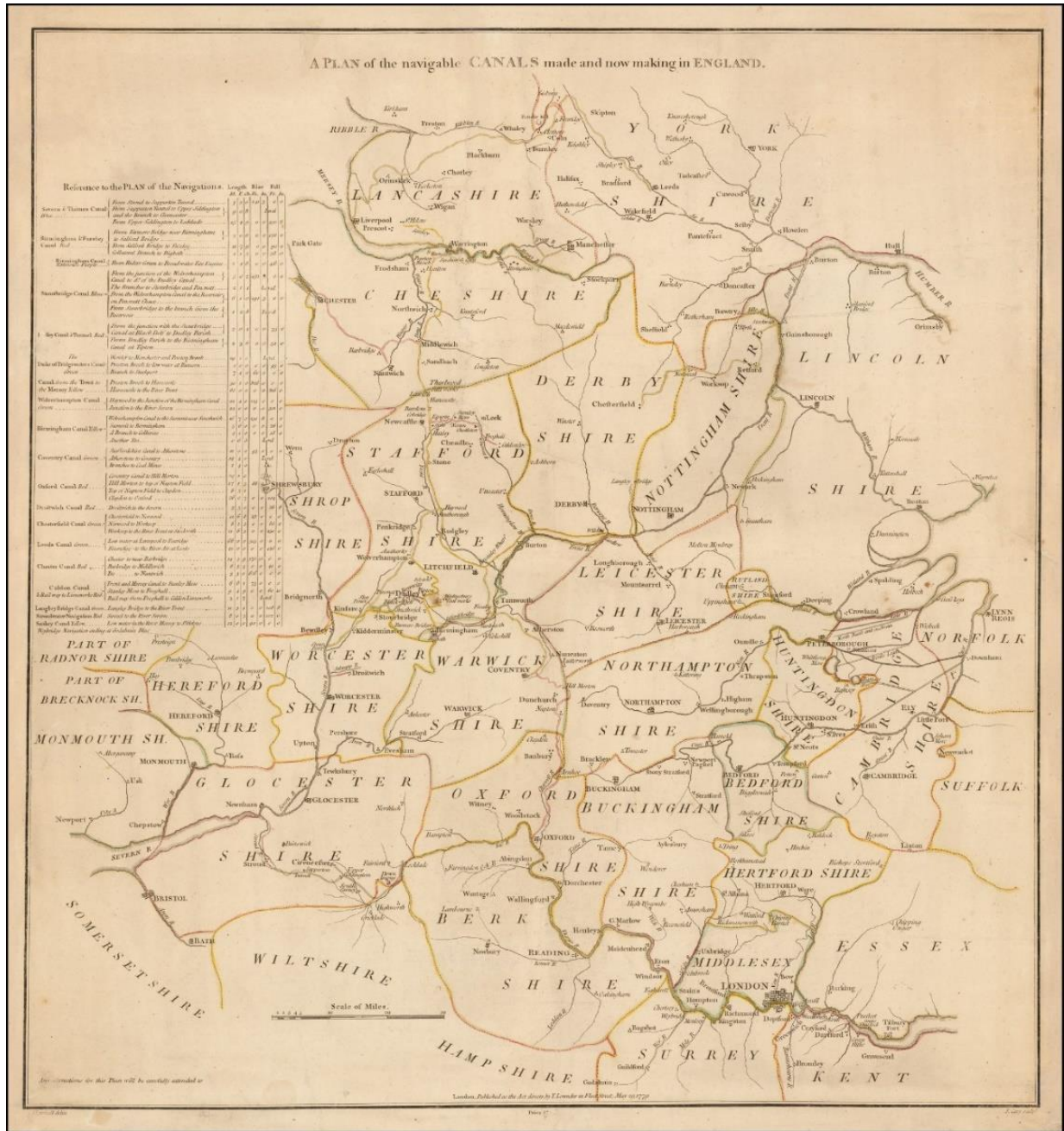


Figure B6: A plan of the navigable canals made and now making in England, 1779 by Hugh Henshall and John Cary

Notes: Antique Maps, <https://www.raremaps.com/gallery/detail/50049/a-plan-of-the-navigable-canals-made-now-making-in-england-henshall>. Accessed on 1 January 2023.

We close this appendix by giving more background discussion of the Grand Cross Canals and later canal development. The Trent and Mersey Canal provided a key link in the early stages of the Grand Cross Plan. 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 southerly 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. 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.

Later canals also provided important links, addressing some limitations of the Cross Plan. 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.

C. Freight rates, estimating transport costs, and producer prices

In this appendix we first discuss the sources for freight rates. They form the basis for per ton mile and per ton rates in our network model, which we explain in the next sub-section. Table C1 repeats Table 1 in the text and gives the source basis for each modal freight rate or fee. Nef (1979, pp. 404-412) gives figures for coastal freight and port loading costs in the important northeast coal trade between London and Newcastle around 1690. We convert Nef's freight costs into a per ton mile rate using coastal distance between Newcastle and London and the Nef loading cost into a per ton flat figure.⁶⁷ For 1830, we use a parliamentary report on the coastal coal trade around this year from the British Parliamentary Papers (1836, State of Coal trade, p.76). One of the most often-cited witnesses in the report, Bentley, gives figures for loading costs and coastal freights at that time (see Ville 1986 for additional discussion). Comparing with our converted figure from Nef, Bentley's testimony implies that the coastal freight rate fell from 0.21 to 0.17 pence per ton mile between around 1690 and 1830. The per ton loading cost fell from 27.1 to 22.9 pence.

Table C1: Per ton mile rates or fees for multi modal models in 1680 and 1830.

| Year | 1680 | | 1830 | |
|--|-------------|--------------------|-------------|-----------------------|
| | Rate or fee | source basis | Rate or fee | source basis |
| Coastal sea transport rate in pence per ton mile | 0.211 | Nef (1979), p. 412 | 0.168 | Bentley in BPP (1836) |
| Sea port fee in pence per ton | 27.1 | Nef (1979), p. 404 | 22.9 | Bentley in BPP (1836) |
| Trans-shipment fee for changing at road, water, or seaports in pence per ton | 17.14 | Nef (1979), p. 404 | 13.9 | Bentley in BPP (1836) |
| inland waterways freight rate in pence per ton mile | 1 | Willan (1964) | 2 | Allnut (1810, p. 20) |
| lock fee in pence per ton | n.a. | | 1 | Priestly (2014) |

⁶⁷ Note there was a tax on sea coal brought into London which Nef details. We do not include this sea coal tax in our coastal loading or freight costs for two reasons. First, the tax was specific to the northeast coal trade and second we want to model coastal freight costs for all heavy products, including grain which was not subject to this tax.

| | | | | |
|--|-----------------------|---|-----------------------|---|
| Lowest quality road freight rate in pence per ton mile (function of height/length) | $11.2+(h/l)*(298.67)$ | Gerhold (2005), MacNeil (BPP 1833, p. 12) | $9.87+(h/l)*(238.93)$ | Gerhold (1996), MacNeil (BPP 1833, p. 12) |
| Highest quality road freight rate in pence per ton mile as a function of height/length | $9.97+(h/l)*(298.67)$ | Gerhold (2005), MacNeil (BPP 1833, p. 12) | $7.5+(h/l)*(238.93)$ | Gerhold (1996), MacNeil (BPP 1833, p. 12) |
| ferry pence per ton | 1 | Willan (1964) | 2 | Allnut (1810, p. 20) |

Notes: (h/l) means height/length of the segment or slope. N.a. is non-applicable. For more details see the text.

Willan (1964) summarizes inland waterway freight rates around 1700 as being 1 pence per ton mile. This figure applies to tidal rivers, like the Thames, which were then the main waterway. For 1830, we use Allnut (1810), who summarized freight rates on the river Thames as being 2 pence per ton mile. Allnut also gives figures for several canals. They were more expensive than tidal rivers. One key factor was the number of locks, which we have included in our network data. Priestley (2014), a reprint of his 1831 book, gives a case where the cost of passing an individual lock was 1 pence per ton. We use the per lock cost to augment the 2 pence per mile cost of using canals.

Several road freight rate observations in the late seventeenth century are given by Gerhold (2005), and separately for wagons and packhorses. The average for wagons was 10.6 pence per ton and the average for packhorses was 11.9. For 1830 Gerhold (1996) reports a road freight rate of 7.5 pence per ton mile between London and Leeds. This rate comes from a large overland trade in woolen textiles, and along one of the best roads in England at the time. However, not all road transport was as cheap as between Leeds and London due to varying road quality. Contemporary engineers, like John McNeil, noted that draught animal power changed significantly with road quality and slope. In testimony to parliament, McNeil provided a formula based on several field experiments (BPP 1833, p. 12). The formula computes draught power based on road condition and slope. McNeil's formula is used to estimate the freight rates per ton mile on turnpike roads of different quality and with different slopes. The quality metrics were described for road networks in Appendix B. Slope was obtained by extracting elevation values in the vertices of the road segment and dividing by the length between them. Table C1 summarizes

our estimates for per ton-mile road freight rates in 1680 and 1830 for the highest and lowest quality roads and depending on slope.

C.1 Estimating transport costs using a multi-modal model

Our new multi-modal model is used to calculate freight transport costs between 590 E&W towns in 1680 and again in 1830. The 590 towns are those with a population of at least 2,500 in 1680, 1801, or 1841 according to Langton (2000). Transport costs were calculated in ArcGIS using geodatabases called Multimodal1680 and Multimodal1830, see the replication file data\raw\GIS\Multimodal model 1680 and 1830 EJ replication.docx for full details. The model is made starting with the historical GIS transport networks described in Appendix B: Coastal_1s, Coastal_2nd, Waterways_1s, Waterways_2nd, Roads_1s, Roads_2nd, Ferries, and xRh_Ro_RoWa, representing bridges. These networks required topological cleaning to ensure there were no drawing errors, unwanted intersections or gaps. It ensured all networks were routable, and therefore suitable for network analysis. The next step was the amalgamation of different networks into one multimodal model including all contemporary transport modes. It included transport infrastructure, such as roads, waterways and coastal routes, plus all those punctual items needed in the model, like towns and ports.

Once the multimodal networks were made, we created a GIS feature dataset containing a copy of all the previous features. Then we created a network dataset including all features, allowing global turns, applying the appropriate connectivity policies (one independent group for each mode of transport), adding elevation data (included in the features) and defining the appropriate freight cost parameters.

The multimodal model is fully summarized in files called NetworkModel_ND, which are contained in Multimodal1680.gdb and Multimodal1830.gdb as part of our replication files. In the summary document, Multimodal model 1680 and 1830 EJ replication.docx, we give the freight rates and freight costs used with networks and junctions, which are either ports or transshipment points (crossings between roads and waterways). In ArcGIS, the right two columns are shown as costs in the travel attribute properties of NetworkModel_ND geodatabases of each year. Note we convert the historical parameters to pence per ton meter rates by dividing the ton mile freight

rates by 1609.34. For example, 1 pence per ton mile is 0.000621373 pence per meter. There will be small rounding errors in the conversion.

The output of our multi-modal model yields calculated freight transport costs in pence per ton between 590 towns in 1680 and 1830. Accounting for symmetry, we estimate 174,343 unique transport costs between town pairs in each year. We refer to the calculated transport cost between town i and j as tc_{ij} .

C.2 Construction of producer prices

Next, this appendix explains how we determine the average producer price in 1680 and 1830, which is used with transport costs to calculate trade costs. Our preferred price uses a weighted average of the per ton price of coal and grain, with the weights being 0.92 coal and 0.08 grain. There are data limitations in our context and we don't know the composition of all traded goods. However, there is good data on coastal shipping tonnage and on this basis, Armstrong and Bagwell (1983) document that coal and grain were the top two goods in terms of coastal shipping tonnage. Thus, we focus on coal and grain for making producer prices. Note, we classify grain as wheat, barley, and oats.

Armstrong and Bagwell (1983, p. 154) report the coal carried coastwise from 1818-1829. The average per year was 4,761,000 tons. Armstrong and Bagwell (p. 156) also report that coastal grain shipments were 406,800 tons per year between 1819 and 1827 (169,700 tons of wheat, 126,500 of barley, and 110,600 of oats). Using these figures, we estimate that in total 5,167,800 tons were shipped between these two categories of goods. Coal represented approximately 92% and grain 8%.

Assuming coal and grain were the only two goods shipped, we calculate the producer price by multiplying the tonnage share of each good by their price per ton. Separating grain into the three types (wheat, oats, and barley), the formula for producer price P_t was the following

$$P_t = \alpha_{coal}coalpricepertont_t + \alpha_{wheat}wheatpricepertont_t + \alpha_{oats}oatspricepertont_t + \alpha_{barley}barleypricepertont_t$$

where $\alpha_{coal} = 0.921$, $\alpha_{wheat} = 0.032$, $\alpha_{oats} = 0.024$, and $\alpha_{barley} = 0.021$.

The next step is to identify the per ton prices of coal and the three types of grain around 1680 and again around 1830. Our ideals are the pithead price, near where coal was mined, and the farmgate price, near where grain was produced. Here the data sources vary and so we need to be flexible with dates. One can find references to the price of coal in Newcastle in the late 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. Houghton's data are published in Rogers (2010). There we find prices for coal in Newcastle and near Carlisle and Penrith in Cumberland (CU). The price of Newcastle coal was very stable at around 46 pence per ton (assuming the Newcastle chaldron is around 53 cwt). The price in Cumberland was also stable around 70 pence a ton. We then find coal prices in the same two locations from the Poor Law Union (PLU) data c.1843, see Satchell, Bogart, and Taylor (2016) for the PLU data and see Satchell (2017f) for a description. This dataset shows that coal prices in Newcastle and in Cumberland were 63.6 and 108 pence a ton respectively. 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.

Next, we focus on grains, 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 were in the top category in 1801 and 1841: Kent, Sussex, Hampshire, Buckinghamshire, Warwickshire, Shropshire, Cheshire, West Riding, Durham, and Essex. For barley the following counties were in the top category in 1801 and 1841: Hampshire, Huntingdon, and Rutland. For oats, the following counties were in the top 2 categories in 1801 and 1841: Derby, Chester, Durham, and Northumberland.

Next, we 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 give grain prices.⁶⁸ 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. For some calculations, it is useful to report that the weighted average per ton price of grain was 784 pence in 1680 and 1954 pence in 1830, where we use the shares of wheat, barley, and oats in coastal trade. Table C2 summarizes the calculations of our preferred producer prices in 1680 and 1830.

Table C2. Details for calculating Producer prices in 1680 and 1830.

| Good | Estimate tons carried coastwise c.1830 in thousands of tons | Share of coastal tons | 1680 price in pence per ton | 1830 price in pence per ton |
|--------|---|-----------------------|--|-----------------------------|
| wheat | 169.7 | 0.032844 | 1179 | 2834 |
| Barley | 126.5 | 0.024483 | 624 | 1461 |
| Oats | 110.6 | 0.021406 | 360 | 1162 |
| Coal | 4761 | 0.921460 | 58 | 86 |
| | | | Producer price of traded good in pence per ton | |
| | | | 115.15 | 232.97 |

Notes: Coastal shipping tonnage comes from authors calculations drawn from Armstrong and Bagwell (1983, pp. 154-156). The prices of goods are based on sources described in the text. The formula for the producer price is $P_t = \alpha_{coal}coalpriceper ton_t + \alpha_{wheat}wheatpriceper ton_t + \alpha_{oats}oatspriceper ton_t + \alpha_{barley}barleypriceper ton_t$ where $\alpha_{coal} = 0.921$, $\alpha_{wheat} = 0.032$, $\alpha_{oats} = 0.024$, and $\alpha_{barley} = 0.021$.

In an extension, we estimate producer prices as the weighted average of the per ton price of coal and grain, with the weights being 0.6 coal and 0.4 grain. However, we think the extension over-states the value of non-coal shipments as we explain below. We start the extension by estimating the share of coal in tonnage across all transport modes. There are two broad data points we use, one of which comes from railways in the mid-19th century. Railways are useful for

⁶⁸ For more information, visit: <https://www.cornreturnsonline.org/>.

identifying inland traffic shares around 1830 even though they come later. Hawke (1970, p. 71) reports that minerals (mainly coal) were 62% of railway tonnage in 1856 and general merchandise (including grain) was 38%. Livestock was excluded. The railway returns generally confirm the composition of traffic in 1859, where 22,381,144 tons of minerals were shipped, largely coal, and 11,584,872 tons of general merchandise (livestock excluded). The mineral share was 66%.

The second data point is coal's share in total coastal trade. Armstrong and Bagwell (1983, p. 155) estimate that 42% of all coastal shipping capacity was devoted to coal around the year 1830. Briefly, Armstrong and Bagwell estimate total tonnage by assuming that annual registered tonnage of individual ships should be multiplied by 11 (for 11 trips a year) and a registered ton should be multiplied by 1.35 (as registered tons were less than actual tons). We try to replicate their calculations and find there were approximately 12.25 million tons of coastal shipping capacity around 1830. Armstrong and Bagwell then compare with reported amounts of coal tonnage shipped coastwise in the late 1820s, approximately 5 million tons (we think the 5 million are actual tons, or 1.35 times a registered ton for a ship). Coal represents $5/12.25$ or 41% of the total capacity by these calculations.

There are some issues with the assumptions made by Armstrong and Bagwell. Few ships would have made 11 trips a year outside of the northeast coal trade. If we assume 9 or 10 trips that would reduce estimated total capacity to 10.0 or 11.1 million tons and that change alone makes coal's share 45 or 50%. It is also possible that non-coal coastal shipments had less usable capacity and so the 1.35 mark-up of registered tonnage is an over-statement (or coal shipped coastwise was also in registered tons, hence there should be no mark-up). If we assume a smaller mark-up of 1.25 for all ships and 9 trips a year, then coal's share is 54%. Thus, we think it is more reasonable that coal represents 50-55% of coastal shipping capacity.

To summarize, coal was 62-66% of railway tonnage in 1856, which would capture the inland segment of transport, and we think coal was approximately 50-55% of coastal shipping tonnage in 1830. A rounded, mid-range between these two figures is 60% or a 0.6 coal share in all transport tonnage. We use this assumption in our extension. We don't know with precision which goods account for the remaining 40% of transport tonnage. We know that grain can

account for a smaller share. However, it is useful to assume grain represented all remaining goods as it is a medium-value product, and therefore will tend to provide more of an upper bound on our producer price. Table C3 summarizes the calculations of producer prices in 1680 and 1830 for our extension.

Table C3. Details for calculating producer prices in our extension using a weighting of 0.6 for coal and 0.4 for grain prices.

| Good | Estimate tons carried coastwise c1830 in thousands of tons | share of coastal tons | Share assuming grain 0.4 & coal 0.6, with grain shares determined by coastal | 1680 price in pence per ton | 1830 price in pence per ton |
|--|--|-----------------------|--|-----------------------------|-----------------------------|
| wheat | 169.7 | 0.032844 | 0.167275 | 1179 | 2834 |
| barley | 125.5 | 0.02429 | 0.123706 | 624 | 1461 |
| oats | 110.6 | 0.021406 | 0.109019 | 360 | 1162 |
| coal | 4761 | 0.92146 | 0.6 | 58 | 86 |
| Producer price of traded good in pence per ton | | | | 348.45 | 833.07 |

Notes: For sources, see table C3.

We close this Appendix remarking that the extension may over-state producer prices, as they assume all non-coal goods were as valuable as grain. Data on shipments by canal suggest more low-value goods were shipped. For example, Maw (2013) reports that on the Rochdale Canal coal was 33% of the tonnage in 1835. Next was corn (i.e., grain) at 12%, goods at 11%, stone at 16%, sundries at 18%, timber at 5%, lime at 4%, wool at 1%, and salt at 1%. Note that after coal and goods, 27% of tonnage was clearly low value products: stone, timber, lime, wool, and salt. The label, goods, probably reflect higher value items, but its tonnage share was only 11%. The unknown category, sundries, is hard to evaluate based on value. Overall, it is possible that much of the tonnage of non-coal traded goods was less valuable than grain.

D. Market integration and reliability of trade cost estimates

The first goal of this appendix is to give evidence that coal market integration increased, consistent with trade costs falling. We observe average coal prices between 1691 and 1703 for 53 towns. These price data are digitized by the authors of this paper from Rogers (2010), which are derived from Houghton’s contemporary price lists (see `data\raw\coal_poorlaw1842_43_Houghton1691_1703.xlsx`). They have been matched to our list of towns described in Appendix A. We also observe coal prices for 249 Poor law unions in 1842 and 358 Poor law unions in 1843. These price data have been digitized by Satchell, Bogart, and Shaw-Taylor (2016). They are described in the replication file, `data\processed\towns_coalprices\poorlawunioncoalprices1842-3documentation.pdf` made by Satchell (n.d.). The urban poor law unions have been matched to our list of towns described in Appendix A using town name. We match 35 towns with price observations both in 1691 to 1703 and in 1842. This first match is shown in the replication file, `data\processed\towns_coalprices\coalpricetownmatch1700_1842_EJ.xlsx`. We also match another 13 towns which are close to one another and have prices in both periods, which we call second match. In table D1 we report coal prices for 35 towns with data in both our periods (i.e., the firstmatch). At the bottom, summary statistics are reported. Importantly, the coefficient of coal price variation, CV, was 0.37 for the sample between 1691 and 1703, while the CV across the same 35 towns was 0.31 in 1842. The lower CV is one indication of greater market integration. The sample with 48 towns (i.e., second match) yields a similar conclusion that the CV in coal prices declined.

Table D1. *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 |

Notes: Authors calculations using Houghton's coal prices digitized from Rogers (2010) for 1691 to 1703 and Poor Law Union (PLU) coal prices from Satchell, Bogart, and Shaw-Taylor (2016) for 1842.

Next, we show that the ratio of London to Newcastle coal prices declined from 1805 to 1845. We observe the average Newcastle price of coal in shillings per ton from 1801 to 1845 using data from Porter (1851). We also observe the London price of coal in shillings per London chaldron using data from a report by the Coal Commission in the British Parliamentary papers (1871). We convert the London price to shillings per ton, assuming the London Chaldron was 26cwt and a ton was 20cwt (see replication file, data\raw\newcastlelondoncoalprices_EJ.xlsx).

We then calculate the ratio of the London to Newcastle price. In Figure D1 we see that the price ratio fell over time, supporting the argument actual trade costs fell on this important route.

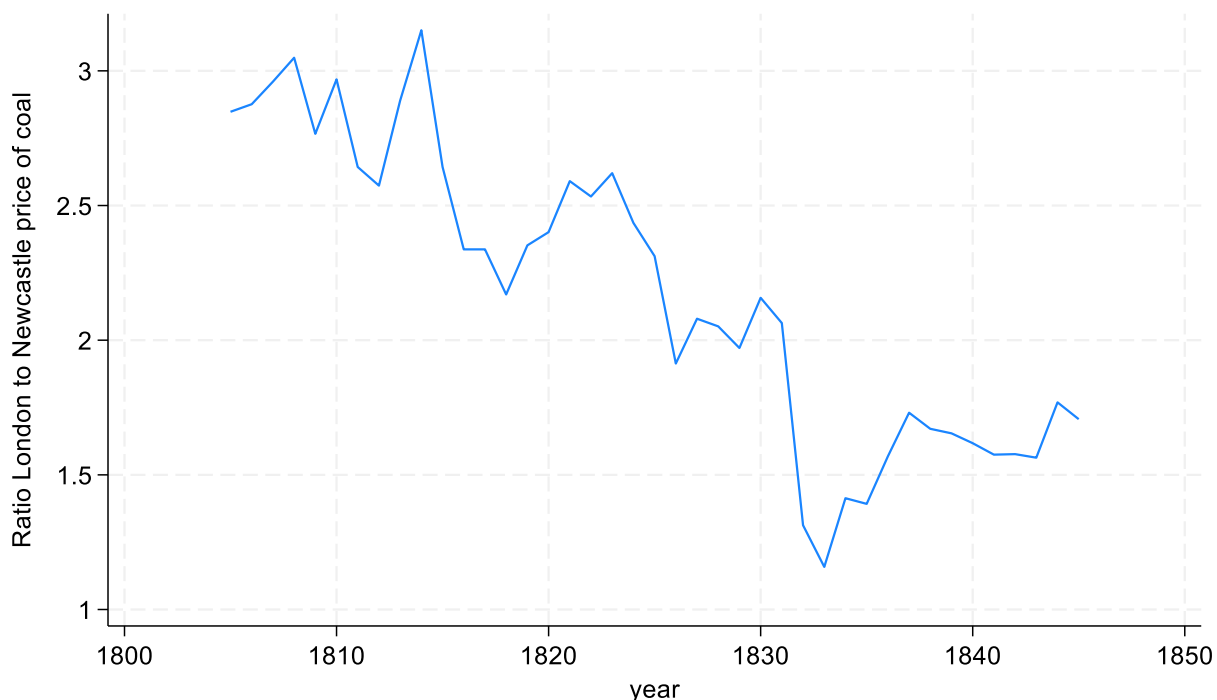


Figure D1 The ratio of London to Newcastle coal prices, 1805-1845

Source: For Newcastle we use Porter (1851, p. 277) who reports prices in shillings per ton. For London we use the Coal Commission (BPP 1871, appendix Table 152, p. 1292), which reports best coal at the ship-side in June expressed in shillings per ton. For making the graph, see the replication file `data/processed/towns_coalprices/LondonNewcastlepriceratio.xlsx`

In the last part of this appendix, we show that our estimated trade costs are similar to observations of actual trade costs. We know that coal was shipped from two major coastal suppliers, Newcastle and South Wales, and to some degree the northwestern coalfield in Lancashire. Drawing on the law of one price, the ratio of coal prices in any importing port relative to its nearest supplying port should equal $(t_{is} + p_s)/p_s$, where t_{is} is the cost of moving a ton of coal from the supplying port s to the importing port i , including any taxes, and p_s is the per ton price of coal in the supplying port. We examine this framework with some data limitations as we explain. First, we calculate the ratio $r = (tc_{is} + P)/P$, where tc_{is} is our estimated per ton transport cost from port i to their nearest supplying port s and P is the average of the price of

coal, 58 pence per ton in 1680 and 86 pence per ton in 1840. We then compare r with the actual coal price ratio p_i/p_s for the selected ports where we observe coal prices around 1700 and 1840.

In practice, we first identified all towns that were within 10 km of a port in 1826 or 1842. Second, we identified 16 towns where we observe some coal prices between 1691 and 1703 using our digitization of Rogers (2010). Third, of these 16 towns, we identify 8 coastal towns that were not major suppliers of coal and have coal prices in the years 1697 to 1702, when there was peace. We believe the coal prices in the peace-years are a better comparison to trade costs for our multi-modal model in 1680. Fourth, we identify whether each of these 8 towns was closer to Newcastle or the South Wales coalfield based on distance through our coastal network. The closest is defined as the supplying port for the town. Fifth, we calculate the price of coal in coastal towns relative to their coastal supplier p_i/p_s and the estimated trade cost between the same two, $r = (tc_{is} + P)/P$. For 1697 to 1702 we use Pembroke's price as representative of the South Wales coalfield, see the replication file `data\processed\towns_coalprices\taucoalprice1680_EJ.xlsx`. Table D2 reports the results for 8 coastal towns around 1700. Note if the supplier price is 46 pence per ton, then Newcastle was the closest supplier and if it was 137 pence, then it was Pembroke. The key finding is that the correlation between r and observed price ratios was quite high in 1700, giving us confidence that our estimated transport costs around 1680 contain useful information.

Table D2. *Coal prices in coastal towns and their supplier around 1700 compared with estimated trade costs 1680*

| TOWN.COUNTY | 1 Av. coal price, 1697_1702 in coastal town | 2 Av. coal price, 1697_1702 for supplier | 3 ratio 1:2 | 4 r=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 |

Notes: Authors calculations using Houghton's coal prices digitized from Rogers (2010) and estimated transport costs in 1680.

A similar set of calculations were made using 1842 coal prices and 1830 trade costs. We first identify all towns that were within 5 km of a port in 1826 or 1842, which we consider coastal towns. Second, we identify 50 coastal towns where we observe coal prices in 1842 and measure trade costs. Third, we identify whether each of these 50 towns was closer to Newcastle, the South Wales coalfield, or the northwestern coalfields along the coast of Lancashire, based on distance through our coastal network. Fourth, like before, we calculate the price of coal in coastal towns relative to their coastal supplier p_i/p_s and the estimated trade cost between the same two, $r = (tc_{is} + P)/P$, see the replication file: data\processed\towns_coalprices\taucoalprice1830_EJ.xlsx. The results are shown in Table D3. Here we generally find that trade costs, r , were less than the observed price ratio p_i/p_s , which is expected as coastal shipments of coal were taxed above the transport costs. More importantly, the correlation between r and observed price ratios is reasonably high for 1830/42. Again, the correlation gives us confidence that our estimated transport costs contain useful information.

Table D3. *Coal prices in coastal towns and their supplier in 1842 compared with estimated trade costs in 1830*

| TOWN.COUNTY | 1 Av. coastal town coal price, 1842 | 2 Av. coastal supplier coal price, 1842 | 3 ratio 1:2 | 4 r=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 |
| WOODBIDGE.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

Notes: Authors calculations using 1842 PLU coal prices and estimated transport costs in 1830. See Satchell, Bogart, and Taylor (2016) for the PLU data and see Satchell (2017f) for a description.

E. Market access calculations and summary statistics

As stated in the text, we start by calculating market access using the simplified formula, $MA_i = \sum_j^J pop_j \tau_{ij}^{-\theta}$, where in our case i is a town, pop_j is the population of other towns j , indexed from $j = 1, \dots, n$, and τ_{ij} are trade costs between i and j , and θ is a scaling parameter. We make separate market access variables for $\theta = 1, 2, 4$, and 8 using the 461 towns with observed, or non-missing population in 1680 and 1841. Once θ is selected, market access for town i is calculated by multiplying the $1 \times n$ vector $pop = (pop_1, pop_2, \dots, pop_n)$ by the $n \times 1$ i 'th row of the trade cost matrix τ to the power $-\theta$, or $(\tau_{i1}^{-\theta}, \tau_{i2}^{-\theta}, \dots, \tau_{in}^{-\theta})$. The 1680 calculation calls on the 1680 town population data and 1680 trade costs between all towns i and j . The 1830 calculation calls on the 1841 town population data and 1830 trade costs between all towns i and j . The calculations are seen in the replication files `data\processed\market_access_simple\marketaccess_simple_1680_EJ.xlsx` and `data\processed\market_access_simple\marketaccess_simple_1830_EJ.xlsx`. The correlations in table 2 are produced using these market access variables after deducting own town population, e.g., $MA_i = \sum_j^J pop_j \tau_{ij}^{-\theta} - pop_i$.

Market access values differ depending on the value of θ . We now explain how we identified our preferred θ . We start by calculating MA_{i1680} and MA_{i1830} using the simplified formula for $\theta = \{1, 2, 3, \dots, 10\}$. We then estimate our baseline specification given by equation (4) in the text, $\Delta \ln pop_i = \beta \Delta \ln MA_i + \gamma \cdot x_i + \varepsilon_i$, where x_i contains geographic and pre-industrial controls, along with county fixed effects as in column 4 of table 3 of the text. We use maximum likelihood and calculate the value of the log likelihood function for each specification of θ . Figure E1 shows the log likelihood values for theta between 1 and 10. We identify that $\theta = 2$ is associated with the highest log likelihood. Henceforth, we work with $\theta = 2$. However, as we show later in this appendix, our econometric estimates are qualitatively similar with other values of θ .

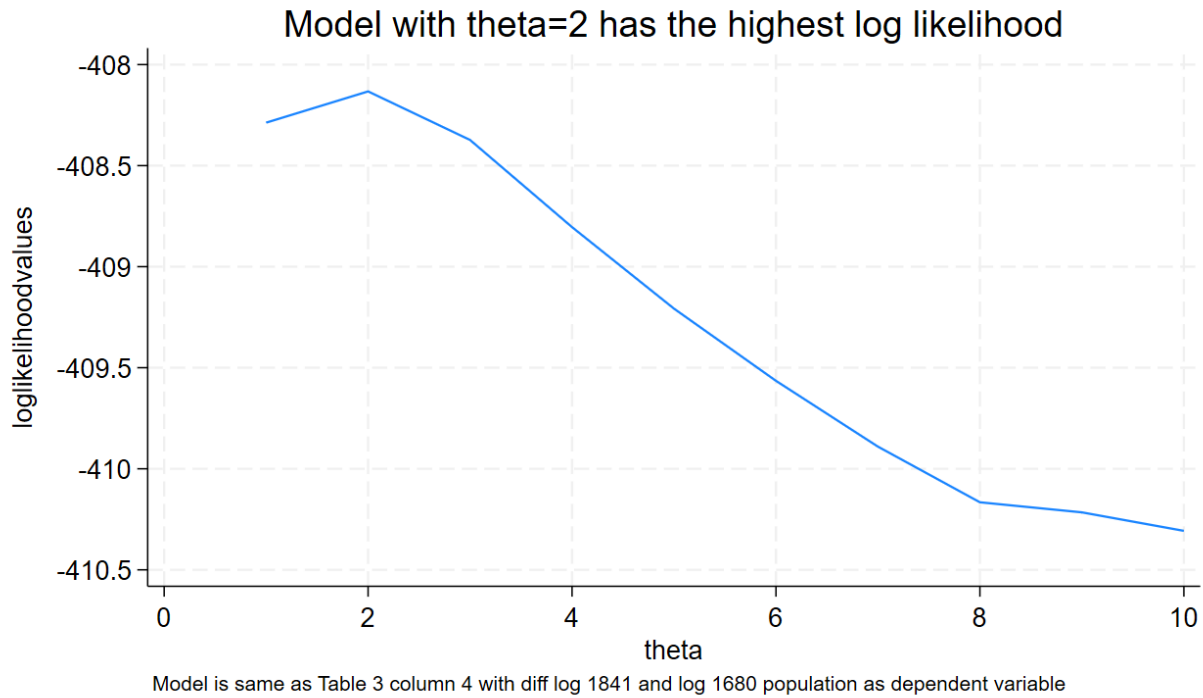


Fig. E1. Values of log likelihood for specifications identical to column 4, Table 3, except using different values of theta.

Notes: Authors calculations. Theta is in the calculation of market access using the simplified formula. See the replication code makefigureE1.do for details.

Next, using $\theta = 2$ we calculate our preferred market access defined by equation 2 in the text for 461 towns with non-missing population in 1680 and 1841. In our replication materials, there is a Matlab file (data\processed\market_access_model\basemacode_coalgrain_theta2\solve_marketaccess461towns.m) which contains the summary code. It uses the FSOLVE function which draws on another Matlab file (to_solve2.m) defining the system of 461 equations in 461 unknowns MA_i based on equation 2. The 1680 calculation calls on the 1680 town population data and 1680 trade costs between all towns i and j in several spreadsheets contained in the file inputsolve1680ma461towns.xlsx. The 1830 calculation calls on the 1841 town population data and 1830 trade costs between all towns i and j in several spreadsheets contained in the file inputsolve1830ma461towns.xlsx. The outputs of these market access calculations are contained in the replication files

data\processed\market_access_model\basemacode_coalgrain_theta2\MA_1680_theta2model.xlsx and MA_1830_theta2model.xlsx, respectively.

Summary statistics for the main town variables are shown in Table E1, restricting to the sample of 448 towns which is used in the estimation. The mean difference in log population (1.682) implies an annual growth rate of 1.05% between 1680 and 1841, or a 437% increase. The mean difference in the baseline log MA_i (1.724) implies a 461% increase in market access from 1680 to 1830. The mean for $\Delta \ln MA_i$ using simplified market formulas is much larger.

Table E1. *Descriptive Statistics for urban population growth and market access change variables*

| VARIABLES | (1) N | (2) mean | (3) sd | (4) min | (5) max |
|--|----------|-------------|-----------|------------|------------|
| $\Delta \ln pop_i$, between years 1680 and 1841 | 448 | 1.682 | 0.818 | -0.307 | 5.467 |
| $\Delta \ln MA_i$, baseline, calculated from equation (2) | 448 | 1.729 | 0.587 | 0.620 | 3.755 |
| $\Delta \ln MA_i$, simplified | 448 | 3.376 | 0.773 | 2.026 | 5.767 |

Notes: For definitions of variables see text.

Table E2 reports correlation coefficients between the main variables. The difference in log town population is positively and significantly correlated with the two market access variables. The two market access variables are also highly correlated with each other.

Table E2. *Correlations urban population growth and market access change variables*

| | Correlation coefficient with | | |
|--|------------------------------|----------|------|
| | (1) | (2) | (3) |
| (1) $\Delta_{1841,1680} \ln pop_i$ | 1.000 | | |
| (2) $\Delta \ln MA_i$ baseline derived from equation 2 | 0.124*** | 1.00 | |
| (3) $\Delta \ln MA_i$, Simplified MA_i | 0.174*** | 0.962*** | 1.00 |

Notes: For definitions of variables see text. *, **, and *** indicates a statistically significant correlation at the 1, 5, and 10% levels respectively.

In Figure E2 we show the distribution for the variable, $\Delta_{1841,1680} \ln pop_i$, according to whether the town had above or below median change in market access growth, or $\Delta \ln MA_i = \ln MA_{i1830} - \ln MA_{i1680}$, where market access is based on the simplified formula: $MA_{it} = \sum_j^J pop_{jt} \tau_{ijt}^{-\theta}$. Towns with market access growth above the median had population growth that was at least 30% higher and the distribution of population growth was shifted to the right.

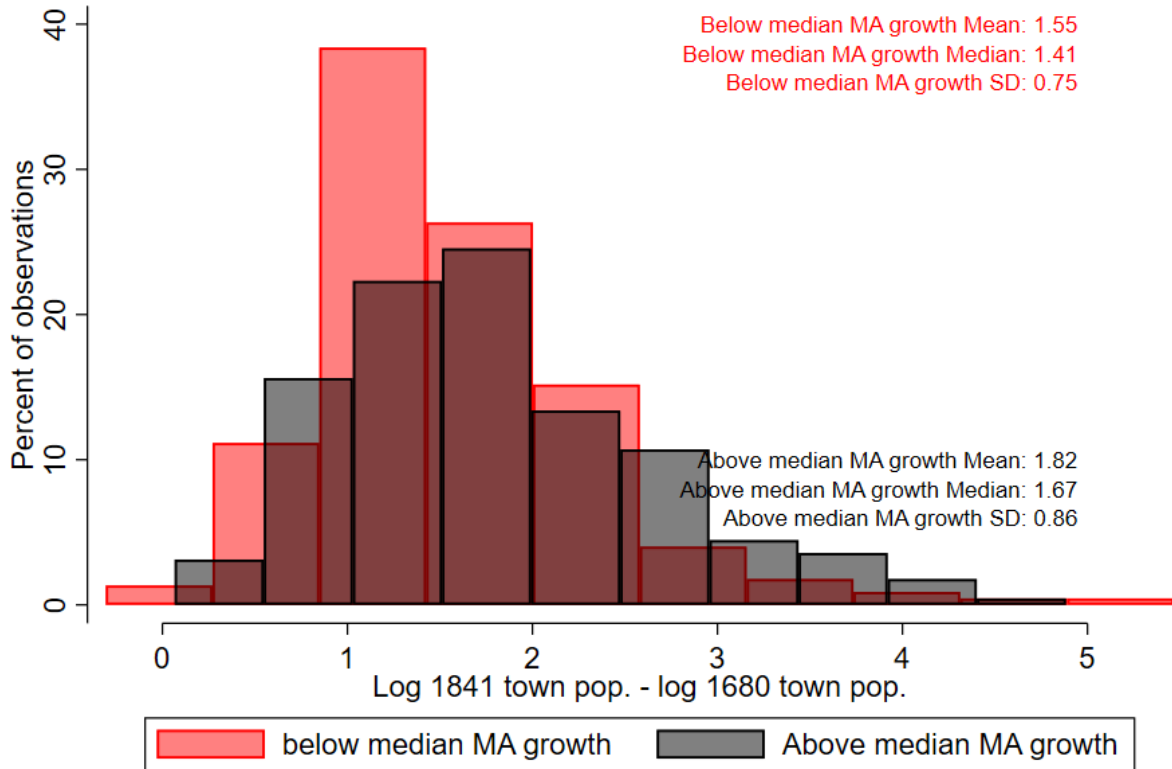


Fig. E2. Distribution of the difference between log 1841 population and log 1680 population according to whether the town had above or below median market access growth

Notes: Authors calculations. Market access growth is $\ln MA_{i1830} - \ln MA_{i1680}$, where $MA_{it} = \sum_j pop_{jt} \tau_{ijt}^{-\theta}$.

E.1 Market access calculations for 586 towns

We also calculate market access for 586 towns with observed population in 1841. Market access is first calculated using the simplified formula for $\theta = 1, 2, 4,$ and 8 . The 1830 trade costs for 586 towns and the calculated market access are in the replication file, `marketaccess_simple_1830_586towns.xlsx`. Market access is also calculated using equation 2 in the text for the same 586 towns with $\theta = 2$. The summary code is in the replication file `data\processed\market_access_model\basemacode_coalgrain_theta2_586towns\solve_marketaccess586towns.m`. It uses the FSOLVE function which draws on a Matlab file (`to_solve2.m`) defining the system of 586 equations in 586 unknowns, MA_i , based on equation 2. The 1830 calculation calls on the 1841 town population data and 1830 trade costs between all towns i

and j in several spreadsheets contained in the file `inputsolve1830ma586towns.xlsx`. The outputs of these market access calculations are contained in the replication file `MA_1830_theta2_586towns.xlsx`.

Summary statistics are shown in Table E3 for the variables used in sections 4 and 5, where we study effects of 1830 market access on 1911 population and 1843 property income. We restrict market access summary statistics to the sub-sample, where town 1911 population is observed ($n=568$). Market access is lower using the baseline formula from equation 2 compared to the simplified market access. Yet the two market access measures are correlated, with a correlation coefficient of 0.935. Town population in 1911 varies more than property income in 1843, consistent with some divergence between the dates.

Table E3. *Descriptive Statistics for town population 1911, town property income in 1843, and market access variables*

| VARIABLES | (1) N | (2) mean | (3) sd | (4) min | (5) max |
|---|----------|-------------|-----------|------------|------------|
| $\ln pop_{i1911}$, log town population 1911 | 568 | 9.505 | 1.252 | 7.422 | 15.69 |
| $\ln property_{i1843}$, log town property income 1843 | 539 | 9.992 | 0.953 | 7.425 | 16.17 |
| $\ln MA_{i1830}$, simplified, 586 towns | 568 | 14.13 | 0.340 | 12.73 | 14.87 |
| $\ln MA_{i1830}$, baseline calculated from equation (2), 586 towns | 568 | 5.895 | 0.414 | 4.535 | 7.116 |

Notes: Authors calculations. MA_{i1830} baseline is calculated from equation 2 using 586 towns with non-zero population in 1841. MA_{i1830} simplified uses the simplified formula in the text for 586 towns. For sources on 1911 population and 1843 property income see text.

In table 2 of the text, we reported a positive and significant correlation between the simplified market access and log town population in 1911, $\ln pop_{i1911}$. In Figure E3 we show the distribution of the log 1911 population, according to whether the town had above or below median Market access in 1830 (using the simplified formula, $\theta = 2$, with 586 towns). Towns with above median market access had 1911 population that was 71 log points higher and the distribution is shifted to the right.

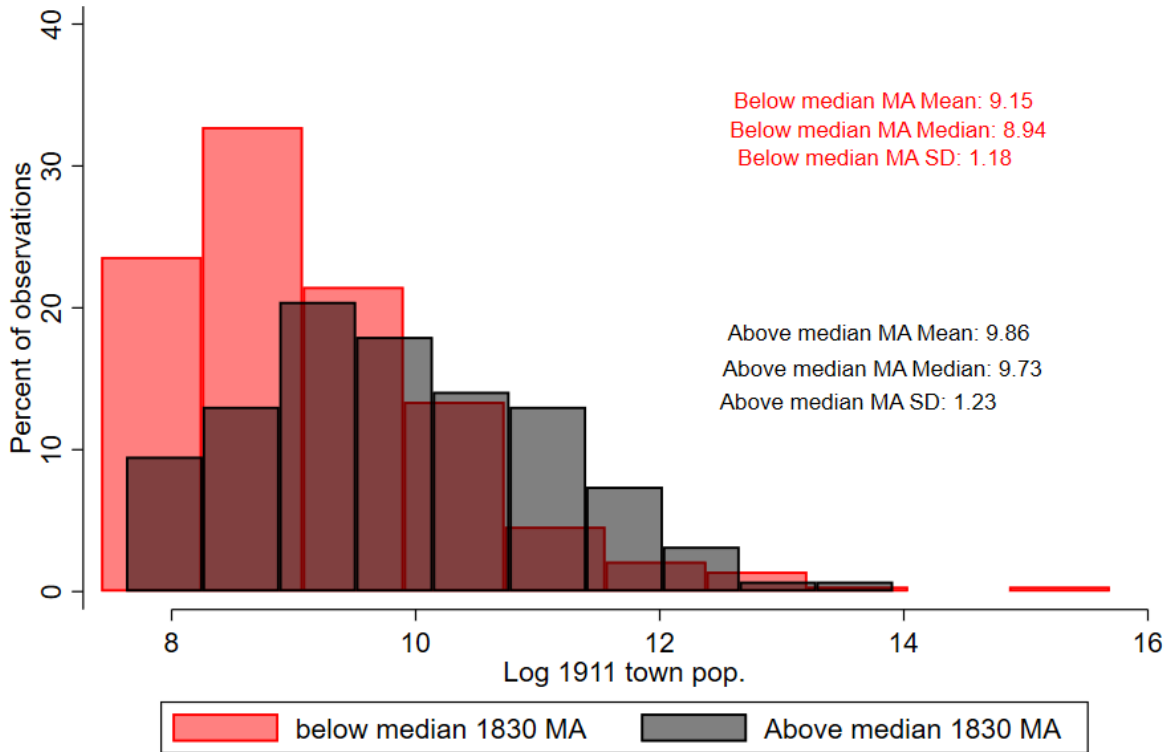


Fig. E3. *Distributions of log 1911 population according to whether the town had above or below median market access in 1830*

Notes: Authors calculations. Market access is $MA_{it1830} = \sum_j^J pop_{jt1841} \tau_{ij1830}^{-2}$ for $j = 1, \dots, 586$.

In table 2 of the text, we also show a positive correlation between the simplified log market access for 1830 and the log property income of the town derived from the real property assessment of 1843, $\ln property_{i1843}$. In Figure E4, we divide the property variable's distribution according to whether the town had above or below median market access in 1830 (using the simplified formula, $\theta = 2$). Towns with above median market access had 1843 property income that was 28 log points higher, and the distribution is shifted to the right.

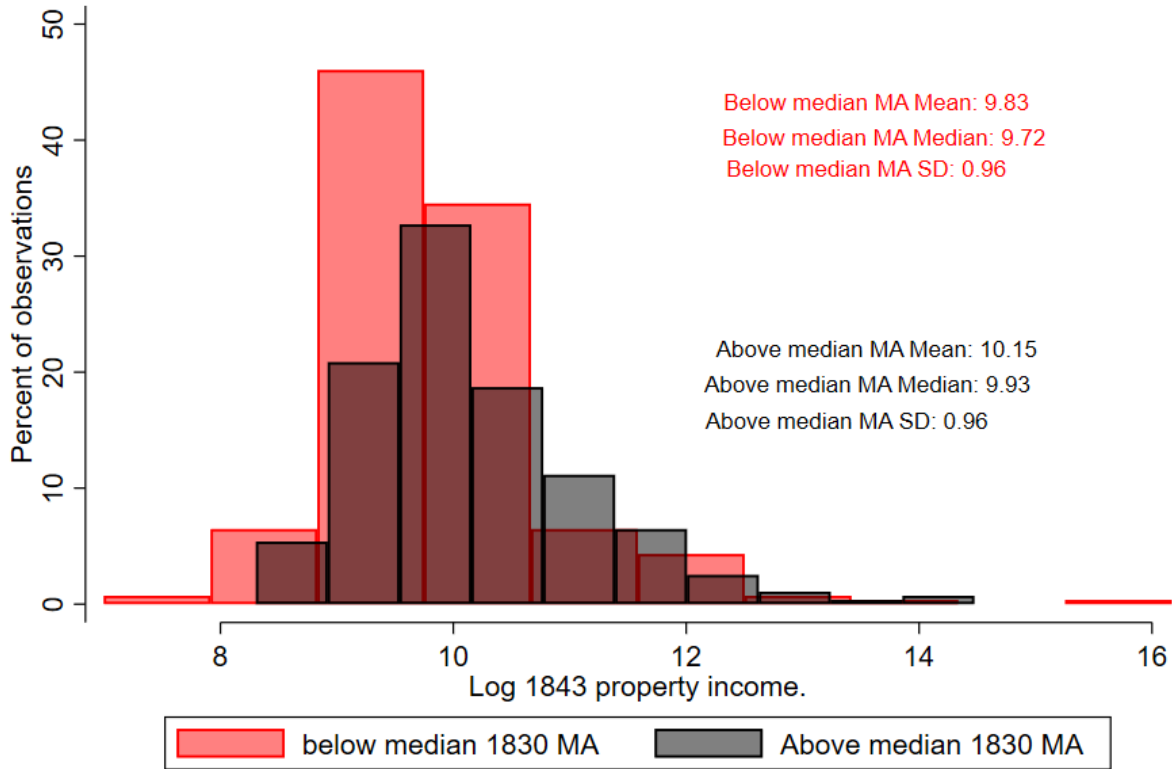


Fig. E4. Distributions of log 1843 property income according to whether the town had above or below median market access in 1830

Notes: Authors calculations. Market access is $MA_{it1830} = \sum_j^J pop_{jt1841} \tau_{ij1830}^{-2}$ for $j = 1, \dots, 586$.

E.2 Descriptive statistics for control variables

We now turn to descriptive statistics for the control variables used in section 3, where we study town population growth from 1680 to 1841. The summary statistics for the geographic variables are given in Table E4. The sample size is 448 applying to variables in Table 3. The geographic variables apply to spatial units derived from all parishes in England and Wales based on an integration of data from the 1851 and 1881 censuses, along with other sources. These units were made by Bogart *et al.* (2022) to study railways, and are sometimes called mappable units. Here we identify a single unit in which our town point belongs. We then assign the geographic characteristics of the unit to the town. For the main analysis we drop 13 towns which share a unit with a larger town based on 1680 population. As robustness these 13 towns are included in a specification shown in Appendix H where we report estimates in various

samples. The results are very similar. The following is a description of the geographic controls. The variables are described as the features of the unit.

- (1) logdistancecoastkm: distance (in logs) from unit center to the nearest of 111 historic ports.
- (2) exposedcoal: indicator equal to 1 if the unit was on the exposed coalfield
- (3) averagerain: average rainfall of the unit in mm.
- (4) averagetemp: average temperature of the unit in Celsius
- (5) elevation mean: mean elevation for scattered points in the unit
- (6) elevation SD: standard deviation of elevation for scattered points in the unit, a measure of ruggedness
- (7) latitude: latitude in degrees, WGS84
- (8) longitude: longitude in degrees, WGS84
- (9) lat*lon: Latitude multiplied by longitude, part of 2nd degree polynomial in coordinates
- (10) lon*lon: Longitude multiplied by Longitude, part of 2nd degree polynomial in coordinates
- (11) lat*lat: Latitude multiplied by latitude, part of 2nd degree polynomial in coordinates

Table E4: Descriptive Statistics: geographic controls used in Table 3 of text.

| VARIABLES | (1) N | (2) mean | (3) sd | (4) min | (5) max |
|----------------|----------|-------------|-----------|------------|------------|
| exposedcoal | 448 | 0.221 | 0.415 | 0 | 1 |
| elevation_mean | 448 | 83.85 | 65.44 | 0.326 | 401.5 |
| elevation_sd | 448 | 29.71 | 27.45 | 0.500 | 166.0 |
| averagerain | 448 | 787.2 | 188.8 | 558 | 1,372 |
| averagetemp | 448 | 8.949 | 0.707 | 5.500 | 10 |
| logdistcoastkm | 448 | -4.069 | 1.588 | -9.596 | -2.335 |
| latitude | 448 | 52.27 | 1.188 | 50.10 | 55.77 |
| longitude | 448 | -1.565 | 1.528 | -5.537 | 1.753 |
| lat.*lon. | 448 | -81.73 | 78.94 | -277.5 | 92.02 |
| lon.*lon. | 448 | 4.778 | 5.908 | 2.52e-05 | 30.66 |
| lat.*lat. | 448 | 2,733 | 124.8 | 2,510 | 3,110 |

Notes: see text for description of variables.

In Table E5, we give the summary statistics for our pre-Industrial Revolution controls. All except one, derive from Richard Blome's *Britannia*, which summarizes the characteristics of 783 towns around 1673 (see Bogart 2018 for their first use). See Appendix A for a description of these variables. The 1670 dating refers to the variables coded from Blome's description. The dating 1700 on the Morden variable refers to this town being on Morden's map of main roads around 1700. The sample size for most variables is 375 because 33 towns in our main estimating sample of 448, were mentioned by Blome, but he does not give a summary of the

town, which means we cannot code their characteristics. Also 40 towns in our main estimating sample of 448 were missing from Blome entirely. We do not drop these towns. Instead, the 33 main sample towns that are mentioned By Blome, but do not have a summary, are given an arbitrary value of -20 for their pre-industrial control variables. We also create a dummy variable, *Blome_nosummary*, which equals 1 for the 33 towns that have no summary and 0 otherwise. Also, the 40 main sample towns that are entirely missing from Blome are given an arbitrary value of -30 for their pre-industrial controls. We also create a dummy variable, *Blome_missing*, equal to 1 for the 40 towns that are absent from Blome, and 0 otherwise. We always include the dummy variables *Blome_nosummary* and *Blome_missing* in our specifications with pre-industrial revolution controls and 448 towns. The arbitrary values will have no effect on the estimates, if *Blome_nosummary* and *Blome_missing* are included, and they allow us to avoid dropping these towns. In Table E5 Panel A, we give summary statistics only for the towns that are found in Blome and have a summary.

Table E5 Panel A. *Descriptive Statistics pre-Industrial Revolution controls when Blome missing or no summary dummy variables are zero*

| VARIABLES | (1) N | (2) mean | (3) sd | (4) min | (5) max |
|-------------------|----------|-------------|-----------|------------|------------|
| harbour1670 | 375 | 0.101 | 0.302 | 0 | 1 |
| mining1670 | 375 | 0.0507 | 0.220 | 0 | 1 |
| cloth1670 | 375 | 0.144 | 0.352 | 0 | 1 |
| brewing1670 | 375 | 0.0347 | 0.183 | 0 | 1 |
| othermanuf1670 | 375 | 0.0933 | 0.291 | 0 | 1 |
| freeschool1670 | 375 | 0.0960 | 0.295 | 0 | 1 |
| alms1670 | 375 | 0.0293 | 0.169 | 0 | 1 |
| townofficials1670 | 375 | 0.368 | 0.483 | 0 | 1 |
| hasmps1670 | 375 | 0.352 | 0.478 | 0 | 1 |
| marketdays1670 | 375 | 1.144 | 0.642 | 0 | 8 |
| largemarket1670 | 375 | 0.683 | 0.466 | 0 | 1 |
| smallmarket1670 | 375 | 0.171 | 0.377 | 0 | 1 |
| mordenroad1700 | 375 | 0.707 | 0.456 | 0 | 1 |
| rivernav1670 | 375 | 0.235 | 0.424 | 0 | 1 |
| stream1670 | 375 | 0.547 | 0.498 | 0 | 1 |
| coastal1670 | 375 | 0.144 | 0.352 | 0 | 1 |

Notes: see text for description of variables.

In table E5, Panel B, we give summary statistics for the indicator variables Blome_nosummary and Blome_missing in our estimating sample with 448 towns.

Table E5 Panel B. *Descriptive Statistics for Blome missing or no summary*

| VARIABLES | (1) N | (2) mean | (3) sd | (4) min | (5) max |
|-----------------|----------|-------------|-----------|------------|------------|
| Blome_nosummary | 448 | 0.0737 | 0.262 | 0 | 1 |
| Blome_missing | 448 | 0.0893 | 0.285 | 0 | 1 |

Notes: see text for description of variables.

F. Balance tests for incidentally connected towns

In our dataset of 590 towns with trade costs, there are 40 towns we classify as incidentally connected. As explained in the text, ‘incidentally connected’ towns have two characteristics. (i) They were within 2.5km distance of the built version of the 17 waterways depicted in the 1779 Henshall and Cary Map. (ii) Either towns were not named on the 1779 Map, or they were named but not depicted as being directly on route in the Map. We assume either feature in (ii) meant the town was not targeted. Our data show that only 17 of these 40 towns have non-missing population in 1680 and hence enter the sample of 448 towns considered in Table 3. Therefore, the instrument in equation (5) only uses the population of these 17. They are listed in Table F1. Note all but Nottingham has a population of less than 2,000.

Table F1. *The 17 incidentally connected towns with non-missing 1680 population.*

| Incidentally Connected Town.county | 1680 town population |
|------------------------------------|----------------------|
| NOTTINGHAM.NOTTINGHAMSHIRE | 4,264 |
| WIGAN.LANCASHIRE | 1,950 |
| WARRINGTON.LANCASHIRE | 1,700 |
| STAFFORD.STAFFORDSHIRE | 1,430 |
| WEST BROMWICH.STAFFORDSHIRE | 1,330 |
| NUNEATON.WARWICKSHIRE | 1,290 |
| SUTTON COLDFIELD.WARWICKSHIRE | 1,270 |
| BEDWORTH.WARWICKSHIRE | 1,250 |
| KEIGHLEY.YORKSHIRE WEST RIDING | 1,090 |
| BLACKBURN.LANCASHIRE | 990 |
| BINGLEY.YORKSHIRE WEST RIDING | 970 |
| MINCHINHAMPTON.GLOUCESTERSHIRE | 850 |
| HEANOR.DERBYSHIRE | 810 |
| RUGBY.WARWICKSHIRE | 720 |
| CHORLEY.LANCASHIRE | 630 |
| NEWTON IN MAKERFIELD.LANCASHIRE | 580 |
| BURNLEY.LANCASHIRE | 350 |

Notes: for definition of incidentally connected towns see text. Population data derives comes from Langton (2000) and is described further in the text.

For the balance tests, we create a dummy variable for 17 sample towns that were incidentally connected to the 1779 canal plan. We also create a dummy variable for 30 sample towns that we consider as targeted by the 1779 Canal Plan. Specifically, they are within 2.5 km

of 1779 planned canals and they were both named on the Henshall and Cary Map and they were placed next to the depicted routes in the Map.

We compare 17 incidentally connected towns with all other towns, excluding 30 targeted towns. In Table F2 we report differences in means for 1680 population and geographic variables. Summaries of the variables are given in Appendix E. An important first point is that the mean log 1680 population is 6.984 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 F2 we see that several geographic variables, like log distance to coast, exposed coal, and elevation, are statistically different from the other 401 towns in our sample. This is to be expected, since these towns were selected due to location and for engineering and construction considerations. We have controls for geography in our specification, so we are less concerned about this imbalance. Also, as seen in Table F2, there is no evidence that being an incidentally connected town meant greater selection into a Blome town summary or absence from Blome’s *Britannia* altogether.

Table F2. *Log 1680 population and geographic covariate imbalance for incidentally connected towns vs. all non-targeted towns*

| Variable | (1) All non-targeted towns | (2) towns incidentally connected to 1779 canal plan | (3) Difference (2)-(1) |
|----------------|----------------------------------|---|------------------------------|
| log1680pop | 7.029 (0.828) | 6.984 (0.554) | -0.045 (0.203) |
| logdistcoastkm | -4.185 (1.608) | -2.987 (0.528) | 1.198*** (0.391) |
| exposedcoal | 0.180 (0.384) | 0.647 (0.493) | 0.468*** (0.096) |
| averagerain | 782.455 (191.270) | 859.272 (185.475) | 76.816 (47.308) |
| averagetemp | 8.978 (0.721) | 8.647 (0.606) | -0.331* (0.177) |
| elevation_mean | 81.091 (65.413) | 121.724 (66.635) | 40.633** (16.209) |
| elevation_sd | 29.807 (27.853) | 31.743 (27.854) | 1.936 (6.897) |
| latitude | 52.183 (1.212) | 53.073 (0.646) | 0.890*** (0.296) |
| Longitude | -1.516 (1.600) | -1.987 (0.512) | -0.471 (0.389) |

| | | | |
|-----------------|------------------|------------------|------------------|
| Blome_nosummary | 0.072 (0.259) | 0.118 (0.332) | 0.045 (0.065) |
| Blome_missing | 0.092 (0.290) | 0.176 (0.393) | 0.084 (0.073) |
| Observations | 401 | 17 | 418 |

Notes: Variable means and standard deviations are reported. The 30 targeted towns identified from the 1779 canal plan are excluded.

Table F3 reports tests for balance on 13 economic and political Blome variables, which we call our pre-Industrial Revolution controls. Summaries of the variables are given in Appendix A and E. Here we do not include missing values for the 73 towns that had no summary in Blome or were missing from Blome altogether. There is only one significant difference in these variables between incidental and other towns, that is being classified by Morden as being on a main 1700 road. Overall, these balance tests are reassuring in that incidentally connected towns were broadly similar to non-targeted towns.

Table F3. *Blome pre-industrial revolution covariate imbalance for incidentally connected towns vs. all non-targeted towns*

| Variable | (1) All non-targeted towns | (2) towns incidentally connected to 1779 canal plan | (3) Difference (2)-(1) |
|-------------------|----------------------------------|---|------------------------------|
| harbour1670 | 0.110 (0.314) | 0.000 (0.000) | -0.110 (0.091) |
| mining1670 | 0.045 (0.207) | 0.083 (0.289) | 0.039 (0.062) |
| cloth1670 | 0.140 (0.348) | 0.083 (0.289) | -0.057 (0.102) |
| brewing1670 | 0.036 (0.186) | 0.000 (0.000) | -0.036 (0.054) |
| othermanuf1670 | 0.090 (0.286) | 0.083 (0.289) | -0.006 (0.084) |
| freeschool1670 | 0.099 (0.298) | 0.000 (0.000) | -0.099 (0.086) |
| alms1670 | 0.030 (0.170) | 0.000 (0.000) | -0.030 (0.049) |
| townofficials1670 | 0.370 (0.484) | 0.250 (0.452) | -0.120 (0.142) |
| hasmps1670 | 0.352 (0.478) | 0.417 (0.515) | 0.064 (0.141) |
| marketdays1670 | 1.143 | 1.167 | 0.023 |

| | | | |
|-----------------|---------|---------|---------|
| | (0.659) | (0.718) | (0.194) |
| largemarket1670 | 0.681 | 0.583 | -0.097 |
| | (0.467) | (0.515) | (0.138) |
| smallmarket1670 | 0.164 | 0.250 | 0.086 |
| | (0.371) | (0.452) | (0.110) |
| mordenroad1700 | 0.722 | 0.500 | -0.222* |
| | (0.448) | (0.522) | (0.133) |
| rivernav1670 | 0.248 | 0.167 | -0.081 |
| | (0.432) | (0.389) | (0.127) |
| stream1670 | 0.528 | 0.583 | 0.055 |
| | (0.500) | (0.515) | (0.147) |
| coastal1670 | 0.155 | 0.000 | -0.155 |
| | (0.363) | (0.000) | (0.105) |
| Observations | 335 | 12 | 347 |

Notes: 30 targeted towns identified on 1779 canal plan are excluded. Also, we exclude 71 towns that had no summary in Blome or were missing from Blome altogether

G. Robustness to baseline and first stage IV estimates

Table G1 provides coefficient estimates for all variables in Table 3 excluding county fixed effects. For definitions of variables, see Appendix A and Appendix E. Summary statistics are in Appendix E. The coefficients on $\Delta \ln MA_i$ are the same as those found in Table 3.

Table G1. *Coefficient estimates for models in Table 3*

| VARIABLES | (1) | (2) | (3) | (4) | (5) |
|-------------------|--------------------|------------------------|-----------------------|------------------------|------------------------|
| $\Delta \ln MA_i$ | 0.173* (0.0926) | 0.180** (0.0772) | 0.240*** (0.0755) | 0.205** (0.0920) | 0.189** (0.0912) |
| logdistcoastkm | | -0.0993*** (0.0279) | -0.0542 (0.0353) | -0.0495 (0.0349) | -0.0441 (0.0336) |
| exposedcoal | | 0.518*** (0.123) | 0.406*** (0.124) | 0.287* (0.167) | 0.277 (0.169) |
| averagerain | | 0.00127* (0.000741) | 0.00125 (0.000760) | 0.00123 (0.000815) | 0.00126 (0.000852) |
| averagetemp | | 0.267** (0.115) | 0.179 (0.127) | 0.0205 (0.122) | 0.0335 (0.122) |
| elevation_mean | | 0.000748 (0.00108) | 8.29e-05 (0.00118) | -0.000641 (0.00137) | -0.000422 (0.00134) |
| elevation_sd | | -0.00357* (0.00197) | -0.00336 (0.00216) | -0.00222 (0.00229) | -0.00254 (0.00228) |
| latitude | | -4.083 (2.935) | -5.259* (2.812) | 10.81* (6.001) | 10.88* (5.819) |
| longitude | | 3.143** (1.353) | 2.977** (1.469) | -9.087 (5.545) | -8.925 (5.516) |
| lat.*lon. | | -0.0617** (0.0261) | -0.0588** (0.0282) | 0.171 (0.105) | 0.168 (0.104) |
| lon.*lon. | | -0.0334 (0.0251) | -0.0427 (0.0261) | 0.000917 (0.0429) | -4.24e-05 (0.0427) |
| lat.*lat. | | 0.0393 (0.0277) | 0.0501* (0.0267) | -0.102* (0.0563) | -0.102* (0.0547) |
| harbour1670 | | | -0.0779 (0.171) | -0.112 (0.173) | -0.0820 (0.175) |
| mining1670 | | | 0.483* (0.258) | 0.516* (0.276) | 0.500* (0.293) |
| cloth1670 | | | 0.221 (0.161) | 0.237 (0.150) | 0.236 (0.148) |
| brewing1670 | | | 0.216 (0.182) | 0.212 (0.201) | 0.216 (0.203) |
| othermanuf1670 | | | 0.203 (0.149) | 0.250 (0.160) | 0.245 (0.159) |
| freeschool1670 | | | -0.189 (0.117) | -0.0463 (0.131) | -0.0593 (0.133) |

| | | | | | |
|---------------------------|-------|-------|---------------------|---------------------|---------------------|
| alms1670 | | | -0.295 (0.269) | -0.365 (0.308) | -0.334 (0.312) |
| townofficials1670 | | | 0.0830 (0.0754) | 0.107 (0.0884) | 0.119 (0.0906) |
| hasmps1670 | | | -0.116 (0.106) | -0.144 (0.109) | -0.137 (0.113) |
| marketdays1670 | | | -0.0347 (0.0709) | -0.0932 (0.0760) | -0.0902 (0.0693) |
| largemarket1670 | | | 0.0310 (0.0916) | 0.142 (0.147) | 0.152 (0.147) |
| smallmarket1670 | | | 0.0187 (0.141) | 0.178 (0.173) | 0.184 (0.175) |
| mordenroad1700 | | | -0.0768 (0.106) | 0.0433 (0.0986) | 0.0465 (0.0968) |
| rivernav1670 | | | 0.0459 (0.159) | -0.00568 (0.153) | -0.0135 (0.155) |
| stream1670 | | | -0.101 (0.110) | -0.0875 (0.117) | -0.0896 (0.120) |
| coastal1670 | | | 0.366* (0.206) | 0.509** (0.213) | 0.497** (0.213) |
| Blome_nosummary | | | 15.70 (10.25) | 27.20** (11.44) | 28.19** (11.43) |
| Blome_missing | | | 23.43 (15.31) | 40.47** (17.05) | 41.93** (17.05) |
| Observations | 448 | 448 | 448 | 448 | 448 |
| R-squared | 0.015 | 0.269 | 0.321 | 0.456 | 0.454 |
| Lat. Lon. & Geo. Controls | NO | YES | YES | YES | YES |
| Pre-IR controls | NO | NO | YES | YES | YES |
| County FEs | NO | NO | NO | YES | YES |
| Weight obs. by lnpop_1680 | NO | NO | NO | NO | YES |

Notes: The dependent variable is log 1841 pop. minus log 1680 pop. $\Delta \ln MA_i$ refers to the difference in log 1830 and log 1680 market access. MA_i is calculated using model equation 2 with $\theta=2$, omitting own town population. Latitude and longitude enter as a 2nd order polynomial. For description of Geo. and Pre-IR controls, see text and Online appendix A. Standard errors clustered on the county are reported. *, **, and *** represent statistical significance at the 10, 5, and 1% levels.

G.1 Appendix Table G2

Appendix Table G2 repeats selected estimates in Table 3 adding Conley standard errors. We estimate Conley S.E.'s for spatial kernel cutoffs of 50km, 100km, and 150km using the STATA command ACREG (Collela *et al.* 2023). Each panel in Table G2 reports clustered and Conley standard errors with the three different cutoffs for specifications with different controls. The clustered and Conley standard errors are very similar within each specification.

Table G2: *Effect of market access on town population change: baseline OLS estimates with Conley standard errors compared to clustered standard errors*

| Panel A | (1) | (2) | (3) | (4) |
|---------------------------|--------------------------|--------------------------------|---------------------------------|---------------------------------|
| VARIABLES | S.E. clustered on county | S.E. Conley kernel cutoff 50km | S.E. Conley kernel cutoff 100km | S.E. Conley kernel cutoff 150km |
| $\Delta \ln MA_i$ | 0.180** (0.0772) | 0.180** (0.0797) | 0.180** (0.0711) | 0.180*** (0.0640) |
| Observations | 448 | 448 | 448 | 448 |
| R-squared | 0.269 | 0.269 | 0.269 | 0.269 |
| Lat. Lon. & Geo. Controls | YES | YES | YES | YES |
| Pre-IR controls | NO | NO | NO | NO |
| County FEs | NO | NO | NO | NO |
| Weight obs. by Inpop_1680 | NO | NO | NO | NO |

| Panel B | (5) | (6) | (7) | (8) |
|---------------------------|--------------------------|--------------------------------|---------------------------------|---------------------------------|
| VARIABLES | S.E. clustered on county | S.E. Conley kernel cutoff 50km | S.E. Conley kernel cutoff 100km | S.E. Conley kernel cutoff 150km |
| $\Delta \ln MA_i$ | 0.240*** (0.0755) | 0.240*** (0.0854) | 0.240*** (0.0831) | 0.240*** (0.0682) |
| Observations | 448 | 448 | 448 | 448 |
| R-squared | 0.321 | 0.321 | 0.321 | 0.321 |
| Lat. Lon. & Geo. Controls | YES | YES | YES | YES |
| Pre-IR controls | YES | YES | YES | YES |
| County FEs | NO | NO | NO | NO |
| Weight obs. by Inpop_1680 | NO | NO | NO | NO |

| Panel C | (9) | (10) | (11) | (12) |
|---------------------------|--------------------------|--------------------------------|---------------------------------|---------------------------------|
| VARIABLES | S.E. clustered on county | S.E. Conley kernel cutoff 50km | S.E. Conley kernel cutoff 100km | S.E. Conley kernel cutoff 150km |
| $\Delta \ln MA_i$ | 0.205** (0.0920) | 0.205** (0.0812) | 0.205*** (0.0678) | 0.205*** (0.0445) |
| Observations | 448 | 448 | 448 | 448 |
| R-squared | 0.456 | 0.456 | 0.456 | 0.456 |
| Lat. Lon. & Geo. Controls | YES | YES | YES | YES |
| Pre-IR controls | YES | YES | YES | YES |
| County FEs | YES | YES | YES | YES |
| Weight obs. by Inpop_1680 | NO | NO | NO | NO |

Notes: The dependent variable is $\ln 1841 \text{pop} - \ln 1680 \text{pop}$. All regressions include a 2nd order

polynomial and in latitude and longitude and geographic controls. Other specifications add pre-industrial revolution (Pre-IR) controls and county fixed effects. See text and table 3 for more information on controls.

G.2 Appendix Table G3

Table G3 replicates the estimates of Table 3 in the text using the simplified formula for market access. The estimates are very similar to table 3 in the text, indicating the functional form for market access does not greatly affect the coefficient estimates.

Table G3: *Effect of market access on town population change: baseline OLS estimates using simplified market access*

| VARIABLES | (1) | (2) | (3) | (4) | (5) |
|--|---------------------|---------------------|----------------------|---------------------|---------------------|
| $\Delta \ln MA_i$, simple | 0.184** (0.0774) | 0.157** (0.0706) | 0.208*** (0.0641) | 0.194** (0.0735) | 0.175** (0.0735) |
| Observations | 448 | 448 | 448 | 448 | 448 |
| R-squared | 0.030 | 0.270 | 0.322 | 0.457 | 0.455 |
| Lat. Lon. & Geo. Controls | NO | YES | YES | YES | YES |
| Pre-IR controls | NO | NO | YES | YES | YES |
| County FEs | NO | NO | NO | YES | YES |
| Weight obs. by $\ln \text{pop}_{1680}$ | NO | NO | NO | NO | YES |

Notes: The dependent variable is $\log 1841 \text{ pop.} - \log 1680 \text{ pop.}$ $\Delta \ln MA_i$, simple refers to the difference in $\log 1830$ and $\log 1680$ market access, where MA_i is calculated using the simplified formula with $\theta=2$, omitting own town population. Latitude and longitude enter as a 2nd order polynomial. For description of Geo. and Pre-IR controls see text and Online appendix A. Standard errors clustered on the county are reported. *, **, and *** represent statistical significance at the 10, 5, and 1% levels.

G.3 Appendix Table G4

Table G4 shows the full first stage estimates for the IV specifications in Table 5.

Table G4: *First stage estimates for the difference in log market access, $\Delta \ln MA_i$, in Table 5.*

| VARIABLES | (1) | (2) | (3) |
|---|----------------------|----------------------|----------------------|
| $\Delta \ln MA_i$, towns > 50km and incidentally connected | 0.716*** (0.0292) | | 0.683*** (0.0388) |
| Log dist. to 1680 waterways km | | 0.219*** (0.0165) | 0.0270** (0.0129) |
| logdistcoastkm | 0.014 (0.0104) | -0.0210 (0.0152) | 0.00587 (0.0104) |

| | | | |
|-------------------|---------------------|--------------------------|-------------------------|
| exposedcoal | -0.004 (0.0230) | -0.0596 (0.0651) | -0.00937 (0.0210) |
| averagerain | 0.000* (0.0002) | 0.000908** (0.000358) | 0.000362* (0.000187) |
| averagetemp | 0.018 (0.0447) | -0.0178 (0.0607) | 0.0231 (0.0446) |
| elevation_mean | -0.000 (0.0004) | 0.000727 (0.000676) | -0.000157 (0.000370) |
| elevation_sd | 0.000 (0.0008) | -0.00106 (0.00173) | 0.000163 (0.000779) |
| latitude | -1.592 (2.2920) | -1.559 (5.218) | -1.818 (2.183) |
| longitude | -2.840* (1.4616) | -0.616 (2.392) | -2.801* (1.430) |
| lat.*lon. | 0.053* (0.0277) | 0.0116 (0.0459) | 0.0529* (0.0271) |
| lon.*lon. | -0.020 (0.0142) | 0.0109 (0.0165) | -0.0182 (0.0141) |
| lat.*lat. | 0.016 (0.0214) | 0.0160 (0.0500) | 0.0185 (0.0204) |
| harbour1670 | 0.030 (0.0448) | 0.101 (0.0680) | 0.0290 (0.0450) |
| mining1670 | 0.021 (0.0387) | -0.0346 (0.0956) | 0.0161 (0.0409) |
| cloth1670 | -0.038 (0.0296) | -0.0126 (0.0594) | -0.0378 (0.0292) |
| brewing1670 | -0.121 (0.0782) | -0.0384 (0.0976) | -0.107 (0.0805) |
| othermanuf1670 | -0.011 (0.0383) | 0.0284 (0.0674) | -0.00185 (0.0381) |
| freeschool1670 | 0.010 (0.0400) | -0.0230 (0.0827) | 0.00538 (0.0413) |
| alms1670 | 0.052 (0.0818) | 0.0483 (0.105) | 0.0506 (0.0791) |
| townofficials1670 | -0.003 (0.0304) | -0.0352 (0.0479) | -0.00361 (0.0303) |
| hasmps1670 | -0.027 (0.0211) | -0.0118 (0.0464) | -0.0267 (0.0205) |
| marketdays1670 | -0.063 (0.0407) | -0.0370 (0.0338) | -0.0629 (0.0400) |
| largemarket1670 | 0.034 (0.0319) | -0.0363 (0.0561) | 0.0318 (0.0305) |
| smallmarket1670 | 0.006 (0.0373) | -0.142** (0.0577) | 0.000586 (0.0358) |
| mordenroad1700 | -0.003 (0.0210) | -0.00240 (0.0373) | -0.00703 (0.0211) |
| rivernav1670 | -0.037 (0.0377) | -0.0777 (0.0600) | -0.0107 (0.0356) |

| | | | |
|---------------------------|--------------------|--------------------|----------------------|
| stream1670 | -0.001 (0.0244) | 0.0291 (0.0525) | -0.00769 (0.0249) |
| coastal1670 | 0.024 (0.0365) | 0.0114 (0.0699) | 0.0271 (0.0362) |
| Blome_nosummary | -2.620 (3.2214) | -4.784 (5.002) | -2.165 (3.166) |
| Blome_missing | -3.889 (4.8074) | -7.089 (7.502) | -3.215 (4.728) |
| Observations | 448 | 448 | 448 |
| R-squared | 0.937 | 0.782 | 0.939 |
| Lat. Lon. & Geo. Controls | YES | YES | YES |
| Pre-IR controls | YES | YES | YES |
| County FEs | YES | YES | YES |

Notes: The dependent variable is $\Delta \ln MA_i$ is the difference in log 1830 and log 1680 market access. MA_i is calculated using model equation 2 with $\theta=2$, omitting own town population. $\Delta \ln MA_i$ towns > 50km and incidentally connected is defined by equation 5 in main text. Log dist. to 1680 waterways km is the natural log of town distance to the nearest 1680 inland waterway. Latitude and longitude enter as a 2nd order polynomial. For description of Geo. and Pre-IR controls see text and Online appendix A. Standard errors clustered on the county are reported. *, **, and *** represent statistical significance at the 10, 5, and 1% levels.

H. Additional estimates for the effect of market access change

In this appendix, we report additional estimates for the effect of market access change from 1680 to 1830 on population change from 1680 to 1841. Most of the additional estimates are meant to address robustness or identifying variation. Table H1 addresses robustness to the assumption that $\theta = 2$. We use the simplified formula for market access defined as $MA_i = \sum_j^J pop_j \tau_{ij}^{-\theta}$, where j are towns indexed from $j = 1, \dots, n$ (omitting i). The Table gives estimates for $\theta = 1, 2, 4$, and 8, including all control variables. The coefficient for $\Delta \ln MA_i$ are all significant except for column 4 which uses $\theta = 8$. In panel B, we report the beta/standardized coefficients for a one-standard deviation change in market access in standard deviation units of the dependent variable, the difference in log population. The standardized coefficients are all similar, except for $\theta = 8$, where it is smaller. Thus, we argue the conclusions are little changed for most values of theta.

Table H1: *Estimates for effect of simplified market access on town population for different values of theta with standardized beta coefficients in panel B*

| Panel A | (1) | (2) | (3) | (4) |
|---|---------------------|---------------------|----------------------|--------------------|
| VARIABLES | | | | |
| $\Delta \ln MA_i$, simplified, theta=1 | 0.403** (0.1529) | | | |
| $\Delta \ln MA_i$, simplified, theta=2 | | 0.194** (0.0735) | | |
| $\Delta \ln MA_i$, simplified, theta=4 | | | 0.0835** (0.0377) | |
| $\Delta \ln MA_i$, simplified, theta=8 | | | | 0.0290 (0.0195) |
| Observations | 448 | 448 | 448 | 448 |
| R-squared | 0.457 | 0.457 | 0.455 | 0.452 |
| Lat. Lon. & Geo. Controls | YES | YES | YES | YES |
| Pre-IR controls | YES | YES | YES | YES |
| County FEs | YES | YES | YES | YES |
| Panel B: beta coefficients | (1) | (2) | (3) | (4) |
| VARIABLES | | | | |
| $\Delta \ln MA_i$, simplified, theta=1 | 0.178 | | | |
| $\Delta \ln MA_i$, simplified, theta=2 | | 0.184 | | |

| | | |
|---|-------|-------|
| $\Delta \ln MA_i$, simplified, theta=4 | 0.166 | |
| $\Delta \ln MA_i$, simplified, theta=8 | | 0.111 |

Notes: The dependent variable is $\ln 1841 \text{pop}$ minus $\ln 1680 \text{pop}$. $\Delta \ln MA_i$ is the difference in log 1830 and log 1680 market access. MA_i is calculated using the simplified formula with different values of theta, omitting own town population. The standardized beta coefficient is the coefficient multiplied by standard deviation change in $\Delta \ln MA_i$ divided by a standard deviation for the dependent variable. All regressions include a 2nd order polynomial and in latitude and longitude, geographic controls, pre-industrial revolution (Pre-IR) controls, and county fixed effects. see text and appendix. Standard errors clustered on the county are reported. *, **, and *** indicates statistical significance at the 10, 5, and 1% levels.

H.1 Appendix Table H2

Table H2 replicates most specifications of Table 3 of the text, but now using as the dependent variable the difference in log 1680 population and log 1560 population. Note the 1560 population is only available for 155 towns, but it includes large towns and cities like London, as well as smaller towns. As we show in Appendix A, the sub-sample of 155 towns has similar 1680 population and similar population growth from 1680 to 1841 as our main estimating sample. We regard this Table as a placebo test, although it is imperfect as there are only 155 towns we can study. We expect that $\Delta \ln MA_i$ should not significantly affect population growth a century earlier. The OLS results from Table H2 show there is a negative and significant effect of $\Delta \ln MA_i$ in columns 1 and 2, where there are few controls. However, once we control for pre-industrial revolution characteristics and county fixed effects the market access coefficient is imprecisely estimated. At the very least, this analysis confirms there is no strong evidence that market access growth from 1680 to 1841 predicts population change from 1560 to 1680.

Table H2: *The effect of market access change 1680 to 1841 on town population change from 1560 to 1680*

| VARIABLES | (1) | (2) | (3) | (4) |
|---------------------------|---------------------|----------------------|-------------------|-------------------|
| $\Delta \ln MA_i$ | -0.236* (0.1353) | -0.313*** (0.111) | -0.155 (0.163) | -0.328 (0.220) |
| Observations | 155 | 155 | 155 | 155 |
| R-squared | 0.030 | 0.198 | 0.314 | 0.506 |
| Lat. Lon. & Geo. Controls | NO | YES | YES | YES |
| Pre-IR controls | NO | NO | YES | YES |

| | | | | |
|---------------------------|----|----|----|-----|
| County FEs | NO | NO | NO | YES |
| Weight obs. by lnpop_1680 | NO | NO | NO | NO |

Notes: The sample is restricted to 155 towns that have population data in 1560. The dependent variable is ln1680pop minus ln1560pop. $\Delta \ln MA_i$ refers to the difference in log 1830 and log 1680 market access where MA_i is calculated using equation (2). For definitions of 2nd order polynomial in latitude and longitude, 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.

H.2 Appendix Table H3

Recall our preferred estimate of producer prices used a weighted average of coal and grain prices with price weights 0.92 for coal and 0.08 for grain. In the text, we mention how we also calculate producer prices with price weights 0.6 for coal and 0.4 for grain. Table H3 replicates the estimates of Table 3 in the text using the simplified formula for market access with trade costs based on a price weighting of 0.6 for coal and 0.4 for grain. The main conclusion is that the coefficient estimates on $\Delta \ln MA_i$ are similar. Thus, our choice of a producer price, which weights coal much more than grain, is not greatly affecting our estimates for the effect of market access.

Table H3: *Effect of market access on town population change: baseline OLS estimates using simplified market access and alternative producer prices weighted 0.6 for coal and 0.4 for grain*

| VARIABLES | (1) | (2) | (3) | (4) | (5) |
|--|---------------------|-------------------|---------------------|--------------------|-------------------|
| $\Delta \ln MA_i$, alternative producer price | 0.210** (0.1027) | 0.186* (0.109) | 0.242** (0.0973) | 0.252** (0.109) | 0.217* (0.108) |
| Observations | 448 | 448 | 448 | 448 | 448 |
| R-squared | 0.019 | 0.266 | 0.317 | 0.455 | 0.453 |
| Lat. Lon. & Geo. Controls | NO | YES | YES | YES | YES |
| Pre-IR controls | NO | NO | YES | YES | YES |
| County FEs | NO | NO | NO | YES | YES |
| Weight obs. by lnpop_1680 | NO | NO | NO | NO | YES |

Notes: The dependent variable is log 1841 pop. minus log 1680 pop. $\Delta \ln MA_i$ refers to the difference in log 1830 and log 1680 market access. MA_i is calculated using the simplified formula with theta=2 and alternative producer price weighted 0.6 for coal and 0.4 grain, omitting own town population. Latitude and longitude enter as a 2nd order polynomial. For description of Geo. and Pre-IR controls see text and Online appendix A. Standard errors clustered on the county are reported. *, **, and *** represent statistical significance at the 10, 5, and 1% levels.

H.3 Appendix Table H4

In Table H4, we replicate our preferred specification (col. 4 Table 3) with various sub-samples. In column 1 we include 13 towns that were dropped as they shared the same spatial unit with a town that had a larger 1680 population. Recall we link to spatial units from Bogart et al. (2022) to obtain geographic variables. We dropped these 13 towns to avoid having towns with identical geographic control variables. Note 3 of these 13 are dropped due to missing observations on other variables. Including these 10 extra towns in the regression does not change our results, as shown in col. 1. In columns 2 and 3 we omit from the sample towns with population below 500, or above 5000 in 1680. In columns 4 and 5 we omit towns in the top 1 or bottom 99th percentiles of population growth from 1680 to 1841 (we call these the top 1% and bottom 1%). In columns 6 and 7 we omit towns with missing summaries in Blome or missing in Blome altogether. The main conclusion is that estimates are generally similar in these sub-samples.

Table H4: *Effect of market access on town population change: baseline OLS estimates with different sub-samples.*

| VARIABLES | (1) Keep 10 towns which shared a common unit with a larger town | (2) Drop towns with 1680 pop. below 500 | (3) Drop towns with 1680 pop. above 5000 | (4) Drop towns in bottom 1% of pop. growth 1680 to 1841 | (5) Drop towns in top 1% of pop. growth 1680 to 1841 | (6) Drop towns with no summary in Blome | (7) Drop towns missing in Blome |
|------------------------------|---|---|--|---|---|--|--|
| $\Delta \ln MA_i$ | 0.190** (0.0883) | 0.162* (0.0956) | 0.229** (0.0967) | 0.209** (0.0903) | 0.187** (0.0931) | 0.184* (0.102) | 0.187* (0.101) |
| Observations | 458 | 390 | 427 | 444 | 443 | 415 | 408 |
| R-squared | 0.450 | 0.485 | 0.461 | 0.472 | 0.442 | 0.461 | 0.463 |
| Lat. Lon. & Geo. Controls | YES | YES | YES | YES | YES | YES | YES |
| Pre-IR controls | YES | YES | YES | YES | YES | YES | YES |
| County FEs | YES | YES | YES | YES | YES | YES | YES |

Notes: Each specification is a different sub-sample defined by excluding variables as summarized in the top row and in the text. The dependent variable is $\ln 1841 \text{pop} - \ln 1680 \text{pop}$. $\Delta \ln MA_i$ refers to the difference in log 1830 and log 1680 market access where MA_i is calculated using equation (2), omitting own town population. All regressions include a 2nd order polynomial and in latitude and longitude,

geographic controls, pre-industrial revolution (Pre-IR) controls, and county fixed effects. see text and appendix. Standard errors clustered on the county are reported. *, **, and *** indicates statistical significance at the 10, 5, and 1% levels.

H.4 Appendix Table H5

In Table H5, we replicate Table 3 in the text, but now include town i 's population in simplified MA_i . As a reminder, town i 's population has been omitted from MA_i throughout our analysis. The coefficient estimates are larger, implying our main results might be under-stating market access effects when own town's population are omitted.

Table H5: *Effect of market access on town population change: baseline OLS estimates using simplified market access but now including town i's population in market access*

| VARIABLES | (1) | (2) | (3) | (4) | (5) |
|---|----------------------|----------------------|----------------------|----------------------|----------------------|
| $\Delta \ln MA_i$, include own town population | 0.223*** (0.0828) | 0.213*** (0.0768) | 0.281*** (0.0707) | 0.269*** (0.0781) | 0.253*** (0.0783) |
| Observations | 448 | 448 | 448 | 448 | 448 |
| R-squared | 0.042 | 0.278 | 0.332 | 0.464 | 0.462 |
| Lat. Lon. & Geo. Controls | NO | YES | YES | YES | YES |
| Pre-IR controls | NO | NO | YES | YES | YES |
| County FEs | NO | NO | NO | YES | YES |
| Weight obs. by $\ln \text{pop}_{1680}$ | NO | NO | NO | NO | YES |

Notes: The dependent variable is $\ln 1841 \text{pop}$ minus $\ln 1680 \text{pop}$. $\Delta \ln MA_i$ refers to the difference in log 1830 and log 1680 market access where MA_i is calculated using the simplified formula, but now own town i population is NOT omitted. For definitions of 2nd order polynomial in latitude and longitude, 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.

H.5 Appendix Tables H6 and H7

In Tables H6 and H7, we consider the role of changes in transport costs versus producer prices. The first part of this analysis, focusing on producer prices, was summarized in a footnote in the text. We calculate hypothetical 1830 trade costs as $\tau_{ij2} = tc_{ij1680}/P_{1830} + 1$, which uses 1680 transport costs and 1830 producer prices. Recall 1830 producer prices were higher than 1680 producer prices. In table H6, we estimate the effect of increasing market access through

τ_{ij2} compared to our baseline 1680 trade costs, meaning $\Delta \ln MA_i = \ln(\sum_j^J pop_{j1680} \tau_{ij2}^{-2}) - \ln(\sum_j^J pop_{j1680} \tau_{ij1680}^{-2})$. The estimates show there is a larger effect of $\Delta \ln MA_i$ on population growth, but it is not precisely estimated. We interpret these estimates as suggesting that our results are not primarily driven by changes in producer prices, which by themselves change trade costs.

Table H6: *Effect of market access on town population change: baseline OLS estimates using simplified market access isolating the effect of higher producer prices*

| VARIABLES | (1) | (2) | (3) | (4) | (5) |
|--|-------------------|------------------|------------------|------------------|------------------|
| $\Delta \ln MA_i$, isolating higher producer prices | 0.339 (0.2471) | 0.144 (0.253) | 0.300 (0.318) | 0.404 (0.331) | 0.305 (0.329) |
| Observations | 448 | 448 | 448 | 448 | 448 |
| R-squared | 0.008 | 0.260 | 0.311 | 0.451 | 0.450 |
| Lat. Lon. & Geo. Controls | NO | YES | YES | YES | YES |
| Pre-IR controls | NO | NO | YES | YES | YES |
| County FEs | NO | NO | NO | YES | YES |
| Weight obs. by $\ln pop_{1680}$ | NO | NO | NO | NO | YES |

Notes: The dependent variable is $\ln 1841 \text{pop}$ minus $\ln 1680 \text{pop}$. $\Delta \ln MA_i$ refers to the difference in log 1830 and log 1680 market access where MA_i is calculated using the simplified formula, but now we replace the 1830 population with 1680 population and we replace 1830 trade costs τ_{ij} with an alternative that uses 1680 transport costs and 1830 producer prices and thus $\Delta \ln MA_i$ isolates the effect of higher producer prices. For definitions of 2nd order polynomial in latitude and longitude, 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.

The second part of this analysis, focusing on transport costs, was explained in the text. We now calculate hypothetical 1830 trade costs as $\tau_{ij1} = tc_{ij1830}/P_{1680} + 1$, which uses 1680 producer prices and 1830 transport costs. Recall 1830 transport costs are lower than 1680 transport costs. In table H7, we estimate the effect of increasing market access through τ_{ij1} compared to our baseline 1680 trade costs, meaning $\Delta \ln MA_i = \ln(\sum_j^J pop_{j1680} \tau_{ij1}^{-2}) - \ln(\sum_j^J pop_{j1680} \tau_{ij1680}^{-2})$. Table H7 shows the results. Here we find that increasing market access through τ_{ij1} compared to our baseline yields a precisely estimated coefficient very similar to our baseline (Table 3). Our interpretation is that market access effects are more clearly driven by changes in transport costs from 1680 to 1830.

Table H7: *Effect of market access on town population change: baseline OLS estimates using simplified market access isolating the effect of lower transport costs*

| VARIABLES | (1) | (2) | (3) | (4) | (5) |
|---|---------------------|----------------------|----------------------|----------------------|----------------------|
| $\Delta \ln MA_i$, isolating lower transport costs | 0.187** (0.0773) | 0.192*** (0.0693) | 0.235*** (0.0607) | 0.231*** (0.0736) | 0.219*** (0.0740) |
| Observations | 448 | 448 | 448 | 448 | 448 |
| R-squared | 0.024 | 0.274 | 0.325 | 0.460 | 0.459 |
| Lat. Lon. & Geo. Controls | NO | YES | YES | YES | YES |
| Pre-IR controls | NO | NO | YES | YES | YES |
| County FEs | NO | NO | NO | YES | YES |
| Weight obs. by $\ln \text{pop}_{1680}$ | NO | NO | NO | NO | YES |

Notes: The dependent variable is $\ln 1841 \text{pop}$ minus $\ln 1680 \text{pop}$. $\Delta \ln MA_i$ refers to the difference in log 1830 and log 1680 market access where MA_i is calculated using the simplified formula, but now we replace the 1830 population with 1680 population and we replace 1830 trade costs τ_{ij} with an alternative that uses 1830 transport costs and 1680 producer prices and thus $\Delta \ln MA_i$ isolates the effect of lower transport costs. For definitions of 2nd order polynomial in latitude and longitude, 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.

I. Additional estimates for the persistent effect of 1830 market access

In this Appendix, we first estimate the same regressions as Table 7 replacing log 1911 town population with log 1861 town population. The results are reported in Table I1. The coefficients are generally smaller than Table 7, yet they remain precisely estimated and economically meaningful. For example, the IV coefficient on $\ln MA_{i1830}$ is 0.136 and the standard error (0.052) indicates the IV estimate is precisely estimated. Recall the coefficient in col. 6 Table 7 is 0.328, smaller than col. 6 in Table I1. Therefore, we find evidence that the effect of 1830 market access on subsequent town population increased from 1861 to 1911.

Table I1: *Estimates for the effect of 1830 market access on 1861 town population*

| VARIABLES | (1) | (2) | (3) | (4) | (5) | (6) |
|--------------------------------|---------------------|----------------------|----------------------|----------------------|-----------------------|----------------------|
| $\ln MA_{i1830}$ | 0.305** (0.1294) | 0.182*** (0.0252) | 0.184*** (0.0334) | 0.179*** (0.0335) | 0.164*** (0.0351) | 0.136*** (0.0525) |
| log pop. 1841 | | 1.074*** (0.0101) | 1.076*** (0.0107) | 1.076*** (0.0127) | 1.061*** (0.0144) | 1.079*** (0.0117) |
| log dist. station 1841 | | | | | -0.0167 (0.0122) | |
| log dist. steamship port 1843 | | | | | -0.0697** (0.0307) | |
| Observations | 532 | 531 | 527 | 527 | 527 | 527 |
| R-squared | 0.016 | 0.935 | 0.946 | 0.955 | 0.956 | 0.948 |
| Lat. Lon. & Geo. Controls | NO | NO | YES | YES | YES | YES |
| Pre-IR controls | NO | NO | YES | YES | YES | YES |
| County FEs | NO | NO | NO | YES | YES | YES |
| Kleibergen-Paap F statistic | | | | | | 95.33 |
| Endogeneity test stat. p-value | | | | | | 0.347 |

Notes: This specification is the same as table 7 in text except the dependent variable is log 1861 town population. MA_{i1830} is market access calculated using model equation 2 with $\theta=2$ using 1830 trade costs and 586 towns with non-zero population in 1841. The instrument in col. 6 is the Plan Levels IV explained in the text. Standard errors are clustered on counties. *, **, and *** indicates statistical significance at the 10, 5, and 1% levels.

We repeat the same estimates in Table I2 using log 1891 town population as the dependent variable. The coefficients are larger and closer to what we find for 1911 population. For example, our IV estimate gives a coefficient 0.260 (s.e. 0.127), implying that the effect of 1830 market access on 1911 population was not fully established by 1891.

Table I2: *Estimates for the effect of 1830 market access on 1891 town population*

| VARIABLES | (1) | (2) | (3) | (4) | (5) | (6) |
|--------------------------------|----------------------|----------------------|----------------------|----------------------|-----------------------|----------------------|
| $\ln MA_{i1830}$ | 0.687*** (0.1076) | 0.554*** (0.0980) | 0.539*** (0.0882) | 0.471*** (0.120) | 0.432*** (0.103) | 0.248** (0.127) |
| log pop. 1841 | | 1.136*** (0.0195) | 1.123*** (0.0220) | 1.118*** (0.0287) | 1.080*** (0.0285) | 1.131*** (0.0271) |
| log dist. station 1841 | | | | | -0.0458* (0.0233) | |
| log dist. steamship port 1843 | | | | | -0.177*** (0.0547) | |
| Observations | 542 | 537 | 533 | 533 | 533 | 533 |
| R-squared | 0.059 | 0.792 | 0.844 | 0.866 | 0.872 | 0.830 |
| Lat. Lon. & Geo. Controls | NO | NO | YES | YES | YES | YES |
| Pre-IR controls | NO | NO | YES | YES | YES | YES |
| County FEs | NO | NO | NO | YES | YES | YES |
| Kleibergen-Paap F statistic | | | | | | 97.03 |
| Endogeneity test stat. p-value | | | | | | 0.0278 |

Notes: This specification is the same as table 7 in text except the dependent variable is log 1891 town population. MA_{i1830} is market access calculated using model equation 2 with $\theta=2$ using 1830 trade costs and 586 towns with non-zero population in 1841. The instrument in col. 6 is the Plan Levels IV explained in the text. Standard errors are clustered on counties. *, **, and *** indicates statistical significance at the 10, 5, and 1% levels.

1.1 Further robustness on 1911 population estimates

Table I3 reports further robustness checks including the log 1680 town population as an additional control. Note we also have a dummy variable if 1680 population is missing. Adding variables for 1680 town population does not change the results in columns 2 to 3, where the latter includes all our control variables. Columns 4 and 5 add distance to nearest railway station in 1851 or 1871. The estimates for $\ln MA_{i1830}$ are largely unchanged. Conley standard errors with a distance cutoff of 100km shown in col. 6 are also similar.

Table I3: *Estimates for the effect of market access on 1911 town population with additional controls and Conley Standard Errors*

| VARIABLES | (1) | (2) | (3) | (4) | (5) | (6) |
|------------------|----------|----------|----------|----------|----------|----------|
| $\ln MA_{i1830}$ | 0.758*** | 0.736*** | 0.578*** | 0.569*** | 0.573*** | 0.580*** |

| | | | | | | |
|-------------------------------|----------|----------|----------|-----------|-----------|----------|
| | (0.1406) | (0.118) | (0.197) | (0.170) | (0.167) | (0.137) |
| log pop. 1841 | 1.146*** | 1.211*** | 1.135*** | 1.088*** | 1.093*** | 1.128*** |
| | (0.0242) | (0.0260) | (0.0372) | (0.0393) | (0.0404) | (0.0316) |
| Log 1680 pop. | | -0.0849 | -0.0224 | -0.0148 | -0.0141 | |
| | | (0.0558) | (0.0551) | (0.0534) | (0.0525) | |
| Dummy if pop_i1680 missing | | -0.0845 | -0.301 | -0.143 | -0.164 | |
| | | (0.435) | (0.739) | (0.695) | (0.685) | |
| log dist. steamship port 1843 | | | | -0.274*** | -0.276*** | |
| | | | | (0.0759) | (0.0751) | |
| log dist. station 1851 | | | | -0.0310 | | |
| | | | | (0.0205) | | |
| log dist. station 1871 | | | | | -0.0210 | |
| | | | | | (0.0274) | |
| Observations | 532 | 532 | 528 | 528 | 528 | 528 |
| R-squared | 0.723 | 0.749 | 0.829 | 0.838 | 0.838 | 0.829 |
| Lat. Lon. & Geo. Controls | NO | NO | YES | YES | YES | YES |
| Pre-IR controls | NO | NO | YES | YES | YES | YES |
| County FEs | NO | NO | YES | YES | YES | YES |
| Conley S.E.'s 100km cutoff | NO | NO | NO | NO | NO | YES |

Notes: The dependent variable is log 1911 population. $\ln MA_{i1830}$ is log market access using equation 2 with 586 towns with non-zero population in 1841. Standard errors are clustered on counties in all specification except col. 6, which uses Conley standard errors and 100 km cutoff. *, **, and *** indicates statistical significance at the 10, 5, and 1% levels.

J. Registration sub-district town data and outcomes

Data on sub-registration districts (RSDs) come from the ‘Atlas of Victorian Fertility Decline’ Project (see Reid *et al.* 2018) and specifically the Populations past webpage.⁶⁹ We start by obtaining several RSD-level variables in 1851. See the replication files in `data\raw\RSD_populationspast` for a complete list. Next, we link our 563 sample towns to 769 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. The remaining 52 towns 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 (London, Manchester, Plymouth, and Lambeth) were linked with additional RSDs that approximate urban boundaries of the large urban areas in 1851. For the complete list of town-RSD links, see the replication file `data\processed\towns_RSDs\towns_linkedtoRSDs.xlsx`.

The 769 linked RSDs mainly include urbanized and semi-urbanized RSDs. To illustrate, Table J1 summarizes the 1851 population density of RSDs in our linked sample and in all of England and Wales. Note population density is per acre, where one acre is 4047 square meters. Notice that the mean population density is much larger (32.18) in our linked RSDs compared to non-linked (1.370).

Table J1: *Descriptive Statistics of 1851 population density in our RSD linked and non-linked sample.*

| VARIABLES | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) |
|-------------------|----------------------|-------|-------|--------|-------|-----------------------|-------|-------|--------|-------|
| | Linked, 0=no N | mean | sd | min | max | Linked, 1=yes N | mean | sd | min | max |
| RSDpopdensity1851 | 1,428 | 1.370 | 7.164 | 0.0146 | 167.5 | 769 | 32.18 | 71.21 | 0.0923 | 519.0 |

Notes: Author's calculation using town-RSD links.

⁶⁹ See <https://www.populationspast.org/>, accessed 5 June 2024.

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 of our 563 towns), we aggregate the 1851 population of all associated RSDs. Reassuringly the 1851 town-RSD populations are highly correlated ($\rho=0.99$) with 1841 town populations used in our earlier analysis. For outcomes that are defined as rates or percentages of the population, we calculate the population weighted average across all linked RSDs. As RSD birth residency variables are reported separately for men and women, we calculate a weighted average using the share of men and women in the RSD population as weights. See the replication files in `data\processed\towns_RSDs` for the construction of the individual town-RSD variables. The replication file `data\processed\towns_RSDs\town_RSDvars_linked.xlsx` contains the final variables which are linked to our selected 590 towns.

Market access is calculated using equation 2 in the text for 563 town-RSDs with non-missing population in 1851 with $\theta = 2$. The replication file `data\processed\market_access_model\basemacode_coalgrain_theta2_rsds\solve_marketaccess_rsds.m` contains the summary code. It uses the FSOLVE function which draws on another Matlab file (`to_solve2_rsd.m`) defining the system of 563 equations in 563 unknowns, MA_i , based on model equation 2 in the text. It calls on the town-RSD population data for 1851 and the 1830 trade costs between all towns i and j in several spreadsheets contained in the file `inputssolve1850rsd_ma.xlsx`. The outputs of these market access calculations are contained in the spreadsheets `MA_1850_theta2_rsd.xlsx`. We call this variable $MA_{i1830/50}$.

Table J2 gives the summary statistics for all the town-RSD variables in our analysis.

Table J2: *Descriptive Statistics for town-Registration subdistrict (RSD) variables in 1851 and market access at the town-RSD level in 1830/50*

| VARIABLES | (1) N | (2) mean | (3) sd | (4) min | (5) max |
|---------------------------------|----------|-------------|-----------|------------|------------|
| SES 2 higher skilled non-manual | 538 | 3.353 | 1.386 | 0.732 | 13.52 |
| SES 2 lower skilled non-manual | 538 | 11.36 | 6.385 | 1.906 | 57.48 |
| SES 3 higher skilled manual | 538 | 26.30 | 7.089 | 9.644 | 57.82 |
| SES 4 lower skilled manual | 538 | 24.11 | 17.11 | 4.505 | 71.59 |
| SES 5 unskilled manual | 538 | 34.56 | 15.54 | 6.102 | 68.34 |

| | | | | | |
|---|-----|-------|-------|-------|-------|
| Total fertility rate | 538 | 4.473 | 0.635 | 2.508 | 7.004 |
| Early childhood mortality rate | 538 | 111.8 | 34.49 | 41.75 | 289.4 |
| Log town-RSD market access 1830/1850, $LnMA_{i1830/50}$ | 538 | 5.683 | 0.314 | 4.355 | 6.308 |
| % born < 10 km of residence | 538 | 69.90 | 10.82 | 32.41 | 93.77 |
| % born 10 to 49 km of residence | 538 | 18.36 | 7.374 | 3.359 | 68.03 |
| % born >50 km of residence | 538 | 9.687 | 5.614 | 1.723 | 31.28 |
| % born in GB, not E&W, and residing in E&W | 538 | 0.517 | 1.019 | 0 | 16.24 |
| log TownRSD Pop. | 538 | 9.268 | 0.708 | 7.898 | 14.11 |

Notes: Authors calculations. For RSD outcomes we use data from the ‘Atlas of Victorian Fertility Decline’ Project (see Reid *et al.* 2018) and specifically the Populations past webpage. Note town-RSD market access, $MA_{i1830/50}$, is derived from equation (2) in text and uses 1851 population of town-RSDs and the 1830 trade costs of towns using 1830 freight costs and 1830 producer prices, with weights for 0.92 for coal and 0.08 for grain.

J.1 Appendix table J3

We first use town market access variables to estimate the effect on the natural log of town-RSD population in 1851 as the outcome y_{i1851} . In col. 1 of Table J3 we show a parsimonious specification with county fixed effects 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 4.72%. This estimate is larger than what we found for town populations from 1680 to 1841, but broadly similar.

Table J3: *Effect of market access on town-RSD log population in 1851*

| VARIABLES | (1) | (2) | (3) | (4) |
|--------------------------------|----------------------|-------------------|---------------------|---------------------|
| $lnMA_{i1830/50}$ | 0.418*** (0.1115) | 0.346* (0.175) | 0.506*** (0.125) | 0.387*** (0.119) |
| Observations | 538 | 538 | 538 | 538 |
| R-squared | 0.135 | 0.150 | 0.452 | 0.386 |
| County FEs | YES | YES | YES | YES |
| Geographic controls | NO | YES | YES | YES |
| Pre-IR controls | NO | NO | YES | YES |
| Kleibergen-Paap F statistic | | | | 118.5 |
| Endogeneity test stat. p-value | | | | 0.141 |

Notes: The dependent variable is log town-RSD population in 1851. All regressions include latitude, longitude, and RSD land area. $lnMA_{i1830/50}$ is computed using equation (2) with 1851 RSD populations and 1830 trade costs, and $\theta=2$, omitting own town-RSD population. The instrument in col. 4 is the Plan levels instrument discussed in the text. Standard errors clustered on the county are reported. *, **, and *** represent statistical significance at the 10, 5, and 1% levels.

J.2 Appendix table J4

We now estimate how market access affects demographic variables in 1851, which are mentioned in the text. The Victorian Fertility Decline Project gives two important demography 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 Table J4. 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 J4: *Effect of market access on fertility and early childhood mortality in 1851*

| VARIABLES | (1) | (2) | (3) | (4) |
|--------------------------------|--------------------|-------------------|---|--|
| | OLS | IV | OLS Early childhood mortality rate | IV Early childhood mortality rate |
| $\ln MA_{i1830/50}$ | -0.016 (0.0941) | 0.0513 (0.118) | 19.29*** (5.954) | 16.90*** (5.591) |
| Observations | 538 | 538 | 538 | 538 |
| R-squared | 0.505 | 0.255 | 0.607 | 0.443 |
| Kleibergen-Paap F statistic | | 118.5 | | 118.5 |
| Endogeneity test stat. p-value | | 0.423 | | 0.509 |

Notes: The dependent variables are total fertility rate and early childhood mortality rate in 1851. All regressions include latitude, longitude, RSD land area, county fixed effects, town geographic controls, and town pre-industrial revolution controls. $\ln MA_{i1830/50}$ is computed using equation (2) with 1851 RSD populations and 1830 trade costs, and $\theta=2$, omitting own town-RSD population. The instrument in col. 2 and 4 is the Plan levels instrument discussed in the text. 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. The explanation requires more research, but one potential channel is through migration-induced over-crowding of towns and/or the population levels of towns which

had negative health consequences especially for the young. Summarizing, the findings in Table J4 suggest that natural population increase (higher births minus deaths) cannot account for the positive effects of market access on population.

K. Explanation of the counterfactual calculations with additional results

As explained in the text, we express town i 's counterfactual 1841 population, pop_{i1841}^C , and town i 's counterfactual market access, MA_{i1841}^C , with two equations:

$$(i) pop_{i1841}^C = MA_{i1841}^C{}^{0.193} E_{i1841} \text{ and } (ii) MA_{i1841}^C = \sum_j (\tau_{ij}^C{}^{-2} pop_{i1841}^C) * MA_{i1841}^C{}^{-3/2}.$$

In this appendix, we explain how to solve (i) and (ii) for all $i = 1, \dots, n$, using E_{i1841} and τ_{ij}^C as inputs. Recall from the text, we assume $\ln E_{i1841} = \ln pop_{i1841} - 0.193 \ln MA_{i1830}$, where MA_{i1830} is our measure of market access, derived from equation 2 (using $\theta = 2$), and $\kappa_2 = 0.193$, which is our summary elasticity estimate. Returning to (i) and (ii), we make a simplification by substituting the expression pop_{i1841}^C into the formula for market access, equation (ii), which yields a system of equations $MA_{i1841}^C = \sum_j (\tau_{ij}^C{}^{-2} MA_{j1841}^C{}^{0.193} E_{j1841}) * MA_{j1841}^C{}^{-3/2}$ for all $i = 1, \dots, n$. Now we have a non-linear system of equations for MA_{i1841}^C . Once a solution is found, we substitute MA_{i1841}^C into the equation, $pop_{i1841}^C = MA_{i1841}^C E_{i1841}$, to get our estimates of pop_{i1841}^C .

The replication file `data\processed\counterfactuals\counter1680tradecosts\solve_1680tradecostcountermodel2.m` contains the summary code for the first counterfactual using 1680 trade costs. The code uses the FSOLVE function which draws on another Matlab file (`to_solve2_2.m`) defining the system of 586 equations in 586 unknowns MA_{i1841}^C based on equation $MA_{i1841}^C = \sum_j (\tau_{ij}^C{}^{-2} MA_{j1841}^C{}^{0.193} E_{j1841}) * MA_{j1841}^C{}^{-3/2}$. The code calls up values for E_{i1841} and τ_{ij}^C in several spreadsheets contained in the file `inputscounter1680trade_modelma2.xlsx`. The code also uses the solution for MA_{i1841}^C to calculate $pop_{i1841}^C = MA_{i1841}^C{}^{0.193} E_{i1841}$, which is counterfactual population. The output is contained in the replication file `data\processed\counterfactuals\counter1680tradecosts\MAcounter_cg.xlsx`.

The summary code for the second counterfactual using 1680 networks is in `data\processed\counterfactuals\counter1680network\solve_1680networktradecostcountermodel2.m`. Here we replace 1830 networks with 1680 networks when calculating freight costs in

our multi-modal model. We keep other aspects of trade costs the same, including using 1830 producer prices and 1830 freight rates per ton. Practically, this code calls on a different τ_{ij}^C in the spreadsheet `inputscounter1680trade_modelma2.xlsx`, but is otherwise the same as above. The output is contained in the replication file `data\processed\counterfactuals\counter1680network\MAcounter_cg1680net.xlsx`.

We also replicate the first counterfactual, with 1680 trade costs, using the simplified market access formula, $MA_i = \sum_j^J pop_j \tau_{ij}^{-\theta}$. The replication file `data\processed\counterfactuals\counter1680tradecosts_simple\solve_1680tradecostcountersimple.m` uses the FSOLVE function but draws on another Matlab file (`to_solve2_2_simple.m`) defining the system of 586 equations in 586 unknowns, MA_{i1841}^C , based on equation $MA_{i1841}^C = \sum_j^J (\tau_{ij}^C)^{-2} MA_{j1841}^C {}^{0.193} E_{j1841}$. The code calls up different values for E_{i1841} in the file `inputscounter1680trade_simplema.xlsx`. We use the simplified market access to calculate E_{i1841} , along with an elasticity 0.182 corresponding to a lower bound of the estimates in table 4. The output for this counterfactual calculation is contained in the file `data\processed\counterfactuals\counter1680tradecosts_simple\MAcounter_cgsimple.xlsx`.

K.1 Summary statistics for the main counterfactuals: small and medium towns

In the text, we summarized the counterfactual populations and the actual populations for the largest towns in 1841, with populations above 50,000. We now report statistics on the distribution for towns with less than 50,000 population in 1841. Figure K1 shows the two population distributions in the counterfactual where 1830 trade costs are replaced with 1680 trade costs. In the counterfactual, the mean population is 5,793 versus 6,692 in the actual, which is 13.5% lower. The distribution of counterfactual town populations is also shifted to the left.

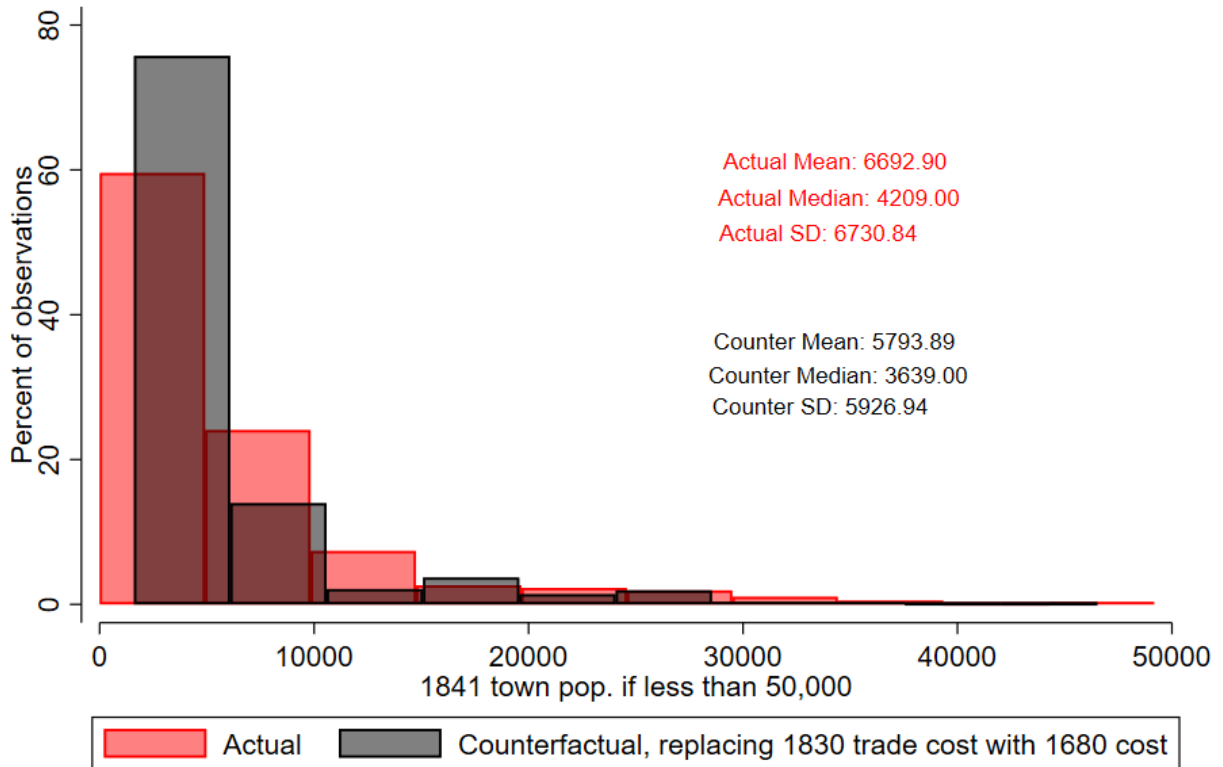


Fig. K1 *Distributions of actual and counterfactual 1841 populations replacing 1830 trade costs with 1680 trade costs, among the set of towns with population 50,000 or less in 1841.*

Notes: Authors calculations. The counterfactual populations are in MAcounter_cg1680.xlsx, contained in our replication files.

Figure K2 shows the two population distributions in the counterfactual where 1830 networks are replaced with 1680 networks. In the counterfactual, the mean population is now 6,292 versus 6,692 in the actual, which is 6% lower. The distribution of counterfactual town populations is also once again shifted to the left.

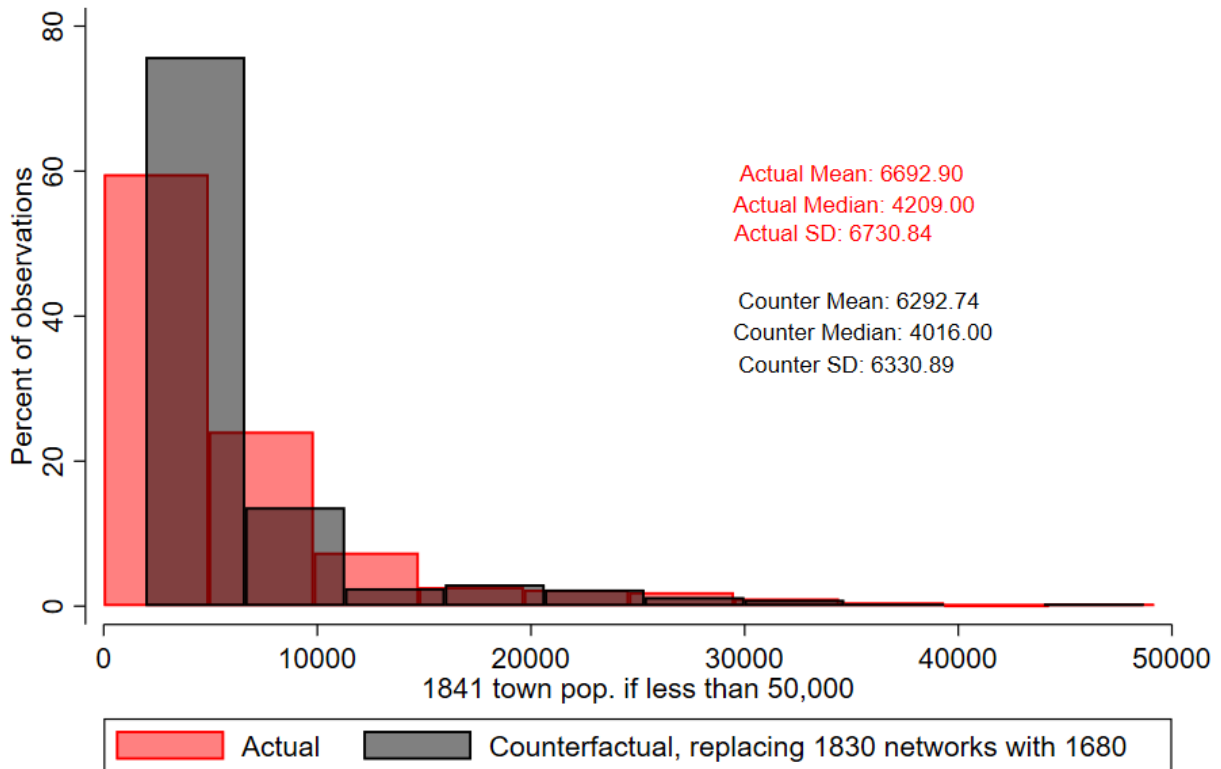


Fig. K2 Distributions of actual and counterfactual 1841 populations replacing 1830 networks with 1680 networks, among the set of towns with population 50,000 or less in 1841.

Notes: Authors calculations. The counterfactual populations are in MAcounter_cg1680net.xlsx, contained in our replication files.

K.2 Additional counterfactual

We also calculate a counterfactual using the simplified market access formula. We find that the switch from 1830 trade costs to 1680 trade costs implies even larger reductions in urban population. The counterfactual populations are in the replication file `data\processed\counterfactuals\counter1680tradedcosts_simple\MAcounter_cg_simple.xlsx`. They show the total urban population would be 25% lower. As examples, London’s population would be 16% smaller and Manchester would be 35% smaller. We think the market access based on equation 2 gives more reliable estimates as it is derived from a trade model. Therefore, we do not emphasize these estimates.

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