Transport improvements, market access, and urban growth in the early industrial revolution

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Abstract[5]

The leading economies of the first industrial revolution were spatially transformed as their populations urbanized. This paper uses a market access approach to estimate the contribution of all transport improvements to urban population growth in England and Wales during the era of wagons, canal barges, and sailing ships. First, we make freight trade cost estimates between 590 cities and towns in 1680 and 1830. We then estimate large positive effects on population from higher market access, especially for towns on coalfields. More broadly we illustrate how locally developed networks can have large national effects and enhance natural resource advantages.

Keywords: Urbanization, transport improvement, market access, industrial revolution, resource advantages

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During the industrial revolution, urban populations grew to levels not previously seen in human history. The fastest growing cities and towns often had natural resources or an inherited skill base which helped develop their industries. They also had access to wider markets, which brought cheaper goods to urban consumers and more customers to urban firms. But expanding market access was no simple matter and beyond the control of an individual city. It depended on technology and infrastructure decisions made by many different actors throughout the network.

This paper uses a market access approach to estimate the contribution of all transport improvements to city and town population growth in England and Wales during the era of wagons, canal barges, and sailing ships. From around 1650, this economy's labor force increasingly left agriculture and sought new manufacturing and service employment in cities and towns, resulting in more than a doubling of the urbanization rate by 1800.[6] London and other coastal cities attracted nearly all the urban migrants in the 1600s, while later migrants increasingly went to inland towns on the coalfields, like Manchester and Leeds. At the same time, England and Wales led the world in developing technology for ships and navigation. Extensive networks of canals, high quality roads, and capable ports were also built to foster the movement of goods, especially coal and grain. We focus on the period starting in 1680, when infrastructure investment in England and Wales began to increase, and ending in 1830, when railways and steamships started a new transport era. The estimates, detailed below, show that collectively all transport improvements changed trade costs and affected urban growth through greater market access. We also find market access effects were much larger for towns on coalfields.

Our findings shed new light on the impact of transport improvements over the last few centuries. Productivity in this sector changed much with railways, steamships, and later with automobiles. It could be argued that earlier transport improvements were minor and did not greatly affect growth. Contrary to this view, we argue they could be significant. Our findings also highlight a setting where private, nonprofit, and municipal actors took the lead in sponsoring, financing, and implementing infrastructure projects. This was unlike other settings, where the central government played the leading role. We emphasize that locally developed infrastructure

[6] See Wrigley (1985), Bairoch (1988), DeVries (2013), and Buringh (2020).

had impacts on distant cities and towns through the network. For example, linking canals sometimes lowered trade costs between towns far apart. Finally, our findings demonstrate interaction effects between market access and coal. It is argued that towns on the coalfields had energy cost advantages in home heating and steam powered manufacturing.[7] However, as we show, there was limited potential to exploit these advantages without increased market access.

Our contribution starts with the creation of network GIS data and their integration with data on population and other features of urban areas. With coverage of nearly 600 cities and towns spanning over three centuries, it is one of the most comprehensive historical urban-transport databases to date.[8] We make new estimates of inter-urban transport costs derived from a multi-modal freight model with roads, inland waterways, ports, and coastal shipping networks. Technology and geography are incorporated through cost parameters, like freight rates per mile, differing by the slope of the terrain and quality of infrastructure, all estimated from historical sources. Crucially, we allow inter-modality—the use of multiple networks—subject to transshipment costs. The final output is a matrix of freight costs in pence per ton by origin and destination between 590 cities and towns in 1680 and 1830. Given the limited sources, almost none of these 174,343 transport cost estimates can be observed without our model.

Next, we construct estimates of inter-urban trade costs, which relate transport costs to producer prices. For our baseline, trade costs between town (or city) i and j equal one plus the ratio of transport costs between i and j to the average pithead coal price. We document that average trade costs declined by 57% between 1680 and 1830. Moreover, where data is available, we demonstrate that trade costs closely correspond with the predicted differences in coal prices between supplying and consuming towns along the coast, giving confidence for their accuracy.

The inter-urban trade costs are used to create a variable for 'urban market access.' We draw on Donaldson and Hornbeck's (2016) general equilibrium model, which yields an expression for a location's market access as a function of its trade costs to all other locations with varying population and market access. Treating towns as locations, their framework gives us an

[7] Wrigley (2010), Crafts and Wolf (2014), Warde (2018), Hanlon (2020), Fernihough and Hjortshøj O'Rourke (2021).
[8] Unfortunately, the data on Scotland are less developed and so this British region is not included in our study.

expression for town market access using our trade costs estimates. We then estimate the effects of the difference in natural log 1830 and log 1680 town market access on the difference in natural log 1841 and log 1680 town population. Various geographic controls, like being located on a coalfield, are added to the specification along with controls for economic and institutional characteristics of towns in 1673, before the acceleration in transport change.

Even with a rich set of controls, endogeneity is a concern as urban interests played a role in improving transport links. This issue is addressed with instrumental variables related to the Grand Cross Canal Plan, devised by the engineer James Brindley in the 1760s and meant to connect distant river basins by canals. The route was shaped by geographic conditions and had few viable alternatives. That said, there were some inland towns that appear to have been targeted, being named on maps of the Cross Plan in 1779. Instead, we focus on incidentally connected towns, within 2.5 km of canals in the Plan, but not named on the map. In terms of observables, like 1680 population, incidentally connected towns are no different from towns away from the Plan. We also give evidence suggesting coordinated infrastructure development was rare between averaged-sized towns more than 50 km away. Building on these points, our main instrument is market access to towns more than 50 km away that were incidentally connected to the Cross Plan.[9] In extensions, we also use distance to the nearest canal in the Cross Plan and distance to 1680 inland waterways as additional instruments.

The ordinary least squares (OLS) and instrumental variable (IV) estimates both show that increasing a town's market access significantly increased its population and produce similar coefficients. The estimates are also similar with different formulations of market access and controls for local infrastructure development. Moreover, market access change between 1680 and 1830 does not precisely explain population growth one century before, as our identification strategy assumes. Using the preferred estimates, we argue that a 10% increase in market access would increase town population by approximately 2.5%.

The main extension highlights the interaction effect between a town's market access and a town being on a coalfield. 22% of towns in our data were on coalfields, and on average their

[9] Our instruments are similar in form to those used by Herzog (2021) to study interstate highways in the US.

population grew significantly more than others. We find that the effect of being on a coalfield was much larger if it had greater changes in market access.

In the last section, we argue there would have been large changes in urban populations if trade costs remained constant between 1680 and 1830. Our estimates imply that the total urban population would be 12.3% lower in 1841. Our interpretation is that potential urban dwellers would have stayed in rural areas of England and Wales and nearby economies. We also argue there would have been substantial population redistribution from inland cities and towns to the coast. Inland urban areas, like Manchester and Leeds, would have had 40% less population, while coastal urban areas, like Liverpool and Bristol, would have little loss or some increase. The reason is that inland areas experienced much greater trade cost reduction.

Our paper contributes to several literatures. The first uses history to study transport infrastructures and economic development.[10] The most related examine economy-wide effects of improving networks using a market access approach.[11] This paper is one of the first to analyze the market access implications of transport improvements before railways.[12] We also add by bringing geography and infrastructure quality into estimates of transport costs. Ours is the most detailed historical, multi-modal transport model thus far in the literature.

Second, our paper contributes to a broader understanding of pre-steam transport improvements. There are several studies on the development of new shipping technologies related to sailing.[13] Others focus on internal improvements, such as canals and roads, and innovation in freight services.[14] Yet these studies rarely emphasize inter-modality and network structure, even though there is evidence it shaped the practices of shippers.[15] As we show, a town's trade costs depended on improvements across modes and throughout the network.

[10] See Baum-Snow (2008), Atack et al. (2010), Faber (2014), Duranton and Turner (2012), Tang (2014), Garcia-López (2015), Hornung (2015), Berger and Enflo (2017), Jedwab (2017), Bogart et al. (2022).

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

[12] To our knowledge only Zimran (2020), Trew (2020), and Flückiger et al. (2022) has studied the pre-steam era.

[13] See Ville (1986), Harley (1988), Armstrong (1991), Solar (2013), Solar and Rönnbäck (2015), Pascali (2017), Kelly and Ó Gráda (2019), Bogart et al. (2020), Kelly et al. (2021).

[14] See Gerhold (1996, 2014), Bogart (2005), Turnbull (1987), Maw (2011), Bogart, Lefors, and Satchell (2019).

[15] Turnbull (1979) shows how the famous shipper Pickfords relied on inter-modality. Other cases are described in the general histories of transport like Dyos and Aldcroft (1969), Aldcroft and Freeman (1983), Bagwell (2002).

Third, our paper also contributes to the literature on the industrial revolution, especially its location within England.[16] One view is that endowments, most importantly coal, were major factors determining the location of industrialization.[17] Another view is that economic specialties in the past had persistent effects on industrialization in the 1700s.[18] Our new urban-transport database advances this literature since most studies focus on county-level outcomes.[19] Also, we provide the first estimates of the contribution of all transport improvements, which reduced trade costs, increased market access, and grew urban areas, especially on coalfields.

I. Background

Rising urbanization is a distinctive feature of the English and Welsh (henceforth E&W) economy (Wrigley 1985). The available statistics demonstrate urbanization rates rose starting in the 1600s. Shaw-Taylor and Wrigley (2014) estimate that 8.0% of the English population lived in cities and towns of 5,000 or more in 1600. This figure rose to 16.3% in 1700, 20.5% in 1750, 29.5% in 1801, and 43.5% in 1851. Rising urbanization occurred in a context of high population growth overall. In England, the total population is estimated to have grown from 4.16 million in 1600 to 5.21 million in 1700, 8.67 million in 1801, and 17.03 million in 1851.

Migration was a primary factor accounting for urban population growth in E&W.[20] Many moved from rural to urban areas like cities and towns.[21] Urban areas provided more employment in manufacturing, including textiles, food, household goods, and metal working (Shaw-Taylor and Wrigley 2014). Factories were normally set up in or near towns, which brought increased employment opportunities (Berg 2005). In rural areas, mortality rates were lower, which created a surplus of labor. Structural changes in agriculture, such as enclosures, also played a role in encouraging rural out-migration. In terms of distances, some migrants went to nearby towns,

[16] Shaw-Taylor and Wrigley (2014), Angelucci et al. (2017), Trew (2020), Heblich, Trew, and Zylberberg.(2021).
[17] See Wrigley (2010), Crafts and Wolf (2014), Stuetzer et al (2016), Hanlon (2020), De Pleijt et al (2020), Fernihough and Hjortshøj O'Rourke (2021).
[18] See Heblich and Trew (2019), Kelly et al. (2020), Mokyr et al. (2021).
[19] The urban population and economic database and multi-modal model will be made available through this paper.
[20] Williamson (1988) argues about half of urban growth 1776 to 1846 was due to natural increase. Even though cities and towns had high mortality rates, which depressed natural increase, migrants tended to be young which raised fertility (see also Davenport 2020).
[21] In this context not all urban settlements were cities, i.e., densely settled areas with an administratively defined boundary. Historians also describe towns as being quite different from rural areas.

while others travelled further to large cities like London (Pooley and Turnbull 2005). Urban to urban migration also occurred, for example when apprentices trained in one town and migrated to another for work (Leunig, Minns, and Wallis 2011). Overall, migration has been associated with occupational upgrading and greater inter-generational mobility (Long 2005).

Importantly for our analysis, the rate of urban growth was not even across cities and towns.[22] London's population is estimated to have increased from 575,000 to 2.3 million between 1700 and 1851. The rate of increase was much larger in Manchester and Liverpool. Both had approximately 2500 inhabitants in 1700, but by 1851 they each had more than 300,000. Others grew less than Manchester and Liverpool. For example, York was the third largest city around 1680 but its population only doubled between 1700 and 1851. There are several explanations for why some urban settlements grew more in this period.[23] Urban proximity to a coalfield is considered very important because it attracted industry. Having access to water (either for trade or production) is another emphasized natural advantage. Yet another argument is that some urban areas grew because of long-held industrial specialties, which were either favored by technological change in the 1700s or because they involved transferable skills. Examples would be cloth making, mining, or milling. The level of commercial activity is also thought to have been an impetus to future urban growth, say by providing finance. The institutional structures of towns are also emphasized and are linked with the absence of guilds or corporate governance.

Well-developed transport connections are another factor highlighted in explaining urban growth. Transport was particularly important in shipping two necessities: food and fuel for home heating (Wrigley 2014). Based on coastal statistics, coal was the most important traded good in terms of weight (Armstrong and Bagwell 1983). Yet one limitation was that the coalfields were found only in certain locations within E&W. The main coalfields were along the northeast coast, near Newcastle upon Tyne, along the South Welsh coast, and in the inland north and midlands. As coal's value was low relative to its weight, the high cost of horse-drawn vehicles made road transport only economical at short distances. Most coal was shipped by coast and second by

[22] The sources for population across cities and towns will be discussed in the data section.
[23] Stobart (2000) provides a good overview of a large historical literature.

inland waterways. This meant that many larger urban areas were near the coast, where coal could be cheaply imported, or along inland waterways with coastal links or to an inland coalfield.

Grain was the second most important traded good in terms of weight and first when measured in value. Towns first drew upon grains produced in their hinterland, which was often shipped by road to be sold in its weekly markets. But a large urban area needed more grain than their hinterland could supply. Food supplies for larger cities and towns generally came from within their region along the better roads, inland waterways, or the coast.[24] Having dense transport connections to nearby markets was most helpful for supplying food.

To summarize, differences in E&W urban growth from 1650 to the early 1800s were mainly due to a city or town's natural advantages and skills, along with its ability to receive and send coal and grain. As our focus is on transport, we now give more background on how it was improved, starting with a detailed discussion of inland waterways.

I.A Improvement of inland waterways

Inland waterway projects were implemented generally when there was a critical mass of support among local interests.[25] However, this did not always happen, resulting in prolonged and uneven development. The legal and political context meant that bills promoting projects were submitted to Parliament, and then rejected or approved through special acts. Landowners and traders, along with county and city officials, were the main promoters, while engineers helped propose the routes. If the bill was successful, promoters usually formed a trust or private corporation to raise capital. Powers of eminent domain were given by the act and toll revenues paid for maintenance, re-investment, dividends, and interest payments.

River navigation projects, making short cuts and clearing obstructions, were the first phase between 1660 and 1740. An important technology was the pound lock, a chamber with gates at both ends that allowed boats to travel by water to higher elevations. Pound locks, originally a Chinese invention, were installed on some E&W rivers, extending navigation inland and thereby increasing accessibility to the coast. But since locks were expensive, rivers with

[24] The international grain trade was limited at this time (Sharpe and Weisdorf 2013)

[25] For more on river and canal promotion see Hadfield (1969), Willan (1964), Bogart (2018), and Satchell (2017).

greater elevation changes were not improved. River navigations were also controversial because they damaged land & weirs, threatened trading interests, and introduced fees. Many inland towns were not reached, and no navigation projects connected distant river basins.

Canals were the next phase, mainly from 1760 to 1830. Canals were like a straightened river with artificial cuts, and made more use of locks, tunnels, and reservoirs. The first was promoted and financed by the Duke of Bridgewater and its chief engineer was James Brindley. It linked the Duke's coal mines in Worsley with Manchester in 1762. A year later, Brindley began work extending the Bridgewater canal from Manchester to Runcorn, near the river Mersey. Runcorn was a rural settlement before the canal; later it would become a major transit point for coastal vessels and barges in the Mersey basin. Several later canals were like the Bridgewater, in being developed almost independently by local interests. The Grand Cross canals were different in also serving regional or national interests. The Cross was originated by the engineer Brindley, but it received support from the mining and manufacturing community (Hadfield 1969). It proposed to link the four major river basins (Thames, Mersey, Severn, and Trent) with two continuous lines of canal and thereby connect the centers of Hull, Bristol, Liverpool, and London (see Appendix III for an illustration). The routes will play a key role in our instruments.

The Trent and Mersey Canal was the first major link in the Grand Cross Plan, approved by an act in 1766. One endpoint was Runcorn, where barges could reach Liverpool and Manchester through the Bridgewater canal. The other endpoint was the navigation head of the river Trent. A detailed plan for the Trent and Mersey canal is shown in Appendix III. The title states it was to "better establish communication between the ports of Liverpool and Hull." By 1770, seven more canals in the Cross Plan had been authorized. The Wolverhampton Canal was meant to link the Trent and Mersey with the river Severn. Stourport was the endpoint on the Severn and was previously a rural settlement. Haywood, also rural, was the endpoint on the Trent and Mersey. The canal got its name because it passed through Wolverhampton, then a medium-sized industrial town. The Coventry canal and Oxford canal were designed to provide a single Cross link from the Trent and Mersey to the river Thames and ultimately London. Their southernly route had few elevation changes and terminated at Oxford, a prosperous university and market town. The Leeds and Liverpool canal was an expansion of the original Cross Plan. It proposed a northern link between the Mersey and Humber basins via the river Aire in West Yorkshire. Leeds and Liverpool were the endpoints because they were emerging industrial and trading towns. It is worth remarking that Birmingham, another emerging industrial town, was targeted with a canal route. However, Birmingham does not appear to have been on the ideal route linking major basins. An early 1769 plan (reproduced in Appendix III) shows the 'Birmingham canal' as a branch of the Wolverhampton canal, not providing through services.[26]

There were significant challenges in making the Grand Cross canals. Progress was slowed by Brindley's death in 1772. Further complications came from a brief financial crisis and the War of American independence (Ward 1974). Most did not open until the 1770s and 80s and there was only one major addition to the Cross plan in these years, the Thames and Severn canal, linking these major rivers. Canal promotion picked up again during the early 1790s.[27] Some new canals addressed limitations in the early Cross Plan. For example, the Grand Junction canal provided a more direct link between the Thames and Mersey basins, bypassing Oxford.[28]

Canals continued to be built through the 1810s and 1820s increasing network density. In these years, canals were also more widely used by private shippers and carriers, which were firms providing scheduled-public freight services (Maw 2013, Bogart, Lefors, and Satchell 2019). Also, a specialized canal barge was developed in the early 1800s which mainly transported coal and other heavy goods. While canals were a major improvement, they were often used in conjunction with roads and coastal ships when goods were shipped between regions as illustrated by the famous Pickford's firm (Turnbull 1979). We now briefly explain improvement in these modes.

I.B Improvement of roads, ports, and shipping

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[26] See the map 'A plan of canals authorized to be made…' shown in appendix 3.

[27] Various factors led to a 'canal mania' in the early 1790s, including optimism about future growth, low interest rates, and more creative financing (Ward 1974).

[28] Other examples. In the southwest, the Kennet and Avon Canal provided a route linking the Severn and Thames, via the river Avon near Bristol and Bath to Newbury on the Thames. 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.

Although it was the most expensive, road transport did improve over the 1700s with more powerful draft animals and logistical innovations among carriers. Road improvements from turnpike trusts were another factor.[29] Like canals, they were created through special acts. Turnpike trusts were given powers to improve individual roads and to levy tolls on users, but with the provision they could not profit. By 1830, there were close to 1000 trusts managing different sections of the main road network. These organizations were generally successful in building new roads and raising their quality. But the degree of change was not the same everywhere. Quality improvements were greatest near the industrial north and southern coast (Appendix II gives detailed maps). Trusts in these areas recruited better engineers and investors took more risks in lending on the security of future toll revenues (Rosevear et. al. 2022).

Improvements in sea transport were also significant in this period with technological change playing a greater role. In the early sailing era, voyages had long and unpredictable travel times, which meant higher costs. Gradually, there were innovations, like copper sheathing and improved rigging, which increased speed and reliability.[30] Navigation also improved with better charts and the chronometer. Shipping innovations were widely adopted, following the leadership of the East India Company and British Navy. In ports, there were also innovations like wet docks, which shut water in and kept it at a given level to facilitate loading. Wet docks were constructed in the major ports of Liverpool, Bristol, London, and Hull as well as emerging ports (Pope and Swann 1960). The implementation of port infrastructure followed the same system as inland waterways and roads through special acts (Jackson 1983). Most port authorities were trusts or municipal corporations, but starting in the early 1800s, some acts created joint-stock companies.

Lighthouses also evolved greatly with the invention of new lamps, lenses, and light vessels. New lights were created by private actors and by Trinity House, a seaman's guild. They famously collected fees, called light dues, igniting a later debate about public goods.[31] For our purposes, the key point is that they lit up most of the E&W coastline by 1830, improving shipping.

[29] For the literature on turnpikes and their effects, see Gerhold (1996), Bogart (2005) and Rosevear et. al. (2022).
[30] For the literature on speeds and shipping innovation, see. Armstrong (1991), Solar (2015), Solar and Ronnback (2015), Kelly and O'Grada (2019), Bogart et. al. (2020), Kelly, O'Grada, and Solar (2021).
[31] For the literature on lighthouses, see Coase (1974), Candela and Geloso (2018), Bogart et. al. (2022).

I.C From transport improvement to urban growth

To summarize, transport was improved in E&W due to several new technologies and locally developed infrastructures. The degree of change was uneven across space depending on distance to the coast and where roads, rivers, and canals were built or improved. Our goal is to identify the effects of varying transport changes on the population growth of all towns in E&W. General equilibrium trade models provide a structured approach to estimating such effects. Many following Eaton and Kortum (2002) and Redding and Venables (2004) emphasize 'trade costs', which capture the wedge between prices paid by consumers and received by firms. Households, who are both workers and consumers, choose their location based on wages, goods prices, and rents. Trade costs influence household location choices through 'market access.' In locations with greater market access, there will be more imports from low-cost producers which reduce consumer prices and attract households supplying labor, and there will be more exports for firms which raises the local demand for labor.

The exact way in which trade costs influence market access and the distribution of population is dependent on the modelling of production and consumption. To inform our specification, we use Donaldson and Hornbeck's (2016) GE model. Stated briefly, it assumes each location has a land endowment. Firms rent land and hire labor to produce a unique product variety subject to constant returns to scale. There are random productivity differences across locations. The model broadly fits our setting because production in the 1700s was mostly based on agricultural or raw material processing and economies of scale were limited.[32] While our baseline market access formula is derived from this model, our estimates shown later are robust to different specifications.

II. Data

There are challenges in analyzing population change before the first census in 1801.[33] Nevertheless, there are sources upon which to base good estimates of urban population. For the

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

[33] The best data are for counties (see Wrigley 2009), but these are not the ideal unit for studying urban growth.

1660s and 1670s, there are counts of enumerated households in the hearth tax and Bishop Compton's count of Anglicans and other religious households. Langton (2000) uses these sources to estimate population for 925 settlements in E&W c.1680.[34] Langton also provides population for 950 settlements in 1801 and 1039 in 1841 using censuses.[35] We use Langton as our main source for studying urban population change, but with two sample restrictions. The first requires settlements to reach a population of at least 2500 in 1680, 1801, or 1841, reducing the sample to 590. Many settlements in Langton are small and a population of 2500 is often the lowest standard for urban in historical studies (e.g. DeVries 2013).[36] The second restriction further requires settlements to have a recorded population in 1680, 1801, and 1841, reducing the sample to 461. It avoids the complication of modelling missing 1680 populations as zero. Note by design our resulting '1680-1801-1841 sample' is positively selected on 1680 population size compared to Langton's list of 925 settlements. For robustness we use sample weights to address potential concerns. Going forward observations are referred to as towns generally or cities in specific cases.

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.[37] 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.[38] Langton's 1680 estimates are thus very accurate in comparing town populations across counties. Nevertheless, accurate town population change from 1801 is also used for robustness.

We also link our sample towns to Clark and Hosking (2005), who give population estimates based on the 1563 Diocesan returns. As they focus on small and medium towns, their estimates are supplemented with Wrigley's (1985) top 10 city populations c.1520. Using both, we link 155

[34] 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. As sources are used in the 1660s and 1670s, we refer to the date as c1680.
[35] Langton's data are digitized and available through Bennet (2012), who also summarizes Langton's methods..
[36] Bairoch et al. (1988) use a threshold of 5000 and Buringh (2020) uses a modern threshold of 10,000.
[37] 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.
[38] County populations in 1680 are estimated by the weighted average of Wrigley (2009)'s figures in 1600 and 1700.

towns to our 1680-1801-1841 main sample. As shown in Appendix I, the 1563-1680-1841 sub-sample has a similar distribution of 1680 population and growth as our main sample.

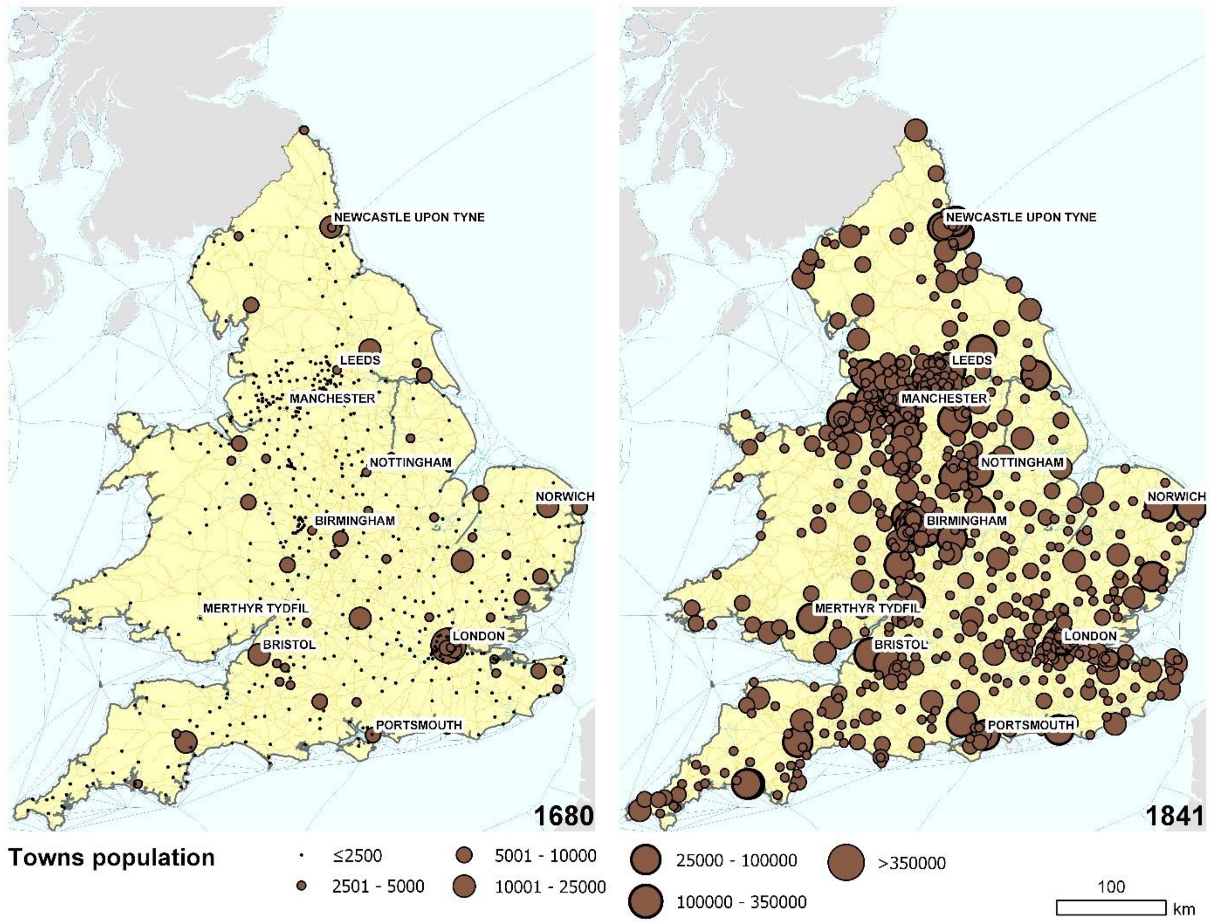

Figure 1: English and Welsh town populations in 1680 and 1841

Sources: Authors representation based on town populations sampled from Langton (2000).

All our sample towns are further linked to a larger GIS database, where settlements are treated as points and coordinates are identified based on a hierarchy of characteristics.[39] The linking allows us to map for the first-time E&W town populations in 1680 and 1841 (see figure 1). In 1680, London is the only large city. Seven towns have a population over 10,000, but most were less than 2500. In 1841 London is still the largest, but towns in the west midlands and northwest

[39] See Satchell, Potter, Shaw-Taylor, and Bogart (2017) for GIS town database. The first step was to identify the coordinates of its market. In its absence, parish church coordinates were assigned. If no parish church, then inns, post offices, public houses, and high streets are used in that order.

have grown significantly. The latter regions have urban clusters in 1841 which are absent in 1680. For reference, Appendix I reports the list of the top 20 towns by population in 1680 and 1841.

II.B Transport networks

A wider project creates GIS maps of historic ports, coastal routes, inland waterways, and roads in E&W.[40] For this paper, additions are made to create networks for two benchmark years, 1680 and 1830. The definition of a port is broad and includes 479 recorded loading/unloading places in published directories, surveys, and archival records like the Port Books. All ports are geo-referenced using the location of the oldest harbors or dock works.[41] The tonnage of ships involved in foreign trade that went inwards and outwards from each customs port in 1791 is also added.[42] Last, coastal routes between ports were digitized according to the navigation charts of the era and physical geography. Digital maps of all ports, customs ports with foreign trade volumes, and coastal routes are shown in Appendix II.A with additional details.

For inland navigation, we start with a digitization of waterways open in 1680 and 1830.[43] In 1680 this is the network of navigable rivers. In 1830 it also includes canals and river navigations made since 1680. Importantly, we add GIS data on locks to 1830 inland waterways. Locks allowed boats to travel by water to higher elevations, but they also led to higher user fees. In both years we also add connections between tidal rivers and coastal routes. Appendix II.B shows digital maps of inland waterways identifying rivers, canals, locks, and coastal route connections.

The road network in 1680 draws on several sources.[44] The principal roads come from a digitization of John Ogilby's Atlas of 1675, which covers over 7,500 miles. It also uses a military survey of 1686 identifying sites with spare stables for horses indicating road use. Sites with more than 15 spare stalls are connected to the Ogilby network using a database of old tracks. We add information on slope of the terrain and vehicle accessibility, either packhorse or wagon, using a London trade directory. Additional details are in Appendix II.C.

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[40] See 'Transport, urbanization and economic development in England and Wales c.1670-1911' https://www.campop.geog.cam.ac.uk/research/projects/transport/.

[41] See Alvarez and Dunn (2019) for GIS data on ports and coastal routes.

[42] These are contained in CUST-17-13, which is digitally available through the National Archive. See appendix II.A.

[43] See Satchell, Shaw-Taylor, and Wrigley (2017a,b) for GIS data.

[44] See Satchell, Rosevear, Dickinson, Bogart, Alvarez, Shaw-Taylor (2017) for GIS data on 1680 roads.

The principle and important secondary roads in 1830 are represented by a digitization of the turnpike trust road network around that year.[45] We incorporate slope and road quality based on a parliamentary survey of 1838.[46] Note that bridges and ferries are added as singular segments of roads digitized from the same sources. Maps and more details are in Appendix II.D.

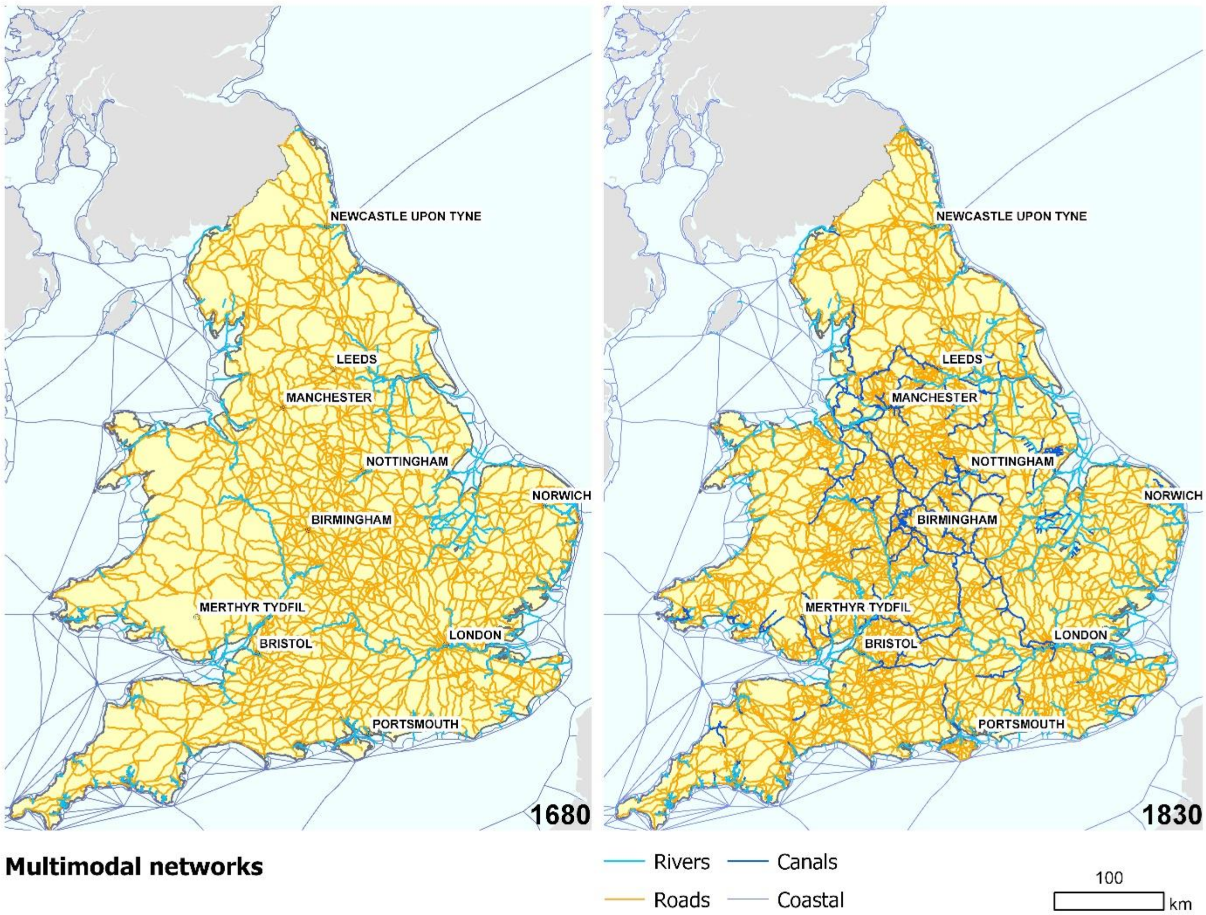

Figure 2. Transport networks in 1680 and 1830.

Source: created by authors using source in text.

Figure 2 shows the full picture of transport networks. Aside from important coastal routes, in 1680 there are many roads and inland waterways extending from the major river basins. In 1830 several canals link distant basins. Also notice the additions to the road network

[45] See Rosevear, Satchell, Bogart, Shaw Taylor, Aidt, and Leon (2017) for GIS data on 1830 roads.

[46] High quality corresponds to trustees rating their roads as good, very good, and excellent. Trustee ratings of middling and below are coded as bad quality. See Rosevear et al. (2022).

by 1830 were often near the canals. Ports were common in both periods, and we don't emphasize the regional differences in coastal transport.

II.C. The 1779 Canal Plan

Our identification strategy uses a map called 'A plan of navigable canals made and now making,' created by Hugh Henshall in 1779.[47] Its key gives a list of 19 canals or river navigations. Research on the list confirms a few depicted canals were open for use, but most were being made or proposed in 1779. The original 1779 Plan map is shown in Appendix III, along with an earlier plan map, to which it closely corresponds except for a few canals.[48]

The 1779 Plan map is difficult to digitize as it is not scaled accurately. Instead, we digitize the actual canal routes which correspond with the shown planned routes. A map of the canals represented in the Plan is shown in the left panel of figure 3. The right panel shows their classification into Grand Cross and other types, along with towns and connections to the 1680 waterway network. A visual comparison with the original map in Appendix III shows great similarity with our representation using the actual canals built. We further identify towns named in the 1779 Plan map at the end points of each canal and approximately on the route. These 22 named towns are linked to our main data and are called targeted towns. We also identify 25 towns within 2.5 km of the 1779 planned canals, but not named in the original map. They are called incidentally connected towns and will be used in the IV approach.

[47] For interested readers see https://www.raremaps.com/gallery/detail/50049/a-plan-of-the-navigable-canals-made-now-making-in-england-henshall, last assessed Aug. 22, 2022.
[48] It is called 'A plan of canals authorized to be made in England'. The date of publication is unknown, but its content and title suggest 1769. This map is available through the British Library King's Topographical Collection.

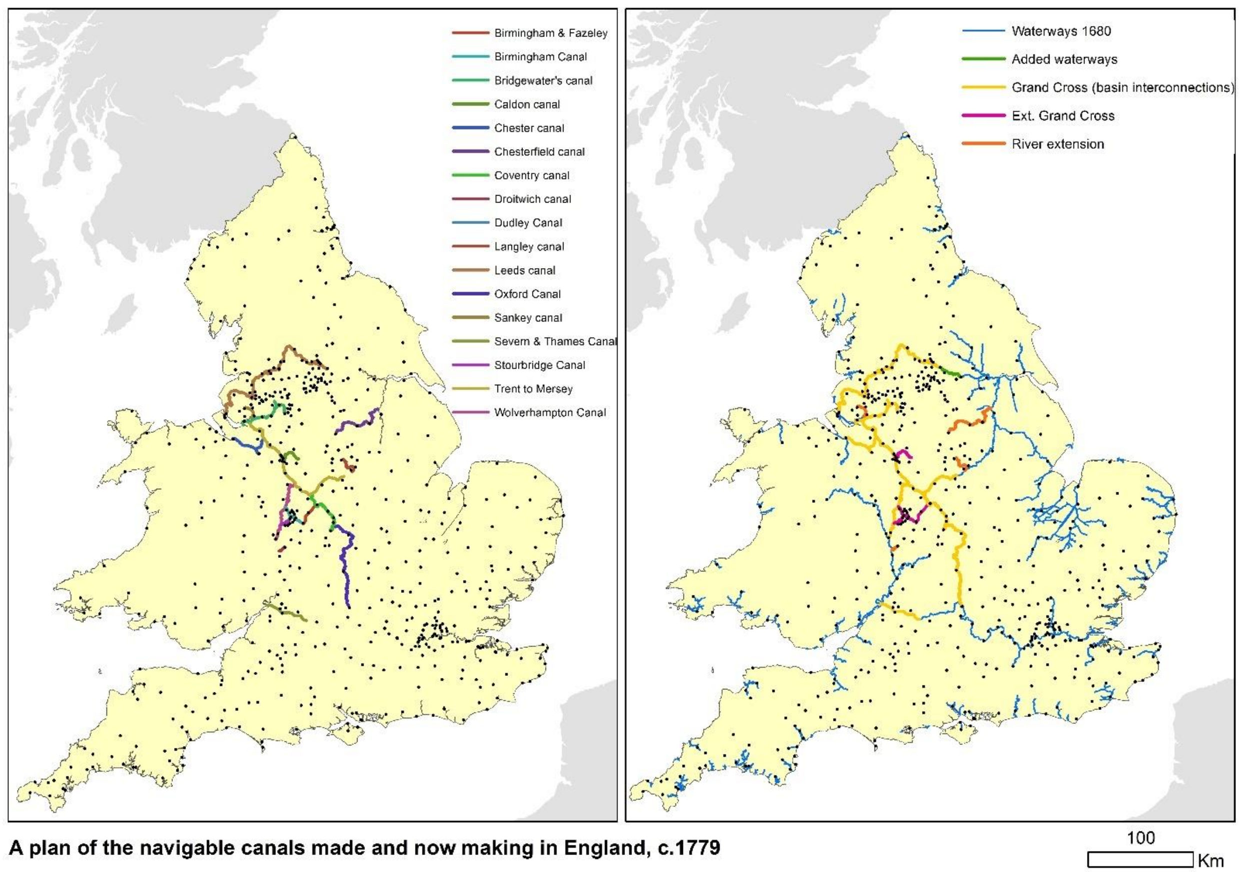

Figure 3: Towns and representation of canals in Henshall's plan 1779 (left), with classification and waterway connections (right)

Notes and sources: Author's creation based on map using Antique Maps, https://www.raremaps.com/gallery/detail/50049/a-plan-of-the-navigable-canals-made-now-making-in-england-henshall. Dots represent towns in our sample. On classifications (right), Grand cross canals connected river basins, added waterways are river navigations from 1680 to 1760 which linked Cross canals to 1680 waterways, extensions to Grand cross were branch canals to towns, river extensions were river navigations unrelated to Grand Cross.

II.D. Town geographic and historic variables

Town geographic characteristics are measured using a rich database of 9700 spatial units in E&W, comprised of parishes and townships.[49] Towns belong to one of these based on their latitude and longitude, and we assign the linked-unit's geographic variables. If two towns were linked to the same spatial unit, we dropped the town with the smallest 1680 population. After also omitting 3 towns with missing variables, this reduces the 1680-1801-1841 sample to 448

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

towns. From the linking, we obtain 5 geographic variables: an indicator for being on an exposed coalfield, average elevation, the standard deviation of elevation, average rainfall, and average temperature.[50] This dataset also gives distance to the nearest port in 1565.

We also use a database of town characteristics from Richard Blome's *Britannia*, originally published in 1673 (see also Blome 1962). For 781 towns, it gives brief summaries of markets, economic specialties, charitable and educational institutions, and government.[51] We use 16 of these 'historic' variables as detailed in Appendix IV. Some of the most important are specialties in mining and cloth manufacturing. Unfortunately, we are only able to link to our 1680-1801-1841 sample, 375 towns from Blome's list with a full set of historic controls. For the rest there are two groups: (1) 33 towns mentioned in Blome, but historic variables can't be assigned because a full description was not given and (2) 40 towns absent in Blome. We create separate dummy variables for towns in (1) and (2) and for each group assign the same arbitrary values for historic variables. The two dummy variables control for missing data due to non-linking.

II.E Price data

Our analysis uses various sources on commodity prices. For coal, Houghton's price lists across several markets from 1691 to 1703 are the best source (Hatcher 1993). We digitized those for all markets as reported in Rogers (1987), who summarizes the range of prices reported in Houghton each year. Linking the markets to our town list yields 53 towns where we can calculate the average coal price between 1691 and 1703. In the early 1840s, parliamentary reports provide comprehensive information on prices paid for coal at workhouses operated by Poor Law Unions or PLUs in 1842 and 1843. Satchell, Bogart, Shaw-Taylor (2016) provide PLU coal prices with location defined by the town if urban, or the workhouse if rural. Linking to the towns in our data yields 359 with coal prices in 1842. The Corn Law returns provide rich data on grain prices in hundreds of markets from the 1770s to the 1830s, which we use along with Houghton's 1691 to 1703 grain prices in some calculations.[52]

[50] The Exposed coalfields were more easily exploited compared to concealed coal (Satchell and Shaw-Taylor 2013). Rainfall and temperature come from the FAO and are averaged from 1961 to 1990. Nonetheless, variation in rainfall and temp. across English and Welsh towns is likely to have been similar in the late 18th century.
[51] Blome's county maps also provide further coding of town geographic variables. See Bogart (2018) for details.
[52] See Appendix VI for more details.

III. Methodology for estimating freight transport and trade costs

A multi-modal model is used to estimate freight transport costs between 590 E&W towns in 1680 and again in 1830. The 590 towns are from the 1680-1801-1841 sample. The details are in Appendix V. Briefly, the model combines several modes of transport to identify the least cost route between each town pair. Points represent towns and ports. Polylines represent networks like roads, waterways, and coastal routes. To ensure connectivity of all towns, interpolated straight lines between point layers and respective networks are created too. A 'global turns policy' is used, which means movements within and between each network are allowed. Dijkstra's algorithm finds the least cost route, minimizing a cost accessibility function C_{ij} between point i and j. In equation (1) c_i^o is the cost from the journey origin to the network, c_{pq}^n is the cost in the n transport modes between p and q, c_r^t is the cost of each trans-shipment between modes r, and c_j^d is the cost to reach the destination from the network.

$$C_{ij} = c_i^o + \sum c_{pq}^n + \sum c_r^t + c_j^d \qquad (1)$$

Each transport mode has been assigned a unique ton per mile cost and some have fixed fees along the route or varying costs due to terrain and quality. These are drawn from historical sources as detailed in Appendix V and summarized in table 1. There are several key features: First, inland waterway per ton mile costs were 4.7 times more than sea transport per ton mile costs in 1680. Inland waterways become relatively more expensive by 1830, mainly because canals charged tolls. We capture differences in tolls with lock fees. Second, all seaport fees, including unloading costs, declined due to innovation and improvement. In 1830 seaport fees equal about 10 miles of inland waterway freight costs. Third, depending on the number of locks and road conditions, per ton mile costs for roads were around 3.3 times more than inland waterways in 1830. Consequently, the arrival of a canal near an inland town could lower its local transport costs by 70%. Fourth, differences in quality can change road transport costs by approximately 30% in 1830, assuming zero slope. Fifth, road transport costs with the best quality and no slope were between 44 and 47 times more expensive than sea transport costs.

The output of our multi-modal model yields estimates of freight transport costs in pence per ton between 590 towns. Accounting for symmetry, we estimate 174,343 unique transport costs between town pairs. They are based on very detailed network and geographic data as Appendix III explains. Even so, there are limitations. Our parameters for freight costs per mile are general and could vary locally for reasons we do not capture, including wind patterns. The quality of the infrastructures embedded in the networks might be greater or less than we allow for in our classifications. Geography could have further effects than just slope. The reliability of our transport cost estimates will be examined more in the next section.

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

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

Notes: (h/l) means height/length of segment or slope. For more details and sources see Appendix V.

III.A Measurement of trade costs

In our baseline, trade costs τ_{ij} between town i and j are defined by $\tau_{ij} = \frac{tc_{ij}}{CoalPrice} + 1$ where tc_{ij} is the transport cost derived from our multi-modal model and $CoalPrice$ is the average pit head price of coal. We estimate $CoalPrice$ to be 58 pence per ton in 1680 and 86 pence per ton in 1830 using prices from Newcastle Upon Tyne and Carlisle (see Appendix VI). The trade cost τ_{ij} is interpreted as the ratio of coal prices in i relative to j (or the mark-up) if coal was shipped from j to i, and there were no other transaction costs. The last qualifier is important since we are isolating trade costs due to freight transport.

We now describe how trade costs changed in general. The overall average between 448 towns in our sample was 14 in 1680. That means the price of coal would be marked up 14 times on average if it was shipped between any two towns, which being so high meant no trade would occur between most towns. In 1830 the overall average was 6, which is a 57% decrease from 1680. Thus in 1830 it was plausible that many towns traded with one another for the first time. For a visualization of how average trade costs differed across space see Appendix VI.

An extension considers $\alpha * CoalPrice + (1 - \alpha) * GrainPrice$ as the price of the traded basket in pence per ton, where α is coal's share in the tonnage of traded goods. The estimated price of the coal and grain basket is 115 pence per ton in 1680 and 233 pence per ton in 1830 (see Appendix VI). The resulting estimated trade costs averaged 7.6 across all town pairs in 1680 and 2.8 in 1830, implying a 63% decrease. The takeaway here is that trade costs are different using the coal-grain basket, but the magnitude of change over time is similar.

One testable implication of lower trade costs is that markets for coal should have become more integrated. Due to data limitations, we can only provide partial evidence. There are 35 towns in Houghton c.1700 that can be matched to a town also observed in the Poor Law Union (PLU) coal price database for 1842. We calculate the average coal price between 1691 and 1703 in those 35 towns. The coefficient of coal price variation, CV, was 0.37. The CV across the same 35 towns in 1842 was 0.31 (see Appendix VI). The lower CV is one indication of greater market integration, with the caveat that the 35-town sample is not necessarily representative. Additional evidence for integration comes from a series of coal prices in London and Newcastle Upon Tyne, the largest coal trading partners. The London to Newcastle coal price ratio fell from around 3 in the early 1800s to 1.5 in the early 1830s (see Appendix VI).

In a sample of coastal towns importing coal, we can also show our trade costs provide a reasonable estimate of the actual ratio between their coal prices and their major coastal supplier. From Houghton's sample c.1700, we identify 10 coastal towns that were less than 10 km from a port. Two, Newcastle and Pembroke, were coal suppliers. We assume the other 8 coastal towns obtained their coal from one of these based on coastal distance. As detailed in Appendix VI, the average ratio of coal prices in each of the 8 coastal towns relative to their nearest coastal supplier was 4.05. Our estimated 1680 trade cost between the 8 coastal towns and their coastal supplier, based on freight costs, averages 3.85. Moreover, the correlation between our 1680 trade costs and the observed coal price ratio c.1700 is 0.82. While limited to 8 observations, the similarity with average price ratios and their correlation give confidence that our trade cost estimates in 1680 are reasonably accurate.

A similar set of calculations is done for 51 coastal towns in the PLU data for 1842, where we can identify prices for their nearest coastal supplier (see Appendix VI). The ratio of coastal coal prices to the supplier averages 3.24, while our estimated 1830 trade costs between these 51 towns and their coastal supplier averages 2.73; the correlation with the actual coal price ratio is 0.60. Thus our 1830 trade costs reasonably match observed price mark-ups.

IV. Empirical specification to study trade costs, market access, and town population

To estimate how trade costs affected town population we build on the theoretical model developed by Donaldson and Hornbeck (2016). They derive an expression for locational population as a function of market access and other variables.[53] Letting towns be locations in their framework, town $i's$ market access is given by (2)

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

where κ is a constant normalized to 1, pop_j is the population of town j, indexed from $j = 1, .. n$ where $i \neq j$, τ_{ij} are trade costs between town i and j, and θ is a parameter greater than 1 measuring the inverse variation in productivity across towns.[54] In the summation, the first two multiplicative terms $({\tau_{ij}}^{-\theta} pop_j)$ imply that market access for i is higher when it has low trade costs to more populated towns all else equal. The third multiplicative term $({MA_j}^{-(1+\theta)/\theta})$ implies that as the market access of other towns MA_j increases, then MA_i decreases. In other words, hypothetically if all other towns market access increased, while town i's trade costs remained fixed, then town i's population should decline.

For the analysis, we solve for all MA_i simultaneously in 1680 and again in 1830.[55] θ is set at 2 for reasons explained later. In 1680 we use estimated trade costs τ_{ij} and town populations from that date. In 1830 we use trade costs from 1830 and town population in 1841. The resulting estimated market access for all towns in the 1680-1801-1841 sample are shown in

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[53] Their model (eqn. 11) implies $\ln\ pop_i = \kappa_1 + \kappa_2 lnMA_i + \kappa_3 lnA_i + \kappa_3 lnL_i$, where $\ln\ pop_i$ is log population, $\kappa_1$is a constant, $lnMA_i$ is log market access, lnA_i is log productivity, and lnL_i is log land area.

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

[55] There is no analytical solution (2) so we use Matlab to solve for market access.

figure 4. In 1680 market access was highest near London and along the east coast. In 1830 market access has changed dramatically, growing most inland and in the northwest. Comparing with figure 3, one can see that market access increased substantially near the Cross Plan canals. This illustrates one conclusion that locally developed infrastructure has broader access effects.

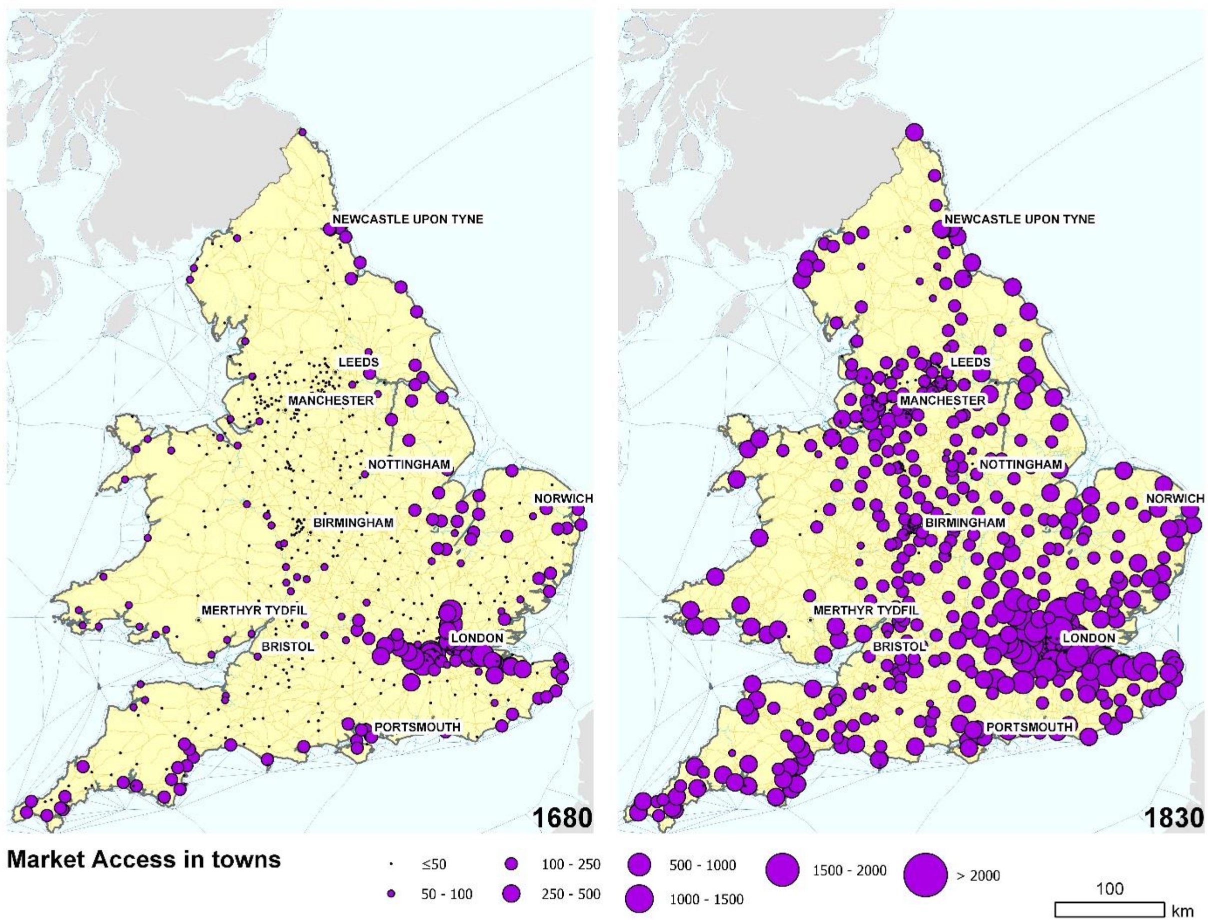

Figure 4: Estimated market access for towns in 1680 and 1830.

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

The main estimating equation is given by (3):

$$\Delta_{1841,1680}\ln pop_i = \beta_1\Delta_{1830,1680}lnMA_i + \beta_2 x_i + \varepsilon_i \quad (3)$$

where $\Delta_{1841,1680}\ln pop_i$ is the difference between town i's natural log 1841 population and its log 1680 population, $\Delta_{1830,1680}lnMA_i$ is the difference between town i's natural log 1830 market access and log 1680 market access, x_i includes nine region fixed effects, a 2nd order polynomial in town latitude and longitude, geographic controls, and historic controls from Blome dated in 1673, before population change in the dependent variable. As our data includes two cross sections, equation (3) is equivalent to a two-period panel with town fixed effects.[56]

We think it is likely that $\Delta_{1830,1680} lnMA_i$ is uncorrelated with the error term ε_i in (3) once we include our full set of control variables x_i. Nevertheless, unobservable town characteristics, like the organizational skill of its inhabitants, could have affected its market access change and population growth, creating omitted variable bias. We address this issue with several IVs. Our preferred IV is the change in town i's log market access to towns incidentally connected to the 1779 Cross Plan and that were more than 50 km away.[57] More precisely, the IV is $\Delta\ln\left[\sum_j^J D_{ij}^{far} D_j^{plan,inc} pop_j \tau_{ij}{}^{-2}\right]$, where Δ is change from 1680 to 1830, D_{ij}^{far} is a dummy variable equal to 1 if town i and j are more than 50 km apart in straight line distance, $D_j^{plan,inc}$ is a dummy equal to 1 if town j was incidentally connected to the 1779 plan, and pop_j and τ_{ij} are population and trade costs as before. Recall incidentally connected towns were within 2.5 km of the 1779 planned canals shown in figure 3, but not named on the Plan. They got close to canals mainly because of their location on the best routes for linking river basins as argued in section I.A. We add the requirement that incidentally connected towns be more than 50 km to eliminate effects from endogenous infrastructure development between nearby towns. We chose 50 km because most weekly trade for towns about the size of the incidentally connected was with rural areas and other towns within 50 km.[58] Also, the average length of the canal projects in the 1779 Plan was just over 50 km. These last two points suggest 50 km was approximately the maximum distance at which incidental towns may have coordinated with other towns to develop infrastructure.[59]

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[56] Notice our spec. is like a changes-on-changes strategy for analyzing city growth (see Duranton and Puga 2014).
[57] Our instruments are similar in form to those used by Herzog (2021) to study interstate highways in the US.
[58] It is a larger project to measure trade, but there are sources like Pigot Directories listing weekly road carrier services between towns around 1830. We randomly selected eight sample towns with 2500-5000 pop. in 1841 and digitized their weekly road services. We then calculated 1830 road distance between towns with weekly services to these 8 sample towns. The average distance is 58 km. Also, 67% of all services are to towns within 50 km.
[59] The key to the 1779 canal plan map lists 19 canal projects and their length. The average length was 52 km.

Balance tests on observables show that incidentally connected towns were like towns away from the Plan. For example, incidentally connected towns' 1680 population is not statistically different from towns more than 2.5 km from the Plan. Also, incidentally connected towns were no more likely to be linked with Blome and if linked, they were no different on all but one historic control (see Appendix VII). That said, incidentally connected towns were significantly different on geographic variables, which is why these controls are important.

We use two additional instruments for robustness. One is town $i's$ log distance to 1680 inland waterways. Our argument for relevance is that towns nearby already had the cheapest form of inland transport and there would be little incentive to build a canal nearby. Also, technological change in river transport was minor and so trade costs for towns near 1680 waterways should change little.[60] Exclusion from the second stage is not straightforward as towns close to 1680 waterways could have grown differently from towns farther away for reasons independent of their role in changing market access. Here we rely on our geographic and historic controls which capture indirect channels. Note that among our historic controls is an indicator for whether the town was on a navigable river c.1673. Thus, by conditioning on this variable, we are identifying towns close to 1680 waterways which did not have direct navigation access. The second additional IV is log distance to any canal in the 1779 Cross Plan. Relevance to market access change should be high because towns close to the Plan were close to a canal by 1830. Exclusion relies on canals in the Plan being routed to link distant basins. With this IV, targeted towns are excluded from the sample, but incidentally targeted towns are kept.

Finally, for robustness and to further address concerns about endogeneity we also consider four alternative market access variables. The first simplifies to an inverse trade cost weighted sum of the population of all other towns $MA_i = \sum_j^J pop_j {\tau_{ij}}^{-\theta}$, which is like market potential. We select $\theta = 2$ to match our baseline parameters. The second alternative is like the first but restricts the accessed towns j to be more than 50 km from town i, or $MA_i = \sum_j^J D_{ij}^{far} pop_j {\tau_{ij}}^{-2}$. As discussed with the instrument, it is meant to eliminate effects from

[60] Donaldson and Hornbeck (2016) employ a similar water access instrument for market access changes associated with railroads. Their logic for relevance is similar to ours.

endogenous infrastructure development between nearby towns. The third uses town populations in 1680 to calculate market access in 1830, or $MA_i^{1830} = \sum_j^J pop_{j1680}\tau_{ij1830}{}^{-2}$. Fixing population at 1680 addresses the potential feedback from town $i's$ population growth to others j. The fourth alternative considers ports as towns and uses foreign trade tonnage as population. The 'foreign-trade' access for each year is $MA_i = \sum_p^P tons_p\tau_{ip}{}^{-2}$ where $tons_p$ is the number of foreign shipping tons that went in and out of customs ports $p = 1, .. P$ in 1791 and τ_{ip} is the trade cost between town i and port p.[61]

Summary statistics for the main variables are shown in table 2. Appendix VIII has summary statistics for the instruments and control variables. Notice that population growth is large on average, increasing at an annual rate of 1.05 percentage points from 1680 to 1841. The growth of baseline market access increases at a similarly large annual rate. Notice the simplified MA_i formula, $\sum_j^J pop_j\tau_{ij}{}^{-2}$, implies higher market access growth. This is due to omitting $MA_j{}^{-(3)/2}$, which implies that as the market access of other towns MA_j increases, then MA_i decreases. Notice further that omitting towns within 50 km reduces market access growth marginally. Also, fixing 1680 population and isolating trade costs changes implies less market access growth as expected.

Table 2: Descriptive Statistics for urban population growth and market access change variables

Variable	Obs	Mean	Std. Dev.	Min	Max
$\Delta_{1841,1680}\ln pop_i$	448	1.682	0.818	-0.307	5.467
$\Delta_{1841,1801}\ln pop_i$	448	0.616	0.346	-0.106	2.324
$\Delta_{1680,1563}\ln pop_i$	155	0.086	0.743	-2.158	2.421
$\Delta lnMA_i$ baseline	448	1.636	0.660	0.550	3.776
$\Delta lnMA_i$, Simplified MA_i	448	3.174	0.890	1.660	5.700
$\Delta lnMA_i$, Simplified MA_i , omit towns within 50 km	448	3.136	0.773	1.706	5.701
$\Delta lnMA_i$, Simplified MA_i, fix 1680 population	448	1.201	0.809	-0.170	3.743
$\Delta lnMA_i$, Foreign trade weighted MA_i	448	1.156	0.841	-0.212	3.941

Notes: For definitions of variables see text.

V. Estimated effects of market access on town population growth

Table 3 reports estimates of our main specification using equation (2) as the definition of MA_i, where coal is assumed to be the traded good when calculating τ_{ij}. Note that in the tables

[61] Note here that all ports are towns, and for port towns $tons_{p=i}$ is omitted from the sum MA_i.

and text, $\Delta lnMA_i$ is the difference in natural log 1830 MA_i and log 1680 MA_i regardless of how MA_i is measured. Also, robust (heteroskedasticity-consistent) standard errors are reported throughout, although standard errors accounting for spatial correlation are similar and do not alter the precision of estimates.[62] In column (col.) 1, we include 9 regional fixed effects and 2nd order polynomials in latitude and longitude as controls. The coefficient for $\Delta lnMA_i$ is positive. In col. 2 and 3, geographic and historic controls from Blome are added (for coefficients see Appendix IX). The $\Delta lnMA_i$ coefficient gets larger in both. The estimate in col. 3 is our preferred OLS estimate since it includes the full set of controls.

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

	1	2	3	4	5	6
Traded good in τ_{ij}		Coal		Coal	Coal	Coal & grain
Dep. Var.		ln1841pop-ln1680pop		ln1841pop-ln1801pop	ln1680pop-ln1563pop	ln1841pop-ln1680pop
	Coeff. (st. err.)	Coeff. (st. err.)	Coeff. (st. err.)	Coeff. (st. err.)	Coeff. (st. err.)	Coeff. (st. err.)
$\Delta lnMA_i$	0.095 (0.049)*	0.179 (0.056)***	0.234 (0.063)***	0.069 (0.027)**	-0.064 (0.127)	0.259 (0.078)***
Geo. controls	N	Y	Y	Y	Y	Y
Historic controls	N	N	Y	Y	Y	Y
N	451	448	448	448	155	448
R-squared	0.235	0.310	0.366	0.237	0.351	0.363

Notes: All regressions include a 2nd order polynomial in latitude and longitude and 9 region fixed effects. Robust standard errors are reported. *, **, and *** represents statistical significance at the 10, 5, and 1% levels.

Further OLS estimates are reported in col. 4-6 of table 3. In col. 4, the dependent variable is ln1841pop - ln1801pop. This specification addresses measurement error in using 1680 population estimates. However, it omits market access effects on population change that occurred by 1801. Nevertheless, the estimates in 4 show positive effects of a similar magnitude to col. 3 in terms of higher annual growth.[63] In col. 5, the dependent variable is ln1680pop -

[62] We use the OLS spatial_hac code developed by Hsiang (2010). For 20, 30, 40, and 50 km distance cutoffs for the spatial kernal, the standard errors in col. 3, table 3, are close to 0.0605, and like the robust std. err. 0.0603.
[63] The coefficient implies going from average $\Delta lnMA_i$ to one SD above the mean gives 0.11 pp extra yearly growth.

ln1563pop using the 1563-1680-1841 sub-sample of towns. Under our identifying assumption, $\Delta lnMA_i$ should not affect population growth a century earlier. The OLS results confirm no precisely estimated effect.[64] In col. 6, $\Delta lnMA_i$ is calculated using coal and grain as the traded goods. Recall these trade costs are different, but on average they change to a similar degree compared to when coal is the only traded good. The estimates for $\Delta lnMA_i$ are similar, implying extensions to more heavy traded goods are unlikely to change our conclusions. For the remainder of the paper, we analyze market access using coal as the only traded good.

Table 4 reports instrumental variable (IV) estimates. Our preferred OLS is in col. 1 for comparison. In col. 2 the instrument is the change in log market access to far towns, incidentally connected to the 1779 Plan. The first stage is very strong based on the F-stat (see Appendix IX for details). The second stage coefficient on $\Delta lnMA_i$ is 0.264 and is precisely estimated. In 3 and 4, towns targeted by the 1779 Plan are omitted from the estimation and we use or add the additional IVs. The estimates change little from col. 2. Moreover, it should be noted over-identification test statistics in 3 and 4 suggests the instruments are valid.

Table 4: Instrumental variable estimates for the effect of market access

	1	2	3	4
Instruments	None, OLS	$\Delta lnMA_i$ to far towns, incidentally connected to Plan	ln dist. to 1680 inland waterways, ln dist. to canals in Plan	Both from 2 and 3
	Coeff. (st. err.)	Coeff. (st. err.)	Coeff. (st. err.)	Coeff. (st. err.)
$\Delta lnMA_i$	0.234 (0.063)***	0.264 (0.113)**	0.259 (0.104)**	0.273 (0.082)***
Geo. Controls	Y	Y	Y	Y
Historic controls	Y	Y	Y	Y
Omit towns targeted by canal plan	N	N	Y	Y
Kleibergen-Paap F statistic		345.6	255.9	254.85
Hanson Overid test P-val.			0.649	0.879
N	448	448	426	426
R-squared	0.366	0.361	0.379	0.378

64 The same results hold if we omit Blome historic controls dated in 1673.

Notes: The instrument in col. 2 uses $\Delta_{1841,1680}\ln\left[\sum_j^J D_{ij}^{far} D_j^{plan,inc} pop_j \tau_{ij}{}^{-2}\right]$. The instruments in 3 are ln distance to 1680 inland waterways and ln distance to all 1779 planned canals. In 4 all three instruments are used. All regressions include a 2nd order polynomial in latitude and longitude and region fixed effects. Robust standard errors are reported. *, **, and *** represents statistical significance at the 10, 5, and 1% levels.

The various IV estimates for $\Delta lnMA_i$ are a little larger than the preferred OLS estimate, but similar. Therefore, we think it is likely that the OLS estimate of 0.234 is a lower bound estimate. It implies that a 10% increase in market access would increase town population by 2.63%.[65] Alternatively, going from the average $\Delta lnMA_i$ (1.64) to one standard deviation above the mean (2.29) would increase the difference in log 1841 and log 1680 population by 0.154, or extra annual growth of 0.10 percentage points.

As further robustness, table 5 reports OLS estimates for the alternative market access formulas. Generally, the coefficients are very similar to our preferred OLS estimates in col. 3 of table 3. This suggests the effects of $\Delta lnMA_i$ are not driven by a specific definition of market access, or by population change or access to towns within 50km, where feedback effects may be an issue. We estimate only slightly smaller coefficients in col. 4, where access is to port towns scaled by total tonnage in foreign trade. We think this reflects the fact that large ports for foreign trade were also large populous towns. Col. 5 reports estimates adding control variables for the log ratio of town distance to 1830 and 1680 waterways and the log ratio of town distance to 1830 and 1680 main roads. Adding these measures of changed access to local infrastructure does not change the estimates of $\Delta lnMA_i$.

In Appendix IX, specifications using different parameter values for θ are reported as further robustness. The standardized coefficients, quantifying a one-standard deviation change in $\Delta lnMA_i$, are similar. The estimate of market access is most precise with $\theta = 2$, which supports our selection.[66] Also, in Appendix IX, specifications are reported that weight observations to match the distribution of population growth in the full Langton dataset with 925 towns. Other reported specifications add a variable for average distance to all towns in our sample. The

[65] Interestingly, our estimate for the effect of market access on population is broadly similar to that found in other historical contexts, like American railroads (See Donaldson and Hornbeck 2016). This could add confidence that our estimates are accurate if one consider market access to be a fundamental parameter.
[66] Maximum likelihood estimates over different parameter values also suggest $\theta = 2$ provides the best model fit.

coefficient on $\Delta lnMA_i$ is a bit smaller in both extensions, but still positive and precisely estimated.

Table 5: Effect of alternative market access formulations

	1	2	3	4	5
Alternative market access formulations	Simplified MA_i Coeff. (st. err.)	Simplified MA_i, Fix 1680 pop Coeff. (st. err.)	Simplified MA_i , omit towns within 50 km Coeff. (st. err.)	Foreign trade weighted MA_i Coeff. (st. err.)	Simplified MA_i Coeff. (st. err.)
$\Delta lnMA_i$	0.220 (0.057)***	0.230 (0.061)***	0.228 (0.066)***	0.199 (0.059)***	0.221 (0.077)***
Geo. Controls	Y	Y	Y	Y	Y
Historic controls	Y	Y	Y	Y	Y
Local Infrastructure controls	N	N	N	N	Y
N	448	448	448	448	441
R-squared	0.369	0.369	0.367	0.366	0.369

Notes: The DV is ln1841pop - ln1680pop. The simplified MA in 1 uses $MA_i = \sum_j^J pop_j {\tau_{ij}}^{-2}$. The omission of far towns in 3 uses $MA_i = \sum_j^J D_{ij}^{far} pop_j {\tau_{ij}}^{-2}$. The foreign trade weighted in (4) uses $MA_i = \sum_j^J tons_p {\tau_{ij}}^{-2}$. All regressions include a 2nd order polynomial in latitude and longitude and region fixed effects, plus stated controls. Local infrastructure controls are Ln(dist1830waterway/dist1680waterway) and Ln(dist1830mainroad/dist1680mainroad). Robust standard errors are reported. *, **, and *** represents statistical significance at the 10, 5, and 1% levels.

V.A Heterogenous effects of Market access on the coalfields

Figure 5 shows the towns in our sample on exposed coalfields as red circles, along with other major towns. There are many towns on an exposed coalfield (henceforth on a coalfield), about 22% of the sample. One common argument is that being on a coalfield made towns grow more in the 1700s and early 1800s. We first confirm that was true. Col. 1 in table 6 reports our preferred OLS estimates for $\Delta lnMA_i$ and the dummy variable for being on an exposed coalfield. The coefficient 0.421 implies that being on an exposed coalfield increased annual town population growth by an additional 0.26 percentage points from 1680 to 1841. We also report our estimate that having a mining specialty was associated with significantly higher growth. Note that only 20% of sample towns on a coalfield and linked to Blome had mining in 1673. Also mining towns were not exclusively engaged in extracting coal.

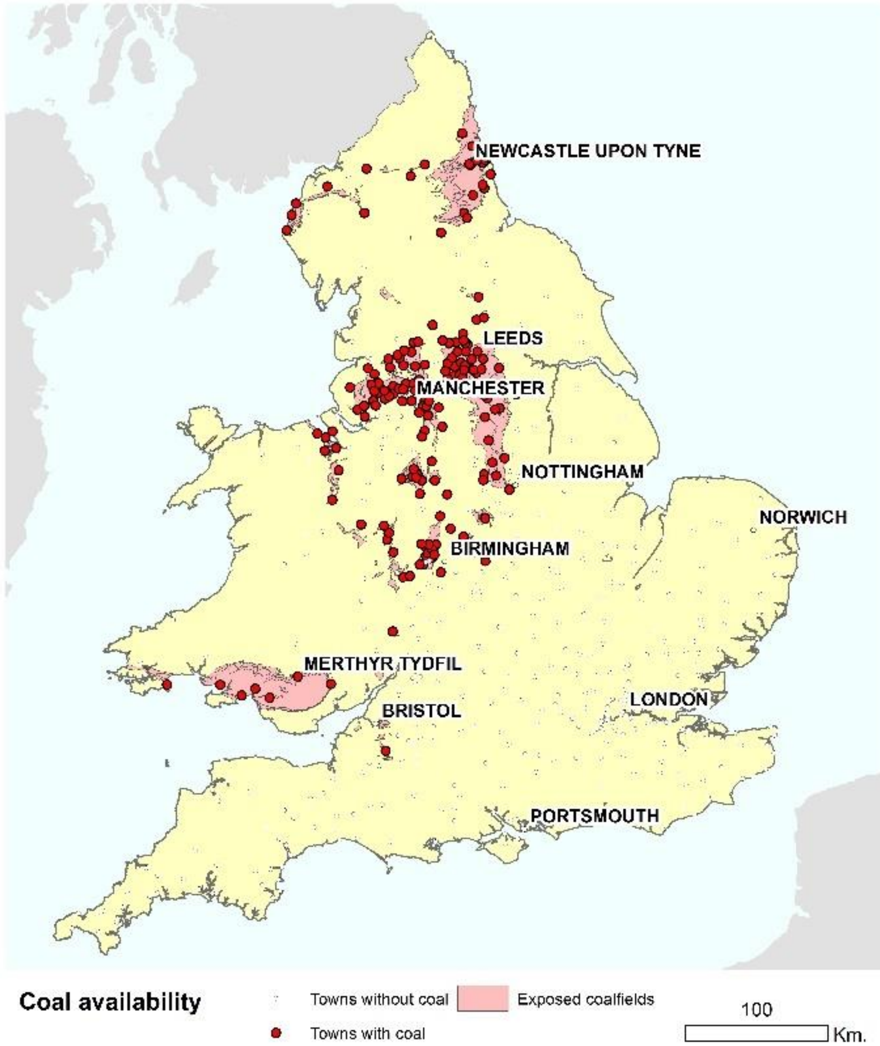

Figure 5: Sample Towns on the exposed coalfield along with major towns
Source: Author's creation based on exposed coal data from Satchell and Shaw-Taylor (2013).

Next, we estimate to what degree towns on a coalfield grew more from increased market access. Col. 2 in table 6 reports a heterogenous effects specification and finds a positive and large interaction effect. The coefficients imply that at the median change in log market access, being on a coalfield led to 0.21 percentage points (p.p.) additional population growth per year, while at the 90th percentile for market access change, being on a coalfield led to 0.41 p.p. more growth per year. For comparison col. 3 reports estimates of the interaction effect between $\Delta lnMA_i$ and the dummy for mining specialty in 1673. The interaction effect is positive, but not precisely estimated.

Table 6: Heterogenous effects of market access depending on being on the coalfield and mining

	(1)	(2)	(3)
	Coeff. (st. err.)	Coeff. (st. err.)	Coeff. (st. err.)
$\Delta lnMA_i$	0.234	0.192	0.209
	(0.063)***	(0.066)***	(0.070)***
Exposed coal dummy	0.421	-0.144	0.308
	(0.127)***	(0.283)	(0.133)***
$\Delta lnMA_i$ *Exposed coal		0.316	
		(0.148)**	
Mining c.1673 dummy	0.543	0.567	-0.029
	(0.240)**	(0.236)**	(0.612)
$\Delta lnMA_i$* Mining c.1673			0.436
			(0.424)
Geo. Controls	Y	Y	Y
Historic controls	Y	Y	Y
N	448	448	375
R-squared	0.366	0.372	0.362

Notes: All OLS regressions include a 2nd order polynomial in latitude and longitude and region fixed effects. Robust standard errors are reported. *, **, and *** represents statistical significance at the 10, 5, and 1% levels.

Broadly, we think these estimates show that greater market access helped to make the coalfields a natural resource advantage. One likely channel is by helping to develop the nearby coal mining industry in the 1700s. Nearly all the coal consumed in E&W came from domestic sources and large cities, like London, could get coal from inland areas once canals opened. The other likely channel is by helping to develop manufacturing. Towns on coalfields had low energy costs and therefore an advantage in using steam power and establishing factories, but these same towns could be deficient in food supplies. The latter meant that without good market access, manufacturing wages needed to increase to pay for expensive food imports. There is also some evidence that after canals opened, they induced lower trade costs for higher value goods, like textiles, which were often made in towns on coalfields.[67]

[67] Bogart, Lefors, and Satchell (2019) show that fly boats (high speed waterway services) were introduced on canals in the early 1800s and were used by textile firms in Manchester and other towns when shipping their goods.

VI. Urban population change with no pre-steam transport revolution

This section estimates how the whole urban population would have evolved in E&W if trade costs did not change between 1680 and 1830. Effectively, this assumes pre-steam transport technology did not change and no infrastructure was built or improved in these 150 years. We first rewrite the baseline theoretical expression for population in location i as $lnpop_i = \beta lnMA_i + e$, where e captures residual factors explaining population. This says that in our context, counter-factual log town population in 1841 is given by $lnpop_{i1841}^C = \hat{\beta} lnMA_i^C + \hat{e}$, and counterfactual market access is $MA_i^C = \kappa \sum_j^J \tau_{ij}{}^{-\theta} pop_{i1841}^C MA_j^{C^{-(1+\theta)/\theta}}$ with κ being a constant and τ_{ij} fixed at 1680 trade costs. We use $\theta = 2$ and $\hat{\beta} = 0.214$, which is conservative following our earlier estimates. The constant κ continues to be normalized to 1. Note though that as κ is a function of worker utility in the theoretical model, there is an implicit assumption of constant worker utility. One interpretation is that urban workers were elastically supplied by rural areas, which beyond E&W could include Scotland, Ireland, Europe, and the new world. In this larger economy, utility is fixed and plausibly independent of E&W trade costs. Finally, we think it is reasonable to assume that $\hat{e} = \ln\ pop_{i1841} - \hat{\beta} \ln MA_i$, that is actual log 1841 population minus the estimated effect of actual market access. The difference captures the effects of all our control variables, like being on coal, plus the regression residual.

With the crucial parameters defined, the computation is done in two steps: First, we substitute the expression $pop_{i1841}^C = MA_i^{C^{\hat{\beta}}} \exp(\hat{e})$ into the equation for counterfactual market access. The substitution yields a system of n non-linear equations, $MA_i^C = \sum_{j \neq i}^J \tau_{ij}{}^{-\theta} MA_i^{C^{\hat{\beta}}} \exp(\hat{e})\, MA_j^{C^{-(\theta+1)/\theta}}$, in n unknown variables MA_i^C. Using a computer, we solve this system for MA_i^C. In the second step, $pop_{i1841}^C$is obtained through substitution into $MA_i^{C^{\hat{\beta}}} \exp(\hat{e})$.

In the counterfactual where trade costs did not change between 1680 and 1830, our estimates imply that the total town population in E&W would be 9.6% lower in 1841 or 0.67 million less. With our assumption that utility remains constant, this means there had to have been fewer workers in towns to keep wages high enough to compensate for higher prices. Those 0.67 million former town-dwellers would have stayed in rural areas. A summary of actual and counterfactual populations in 1841 for the top 20 cities and towns are given in table 7. Most lose population in the counterfactual. London for example, loses 7.3% of its 1841 population. However, some cities gain. Norwich, an ancient textile town in East Anglia, would increase in population by 7.9%. One interpretation is that Norwich gained workers who migrated to textile towns in the northwest with the actual reduction in trade costs. Broadly, there is a redistribution of population from inland to the coast. Bristol and Liverpool, two coastal towns, would have 2-4% lower population. Inland towns like Manchester, Birmingham, and Leeds have 21-28% less. In other words, the large inland urban areas would have been much smaller had trade costs not changed from 1680 to 1830.

Table 7: Counterfactual 1841 populations for top 20 cities and towns if trade costs do not change between 1680 and 1830

	(1)	(2)	(3)	(4)	(5)
		Baseline without interaction effect between $lnMA_i$ and coal		Extension with interaction effect between $lnMA_i$ and coal	
Town. County	Actual pop. 1841	Counterfactual pop. 1841	ratio (2) to (1)	Counterfactual pop. 1841	ratio (4) to (1)
LONDON	1948417	1807493	0.9276	1750935	0.8986
MANCHESTER	311269	246339	0.7914	185271	**0.5952**
LIVERPOOL	286487	274476	0.9580	285030	0.9949
BIRMINGHAM	182922	134773	0.7367	140575	0.7685
LEEDS	152074	118481	0.7791	89034	**0.5855**
BRISTOL	125146	123095	0.9836	127589	1.0195
SHEFFIELD	111091	85108	0.7661	63662	**0.5731**
WOLVERHAMPTON.	93245	73466	0.7878	54513	**0.5846**
NEWCASTLE U. TYNE	70337	72141	1.0256	83562	**1.1880**
HULL	67308	70448	1.0466	73110	1.0862
BRADFORD	66715	48989	0.7343	32549	**0.4879**
NORWICH	61846	66768	1.0795	69298	1.1205
NEWINGTON	54606	55422	1.0149	58277	1.0672
SUNDERLAND	53335	54228	1.0167	62226	**1.1667**
BATH	53196	40191	0.7555	42480	0.7986
PORTSMOUTH	53032	55255	1.0410	57481	1.0839
NOTTINGHAM	52360	54504	1.0409	56338	1.0760
BOLTON	51029	40605	0.7957	30536	**0.5984**
PRESTON	50887	49622	0.9751	51358	1.0093
LEICESTER	50806	37769	0.7434	39879	0.7849

Notes: author’s calculations. See text for details. In col. 5, towns in bold are on the coalfield.

We next modify our counterfactual estimate accounting for the interaction effect, where towns on a coalfield grew more in response to higher market access. The expression for market access remains as in equation (2), but we modify expressions for pop_{i1841}^{C} and $\hat{e}$ based on estimates in col. 2 of table 6.[68] Here with no change in trade costs, we estimate the total town population in E&W would have been 12.2% lower in 1841 or 0.86 million less. Col. 4 in table 7 shows the counterfactual populations in 1841 for the top 20 towns using the modified estimate. The main difference is that coalfield towns (in bold font) generally lose more population. For example, the industrial hub of Manchester loses 40.5%. The two exceptions are Newcastle upon Tyne and Sunderland. These coalfield towns were near the coast and relied less on internal infrastructure improvements to trade. In the counterfactual their population rises by 16-19%, which shows how population would have relocated away from inland coalfields to the coasts.

We have analyzed other counterfactuals, like supposing infrastructure networks remained the same between 1680 and 1830, but per ton mile freight costs and fees evolved as shown in table 1. This scenario aims at quantifying the impact of adding inland waterways and building more roads, while assuming shipping and road transport continued to get more productive. Those estimates show a sizeable effect of infrastructure (the details are in Appendix X). Inland towns, like Birmingham, Wolverhampton, and Sheffield, lose the most population, as they were especially dependent on the inland canal network. Coastal towns generally lose less population, and some—like Liverpool—are even larger.

VII. Conclusion

Much of the prior literature on transport improvement has focused on impacts of centrally planned investments, like the U.S. inter-state highways. By contrast, our paper studies impact in a setting where transport networks were mainly developed through local and private initiatives. Unplanned networks were common before the 20th century and may become so again as new technologies emerge. In this vein, one of our main conclusions is that locally developed infrastructures have impacts on distant cities and towns through the network. This re-emphasizes

[68] Precisely, $\hat{e} = \ln\ pop_{i1841} - 0.192 \ln MA_i - 0.316 lnMA_i^C$ and $pop_{i1841}^C = \exp(0.192 lnMA_i^C + 0.316 lnMA_i^C * exposedcoal + \hat{e})$.

that urban growth is an inter-dependent process. In other words, a city's growth depends on decisions by others to develop local infrastructure and adopt better technology.

We also offer new insights on the effects of pre-steam transport improvements in the era of wagons, canal barges, and sailing ships, where much less is known. We present new estimates of trade costs between 590 towns in 1680 and 1830 derived from a new multi-modal freight transport model. We then estimate how lower trade costs positively affected town population growth through market access. Our OLS estimates, which are supported by IV estimates, point to large, positive effects of greater market access on town population growth. They also imply that the total urban population would have been 12.2% lower if trade costs remained unchanged between 1680 and 1830. To compare with railways, Heblich, Redding, and Sturm (2020) estimate that removing the entire rail network near London would have reduced London's population by 13.7% in 1921. Pre-steam transport change had an even greater impact on where urban growth occurred within England and Wales. Towns on inland coalfields are estimated to be 40% smaller in 1841 without changes in trade costs. Other cities, mainly on the coast, would have seen a small population increase.

In closing, some previous scholars have noted the importance of transport change for the industrial revolution. For example, Hadfield (1969) remarks on the importance of canals stating:

"…cheap and regular carriage of coal and raw materials meant that steam engines could be fed, factories supplied, factory workers warmed, and mines served; but more, it meant lime to improve the soil, timber, stone and slates for housing, and road making materials, and a means of moving corn and preventing local dearths. With canal boats instead of lumbering many-horsed wagons, with steam instead of waterpower, what could not Britain achieve? Indeed, there would be an industrial revolution (pp. 30-31)."

Our estimates give empirical support to this statement, but also go further in showing that it was all transport changes which to a significant degree helped England and Wales achieve an industrial revolution.

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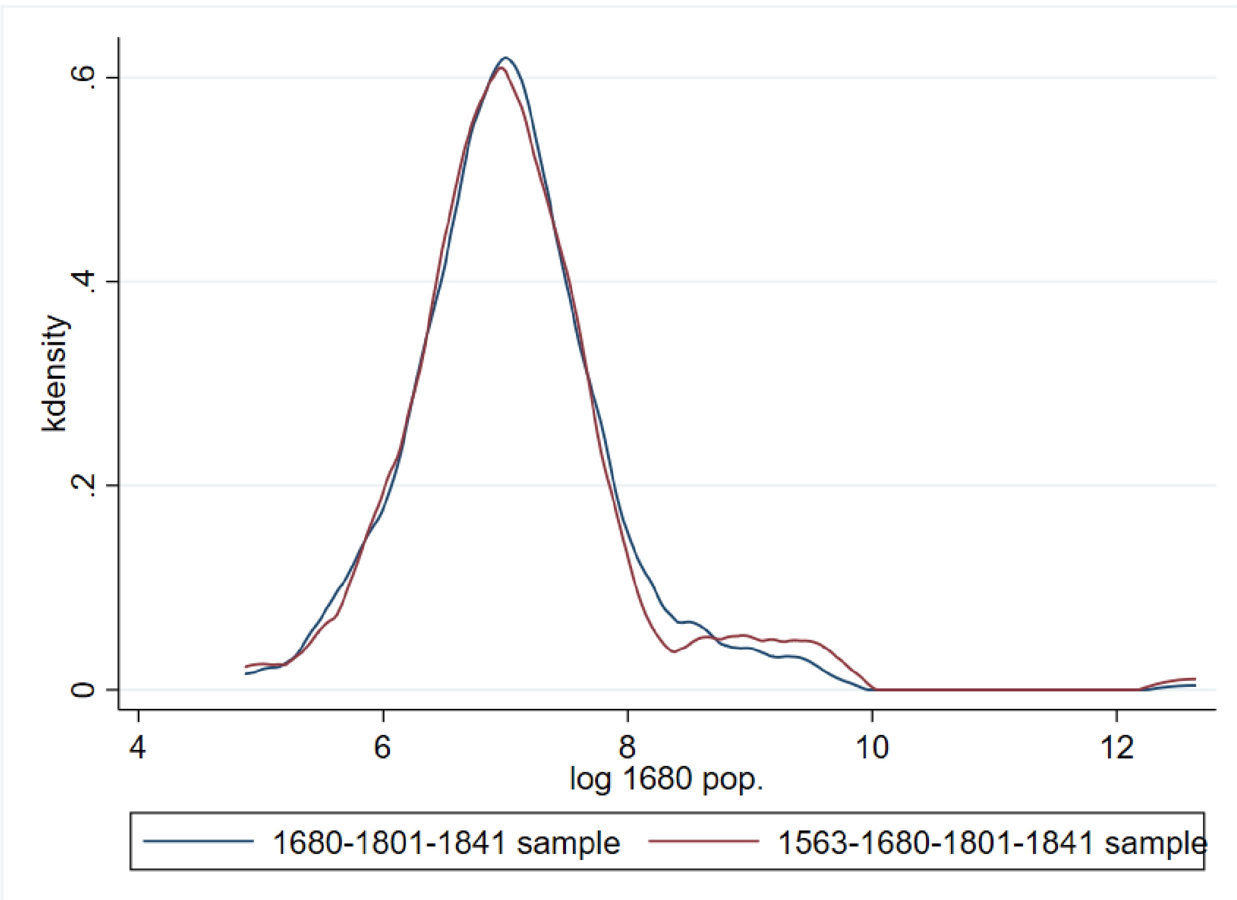
Online Appendix

I. Urban Population data

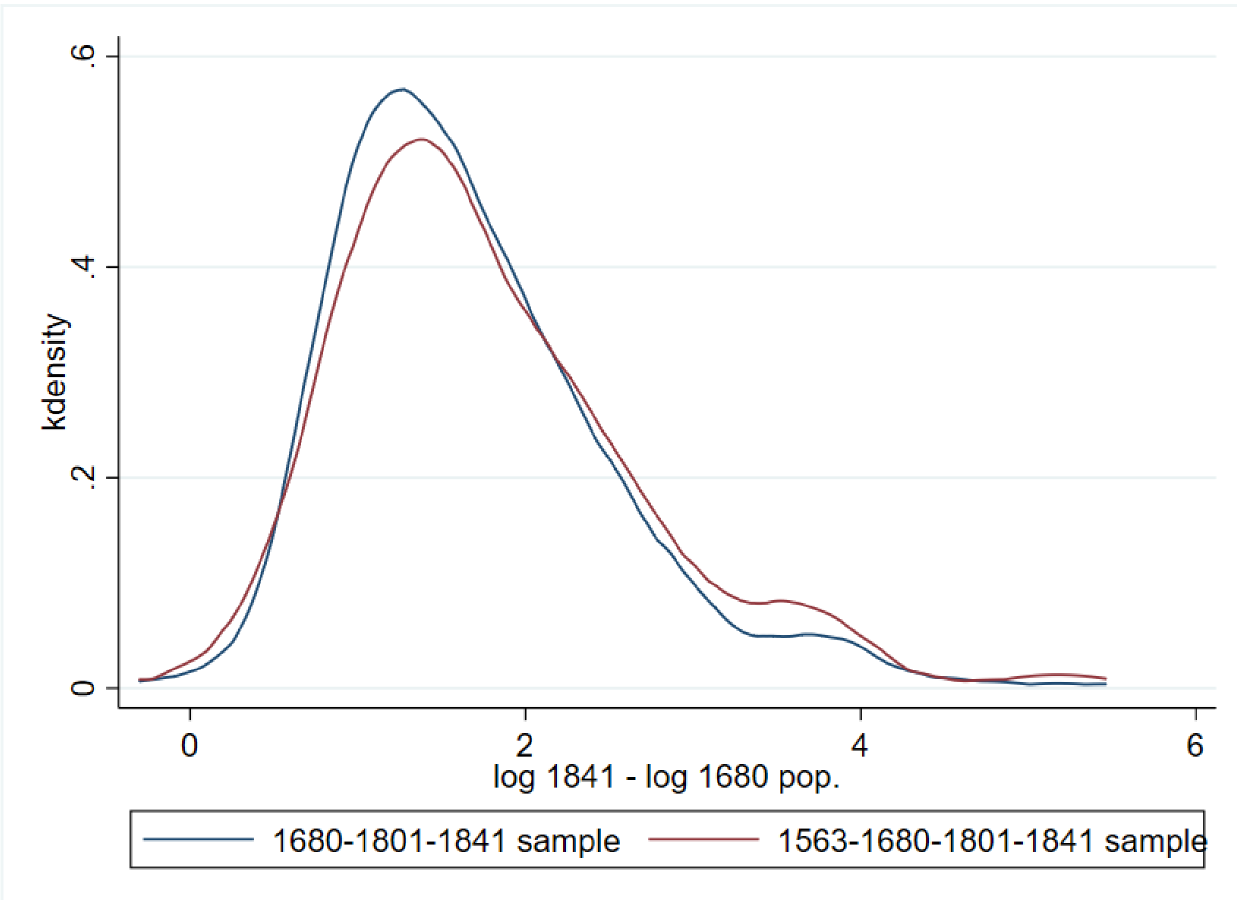
For more on the town database see Satchell, M., Potter, E., Shaw-Taylor, L., Bogart, D., 'Candidate Towns of England and Wales, c.1563-1911', (2017). Appendix figure A.1.1 shows a kernel density estimate of log 1680 population in the 1680-1801-1841 main sample and the 1563-1680-1801-1841 subsample based on linking with Clark and Hoskings plus Wrigley's top 10 cities in 1520. The distributions are similar, including have a long right tail for larger cities.



Appendix figure A.1.1: kernel density estimates of log 1680 population in the 1680-1801-1841 main sample and the 1563-1680-1801-1841 subsample

Source: author's calculation using population samples from Langton (2000), Clark and Hoskings (1995), and Wrigley (1985).

Appendix figure A.1.2 shows the kernel density estimate for the difference in log 1841 and log 1680 population in the main and subsample. The distributions for growth are broadly similar.



Appendix figure A.1.12 kernel density estimates of the difference in log 1841 and log 1680 population in the 1680-1801-1841 main sample and the 1563-1680-1801-1841 subsample

Source: author's calculation using population samples from Langton (2000), Clark and Hoskings (1995), and Wrigley (1985).

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

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

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

Source: Langton (2000).

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

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

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

Source: Langton (2000).

II. Transport Networks

II.A Ports and coastal network

In this section, we describe the database of historical ports and the database of historical coastal routes was created and how we add to it in this paper. For the GIS data see Alvarez-Palau and Dunn (2019) and for a description see Alvarez-Palau, Dunn, Bogart, Satchell, Shaw-Taylor (2019). Eleven different sources were used to create a list of ports and other smaller places where coasting vessels regularly landed to load and discharge goods. Some of these sources include Hargreave (1987), Daniel (1842), Hopwood (1903), Langton (2002), Sacks (2016). The existing literature provides convenient lists of the most important ports. However, coasting vessels called at a much larger range of landing locations than these suggest –including beaches, natural bays, piers, etc. To locate and record more places we drew on new sources that provided us with an array of landing locations at different benchmark dates[69].

Digitizing port information from secondary sources was relatively easy. What was more difficult was to gather port data from 'port book' and 'crew list' coastal shipping data (see Bogart et. al. 2020). Both sources give the movements of coasting ships, and as a result, also recorded myriad landing locations and ports that often do not appear in the secondary sources. These were included in the port data presented here.

In the nineteenth century, the number of reported ports of all kinds increased compared with the sixteenth century due to better information about ports in general, but also because of the expansion of the network. According to earlier sources, ports included harbours, piers, small creeks and even beaches. These were overseen by larger ports with customs houses. Figure

[69] We understand landing locations, creeks, harbours, ports, etc. are different, for example in terms of their facilities and scale. However, we do not distinguish them within the paper. Our sources do not provide enough information to deal with this categorisation. For simplicity, we call them all ports.

Another ambiguity arises from the term "port" in itself. Some historical sources used the term to refer to customs port, which is the entire stretch of coastline under the jurisdiction of regional customs subsystems. In our case, we linked them to the physical port of the same name.

A.2.a.1 shows the geographical distribution of all 479 ports with one or more appearance in our sources[70].

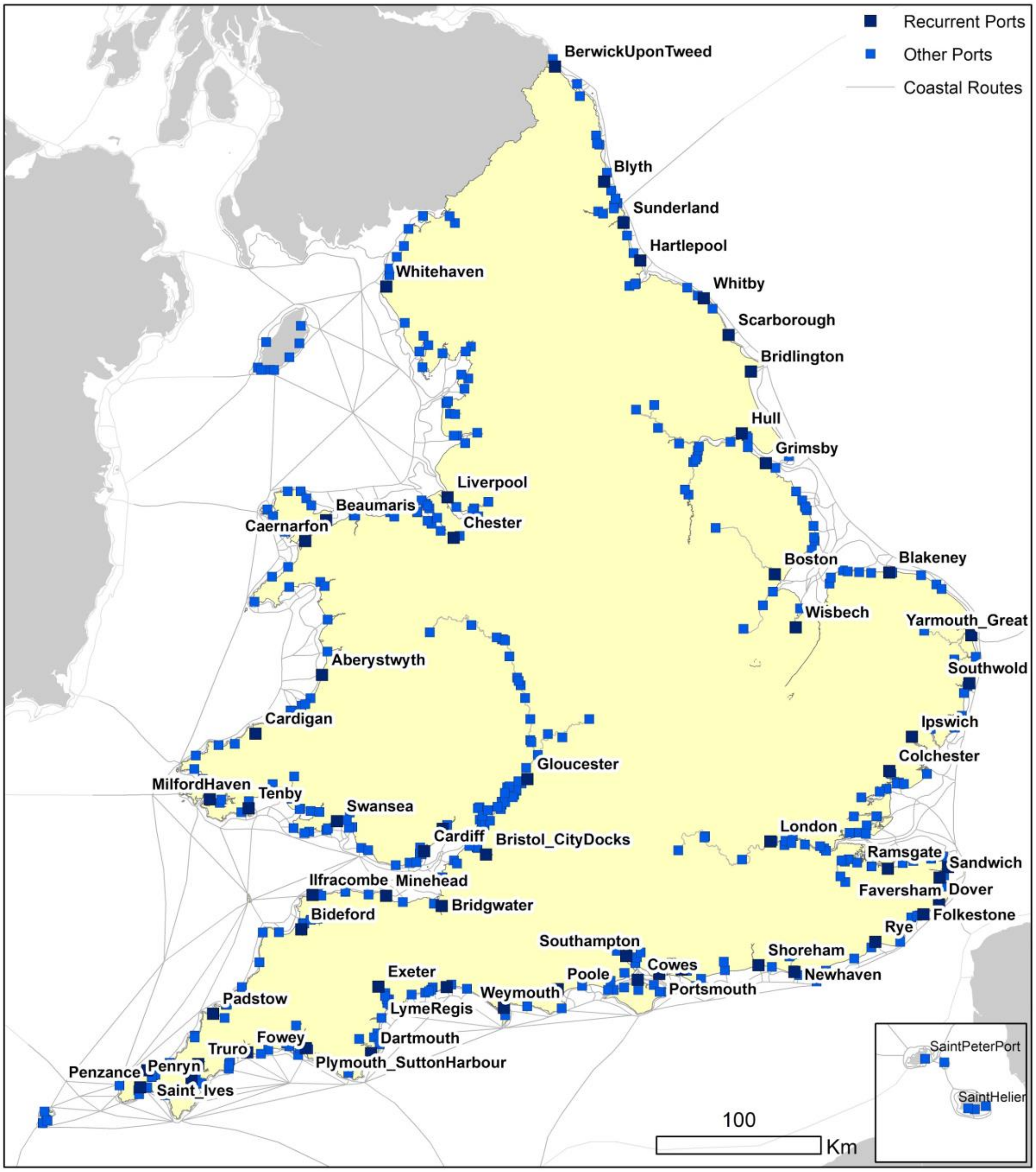


Figure A.2.a.1: Ports with one or more mentions within the sources used. Those places marked as dark blue (recurrent ports) are mentioned in at least nine out of eleven sources.

[70] Ports were removed from the database if they were located at more than two kilometres from a navigable way.

Sources: Alvarez-Palau, E. J., Dunn, O., Bogart, D., Satchell, M., & Shaw-Taylor, L. (2019).

The following principles were used to create coastal networks. In the sailing era, natural conditions constrained operations, especially storms, tides and waves, but also low light, which clearly all had adverse effects. In terms of navigation, instruments used at the time allowed travel only under certain circumstances, and good visibility was necessary for safe passage. Knowledge of bathymetry was key to avoiding damage by grounding on sandbanks or rocks. Navigational charts reported the depth of water at certain locations, but for these to be of any use it was crucial to know the exact position of the ship. Mariners used landmarks to track their position, often using triangulation, and it was thus normal to sail in sight of the coast. During the night or in poor visibility navigation became difficult. Beacons, lighthouses and light-vessels etc. served as an alternative to landmarks where available, but their presence on the coast was very limited at the beginning of our period of study.

We used an amalgamation of different sources to identify coastal routes mariners most likely followed. Specifically, we relied on historical coastal charts, bathymetric depth rasters, topographic elevation rasters, and parliamentary reports to create our database. The main primary sources used to determine coastal routes were navigation charts included in Captain Collin's publication, Great Britain's Coastal Pilot, first published in 1693. For later years, we also looked at coastal charts published by the admiralty in 1830 at the UK Hydrographic Office, Taunton. These documents were digitised and geolocated to gain a workable understanding of the contemporary navigation techniques of each period. Charts always contain landmarks and bathymetry information so mariners could determine their position and avoid danger. Collins also gave specific directions for some routes with their distance in miles given, and this information revealed the routes the author directed ships to take when sailing round the coast.

Bathymetry data was used to distinguish those areas with sand banks and submerged rocks. Although we understand the position of sands changed over time, we assume there was stability in other parts of the coast that were less affected by tides and oceanic currents. We relied on the EMODnet Bathymetry data for the Atlantic Ocean, published by the European Marine Observation and Data Network in 2016. Specifically, we obtained a Digital Terrain Model (DTM) raster with bathymetric depth data with an approximate resolution of 200-metre cell.

Topographical data was gathered from the NASA Shuttle Radar Topography Mission (SRTM). Our raster, though, was a processed version offered by the International Centre for Tropical Agriculture (CIAT); in particular, we worked with its version 4.1. In this case, the different rasters were provided in TIFF format with a resolution of 90-metre cell. A.2.a.1 above shows the coastal routes.

For this paper we add data on head customs ports. We use this to calculate trade costs to customs ports. We assign data on the tonnage of ships entering and leaving these ports of various types. These are available in the CUST 17 records series at the National Archive from 1772. We have digitized CUST 17/13 which applies to 1791. We digitized the tonnage of ships involved in foreign trade that went inwards to a customs port plus the tonnage of ships involved in foreign trade that outwards from a customs port in 1791. The total foreign tonnage in and out in 1791 is shown in Figure A.2.a.2, along with major towns. As tonnage captures weight it mainly captures the coal trade. That is why London's tonnage is like other leading ports.

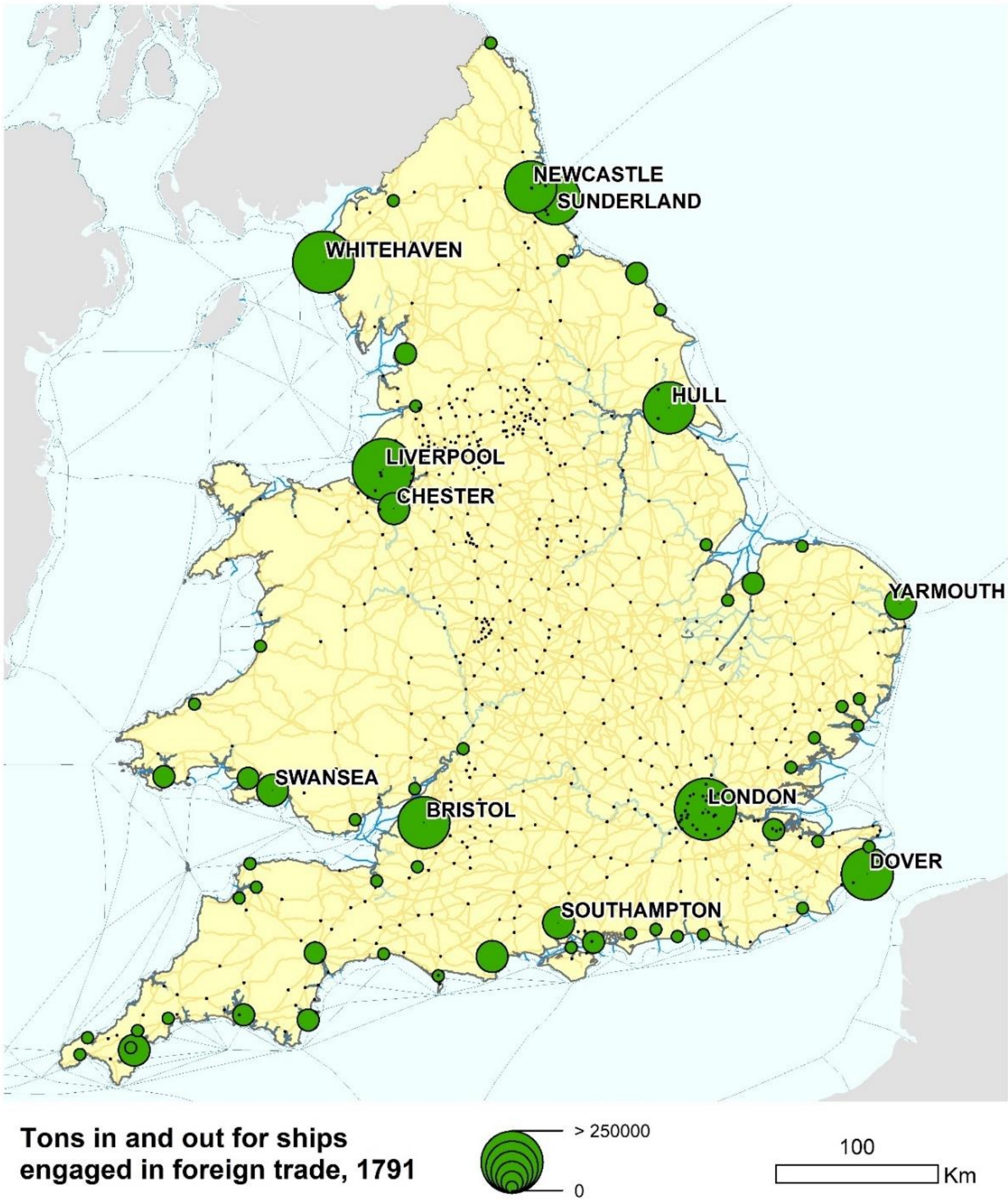


Figure A.2.a.2: Tons in and out for ships engaged in foreign trade in 1791.

Source: authors creation using CUST 17/13 records at the national archive.

II.B Inland waterway network

In this section, we describe how existing GIS data on inland waterways was created and how we add to it further in this paper. For the full GIS of waterways, 1600-1948 see Satchell, Newton, and Shaw-Taylor (2017) and for 1680 and 1830 GIS time slices see Satchell, Shaw-Taylor, and Wrigley (2017a, b). See Satchell (2017 b, c) for descriptions. Previously the extent and expansion of navigable waterways in England and Wales could only be established in a very laborious way. Estimates of national mileage at various dates had to be used, salient information had to be extracted from the regional studies of Hadfield and a variety of paper maps of varying accuracy and utility had to be consulted. The creation of the first time-dynamic Geographical Information System (GIS) model of the English and Welsh waterway network has fundamentally altered our capacity to study this important transportation system. This work was carried out by Max Satchell with the assistance of Owen Tucker, Zoe Crisp, Ellen Potter, and Gill Newton.

We started by digitising the major navigable rivers of England from geo-rectified scans of the Ordnance Survey 1:10560 first edition. Next we digitized all waterways shown on Richard Dean's *Inland Navigation. A Historical Waterways Map of England and Wales*. The c.1:536,448 scale of this map meant that in itself, it was not sufficiently detailed to produce a high standard GIS. As a consequence, the Dean digitisation as a guide to locate the historical waterways on geo-rectified scans of the Ordnance Survey first edition 1:105606 inch map series (surveyed 1840-1890), and the waterways were digitised directly from this map series. For the modest number of waterways which had disappeared before being surveyed by the Ordnance Survey 1:10560 series earlier mapping principally sheets 1-90 of the Ordnance Survey 1:63,360 Old Series (surveyed 1789-c.1840). This work was done using each of Hadfield regional volumes in succession. In every instance emphasis was on establishing as far as possible when each section of the waterway was in commercial use. In addition to the sources already mentioned, usage dates were derived from T.S. Willan, River Navigation in England 1600-1750 (1936), the Royal Commission on Canals and Waterways, BPP, 11 vols, (1906-1911) and H. de Salis Bradshaw's Canals and Navigable Rivers of England and Wales (1904). Where available secondary studies of particular regions and individual waterways were also consulted. Opening, closing and commercial disuse dates for each section of waterway linked to the GIS polyline were entered in an excel table. We used this to create an Access database which enabled the network of navigable waterways for any given year from 1600 to 1948 to be generated.

Now we explain how we add to this data. Figure A.2.b.1 shows the (1) coastal network, (2) inland waterway network by river and canal, (3) interpolations that were made to connect the inland waterway and coastal networks, and (4) locks. The distinction between canals and rivers is important. One must recognise that canals are different from rivers because their routes are deliberately chosen. While a canal route does not require the pre-existence of a potentially navigable river, it is constrained by modest changes in elevation. Locks are also a crucial future. In the eighteenth century, one pound lock was considered necessary for every 7ft (2.13 metres) of elevation and locks constitute a major capital expense. For example, in the late seventeenth century, two new pound locks were built on the River Weaver at an approximate cost of £7000 each - or about £800,000 each in today's money. We add surviving locks to our database using the River and Canal Trust Locks dataset.[71] There is a potential survival bias here, but as locks were so important, they are added. Locks can be seen in the bottom right panel of Figure A.2.b.1:

[71] 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.

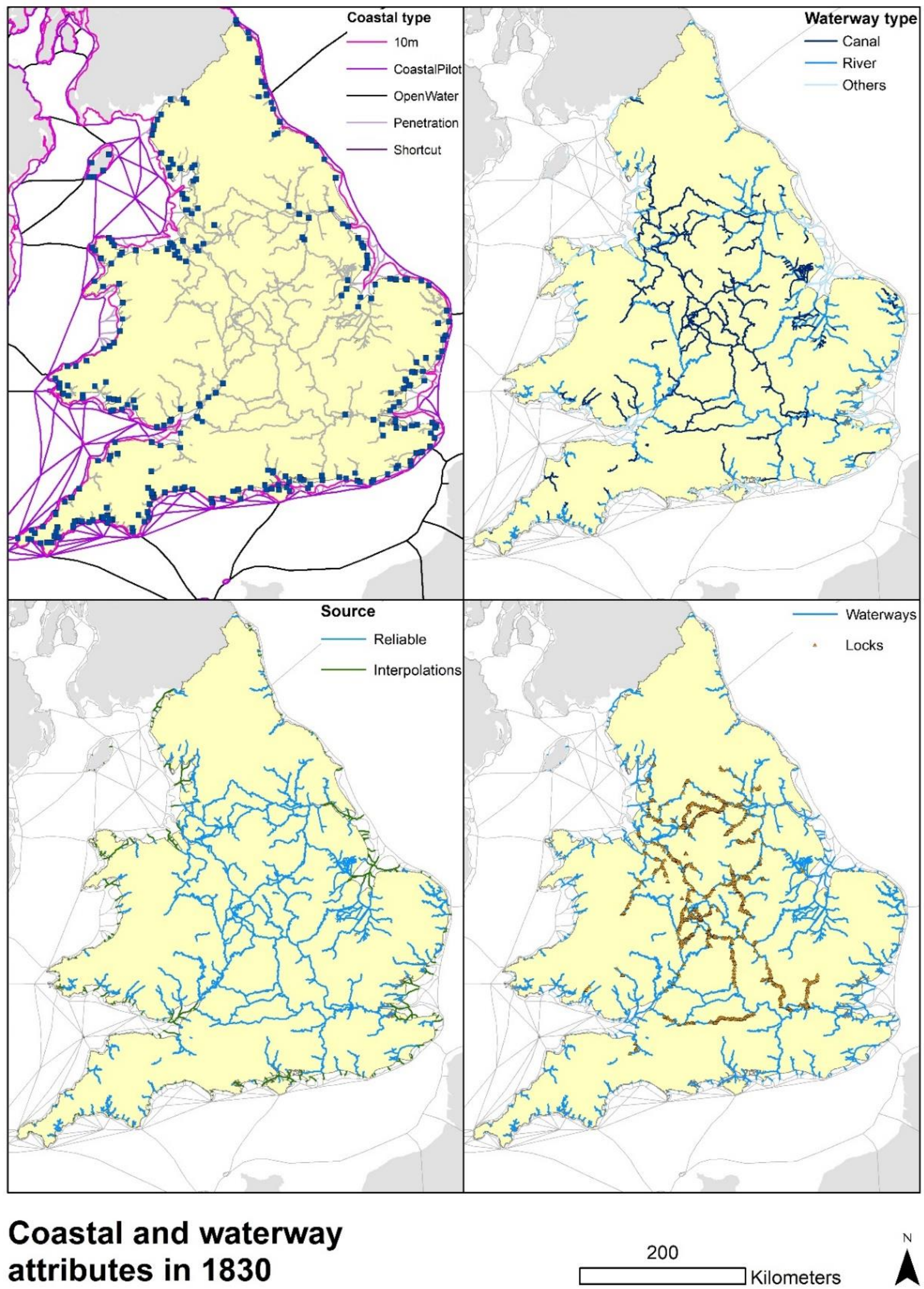


Figure A.2.b.1: Coastal and waterway attributes in 1830

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

II.C Road Network in 1680

In this section, we describe how the GIS data on 1680 roads was created and how we add to it in this paper. This work was largely carried out by Alan Rosevear and Max Satchell. See Satchell, Rosevear, Dickinson, Bogart, Alvarez, Shaw-Taylor (2017) for the original GIS data of 1680 roads and Satchell and Rosevear (2017) for more description. The 1680 roads GIS contains two distinct elements: a digitisation of some 7,493 miles of road which derive from the strip maps of Ogilby's atlas and 13439.8 miles of other roads which derive from a variety of other sources. Identifying and mapping the main roads of England and Wales c.1680 is no easy task. In terms of cartographic sources, the national road network is hardly depicted at all, and certainly not with any accuracy, until John Ogilby published Britannia, his atlas of "principal roads" of England and Wales in 1675. Work by Satchell using a wide range of evidence for road transport has shown that most roads Ogilby mapped were important. Ogilby's Atlas consisted of strip maps at 1:63360 scale of 85 routes on 100 copper plates which surveyed and mapped over 7500 miles of road.

The Ogilby digitisation was created as follows. We identified as a digitisation source O.G.S. Crawford's mapping of Ogilby roads in his A Map of XVII Century England. This was then digitised and a handful of omissions added. However, the 1:1,000,000 scale of Crawford's map meant that the polylines digitised might be up to 1km out of alignment. This degree of inaccuracy is too great for some sorts of spatial analysis, so a more accurate version of Ogilby was begun using the Crawford derived GIS as a guide. This was made practicable by access to the unpublished work of others scholars who had invested thousands of hours in working on particular sections of Ogilby. The GIS that resulted would not have been possible without permission to use the unpublished marked up paper maps of the late Gordon Dickinson (4700 miles), and Derek Bissell (331 miles – Wales and the borders). Use was also made of the maps in the doctoral thesis of Andrew Jones (Yorkshire) and data from online resources created by Jean and Martin Norgate (Hampshire). To ensure congruency with other datasets the digitization was done using a pre-existing GIS of turnpike roads - where the Ogilby roads and the turnpikes coincided the turnpike polylines were recycled to form part of the Ogilby GIS. Ferry crossings were also added. Turnpike roads are described in detail in the following section on 1830 roads.

It was clear from the outset that the network of main roads was larger than what was represented by Ogilby's roads alone. A second class of roads were created to fill this gap. They were not added randomly but were used to link settlements with significant evidence of road travel/ connectivity apparent from their provision of spare stabling given in a military survey of 1686. This comprehensive survey gives counts of spare beds and stalls for some 11,000 separate locations in England and Wales. A threshold of 15 or more stalls was set, and a network constructed programmatically that connected stable points with 15+ stalls by polylines to the nearest section of Ogilby road. 15 spare stalls was chosen as this number reasonably well represented the number of horses in a single packhorse gang engaged in long-distance travel in this period. This increased the number of places that needed to be connected by the network to c. 1,350. We used actual roads to connect stables to Ogibly.

Alan Rosevear took on the formidable task of systematically integrating these disparate materials to build the rest of the network. To assist in selecting routes and interconnections from the Ogilby Roads, he displayed following additional GIS data was over the 1st edition OS 1:10,560 base map;

1. All sections of turnpike road included in Acts that did not mention “Making new” or “Diversion” in the preamble (referred to as “ancient turnpikes”)

2. Destinations in the directories by De Laune (1681) and Taylor (1637).

3. The routes and traffic nodes listed in the Itinerary section of the 1727 Directory

4. The ARC GIS layer of Roman Roads and Old Tracks

5. The full turnpike network

6. Carrier routes listed in the 1791 Universal British Directory

7. Recorded ferries (estimated to be operating ca 1700)

The additional roads were added in a hierarchy based on relevance to 1680 and an "uncertainty" value given to this road as a 1680 road. Roads were added until a minimum level of inter-connection was achieved with the "15 or more" stable stall points. The following criteria were adopted in drawing lines connecting points;

- The road goes through the point, connecting it with two Ogilby roads (i.e. it is on a route not normally a terminus except at coasts, major river crossings or moorland where no obvious trace remains on the OS map)
- Features are relevant if they are within 10 miles of each other in lowland areas and 15 miles in (sparsely populated) upland areas.
- Two stabling points on Ogilby roads may be joined if secondary evidence exists for a route
- Roads may be added if two secondary features occur (secondary features include smaller stabling (between 12 and 14), a de Laune destination, a 1727 transport node, a 1727 route, a 1791 traffic route)
- Sections of Roman Roads may be added, even when not turnpiked, when the road has survived in use to be mapped by the OS. Where stabling is listed next to an old ferry it is assumed the route used the ferry
- Since the stabling is a parish based survey, it is sufficient for the road to pass through any part of the parish (including acting as a boundary line).
- Routes were chosen which were consistent with those in the 1727 Directory Itinerary
- If an Ogilby road exists between two points no other parallel route is drawn (i.e. ancient turnpike option not added)
- Where a ferry occurs between two points, this route is favoured.

A map of the main Ogilby roads and non-Ogilby roads is shown in the upper left box of figure A.2.c.1.

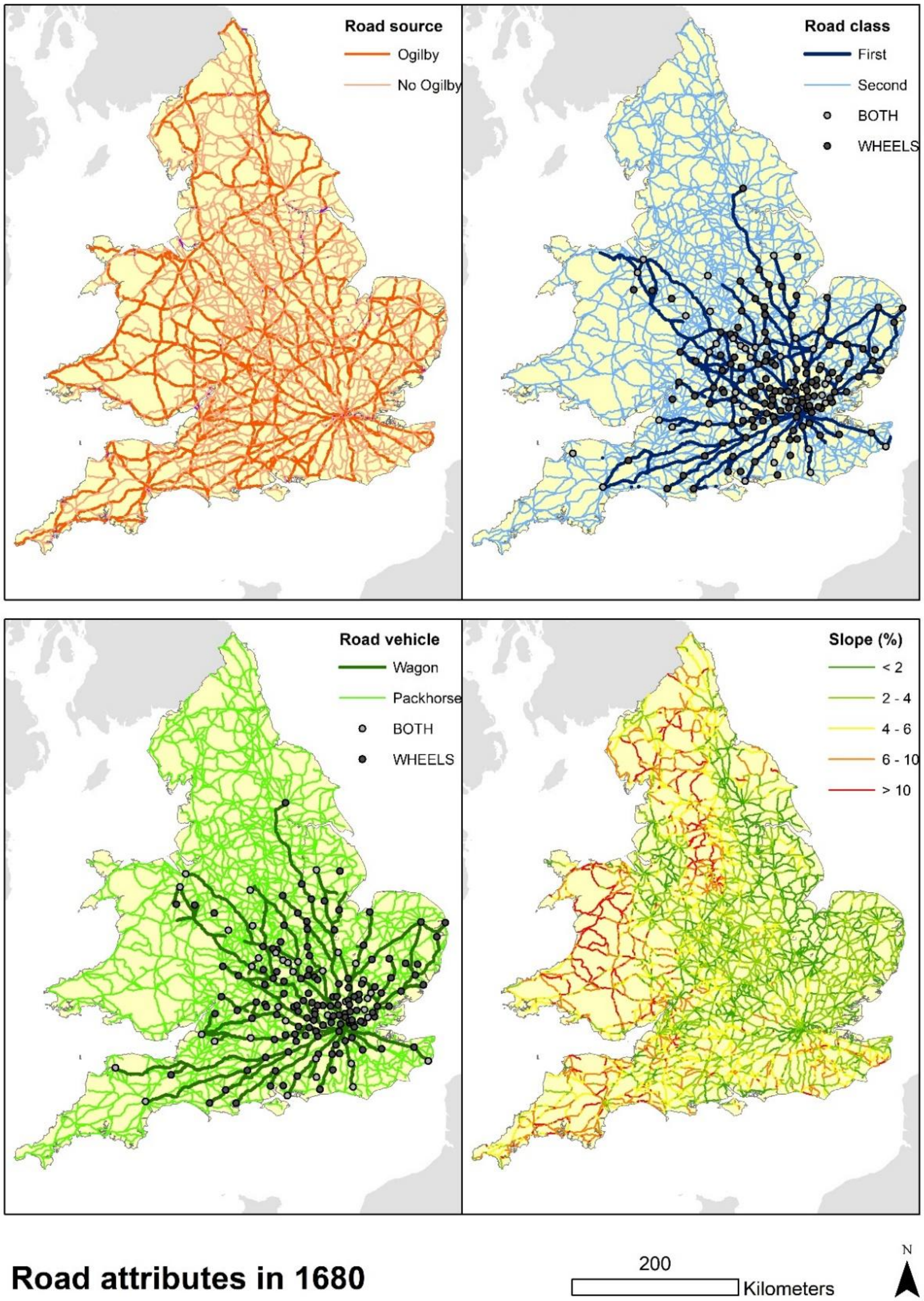


Figure A.2.c.1: Roads and attributes in 1680

Source: author's creation using Satchell, Rosevear, Dickinson, Bogart, Alvarez, Shaw-Taylor (2017) and other sources in text.

In this paper, we enhance the 1680 roads by adding an attribute to determine whether wheeled transport or packhorses were used on the road. Our classification is derived from DeLaune's 1681 publication, which details whether packhorse (carrier) or wagon services were available from London to several towns. We have mapped packhorse versus wagon using Delaune's data. It is shown in figure A.2.c.2 along with Ogilby's main roads in 1680. It is clear wheeled transport was not available everywhere. 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. This is shown in the upper right hand box of figure A.2.c.1. Wheeled transport and packhorse transport were both used in transport to some towns (both) so 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 A.2.c.1.

Finally, slope is a crucial factor in road transport. We overlay a raster file of elevation on the map of 1680 roads to calculate segments where the average slope was fit into different categories. These segments are shown in the lower right hand box of figure A.2.c.1

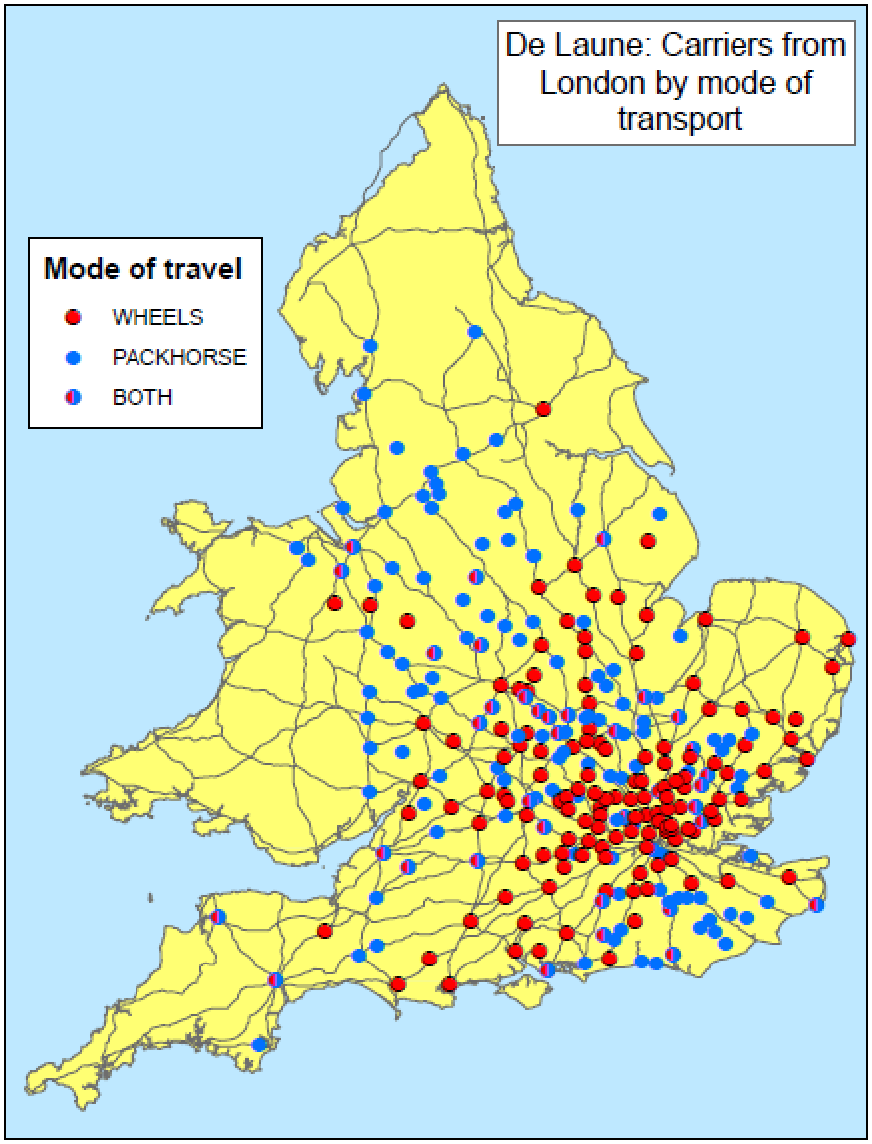


Figure A.2.c.2: Delaune's map of wheeled and packhorse services from London to various towns in 1681.

II.D Road Network in 1830

In this section, we describe how the GIS data on 1830 roads was created and how we add to it in this paper. The 1830 roads are derived from a GIS of the turnpike road network as of 1830. The work in creating turnpike roads was largely carried out by Alan Rosevear, Max Satchell, and Dan Bogart. For the GIS data on turnpike roads see Rosevear, Satchell, Bogart, Shaw-Taylor, Aidt, and Leon (2017). For a description of turnpike roads see Bogart, Rosevear, and Satchell (2017).

A turnpike road was a road managed by a turnpike trust. They were organizations authorized by acts of parliament to build, maintain and operate toll roads. Trusts were most prominent in the 18th and early 19th century prior to railways. They maintained individual roads previously maintained by local governments, specifically parishes. The finances of turnpike trusts were distinctive because they levied tolls on road users and issued bonds mortgaged on the tolls. Also, they were locally managed and financed.

Turnpike roads were digitized using the following method. We identified Cary's New Map of England and Wales and part of Scotland as the primary source for an initial digitisation of the network was done by Satchell. Carey's sheets were published between 1820 and 1828. Cary's road line work distinguishes turnpikes and post roads. It also maps "other main roads" but these were not digitised. However, Cary's map does not identify the individual trusts and the road segments they managed. Scans of the Cary mapping were geo-rectified by Ziyue Chen. The turnpike network was then digitised using the scans laid over Ordnance Survey 1:10560 first edition mapping (25 inches to the mile).

For England the next step used two resources that identify the territories of turnpikes trusts from surviving wayside features, parliamentary records, acts of parliament and historic county maps. The first of these was a dataset of known milestones and tollhouses created by the Milestone Society.[72] Alan Rosevear digitised these records and added the turnpike trust authority name. The second was a series of marked up county maps (generally Thomas Moule's County series ca 1830) with the roads under the jurisdiction of each trust and its opening date clearly identified. Satchell took the milestones digital data and used GIS to link these to the turnpike polylines digitised from Cary. From that we acquired the provisional road segments of each trust. Marked up county maps were then geo-rectified and used to correct and upgrade the trust data acquired from the milestones. The output of this step was a provisional time-dynamic turnpike network for England. In the final step, we checked the trust name and dating was correct and the inter-trust boundaries were clear for each road segment and added the date of closure using

[72] The database manager is Alan Rosevear.

parliamentary records and acts of parliament. The acts of parliament are drawn from the Portcullis database of all acts at the Parliamentary Archives in London.[73] The main parliamentary record used in this exercise is the '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). The appendix records the mileage of individual trusts in each parish in 1838. Tollhouse locations found during mapping were used to confirm the allocation of sections to trusts and better specify trust boundaries. Local history studies of individual trusts were used to date and plot diversions made by the trusts where possible and the recorded trust mileage in 1820, 1838 and 1847 used to interpolate a date for improvements seen on maps where no records found. Unless specified in the Act, it was assumed that the older section of road lapsed at the date the improvement was made.

The acts of parliament also provide an indication of whether the road was old or new. Wording mentioned repairing of roads implied the road was old. Wording mentioning the diversion of the road suggested there was some improvement. Wording mentioning the making of the road suggested that it was new.

For Wales there was no comprehensive milestone record or marked up county maps with which to work. Rosevear took the raw Cary turnpike data and added the trust name and date of opening and closure using parliamentary records and acts of parliament described above. The network for South Wales was refined using the maps and commentary in The Report of the Parliamentary Commission (1843) made after the Rebecca Riots.

The GIS map of all turnpike trusts was used as the starting point for selection in 1830 roads. Polylines were selected first on the basis of the start date of the Turnpike trust and all those with a date after 1830 excluded. A map of turnpike roads in 1830 is shown in the upper left box of Figure A.2.d.1.

[73] http://www.portcullis.parliament.uk/calmview/

We now explain how we add to the 1830 roads GIS for this paper. First, other main roads were added to link a small number of towns to the turnpike network, ensuring complete connection. 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, and excellent were given. We created a simple quality classification 'Good' if the road was described as good, very good, and excellent. Otherwise it is classified as 'Bad'. The mapping of road quality is shown in the upper right box of figure A.2.d.1.

There were some 1680 roads that were not included in the 1830 turnpike network. However, we are almost certain those roads were used. Therefore, we include 1680 roads in the 1830 turnpike network. 1680 roads added to 1830 turnpike roads are shown in the lower left hand box of Figure A.2.d.1. Note they are classified as 'bad' on the quality metric. This assumption is reasonable as parish roads 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 A.2.d.1.

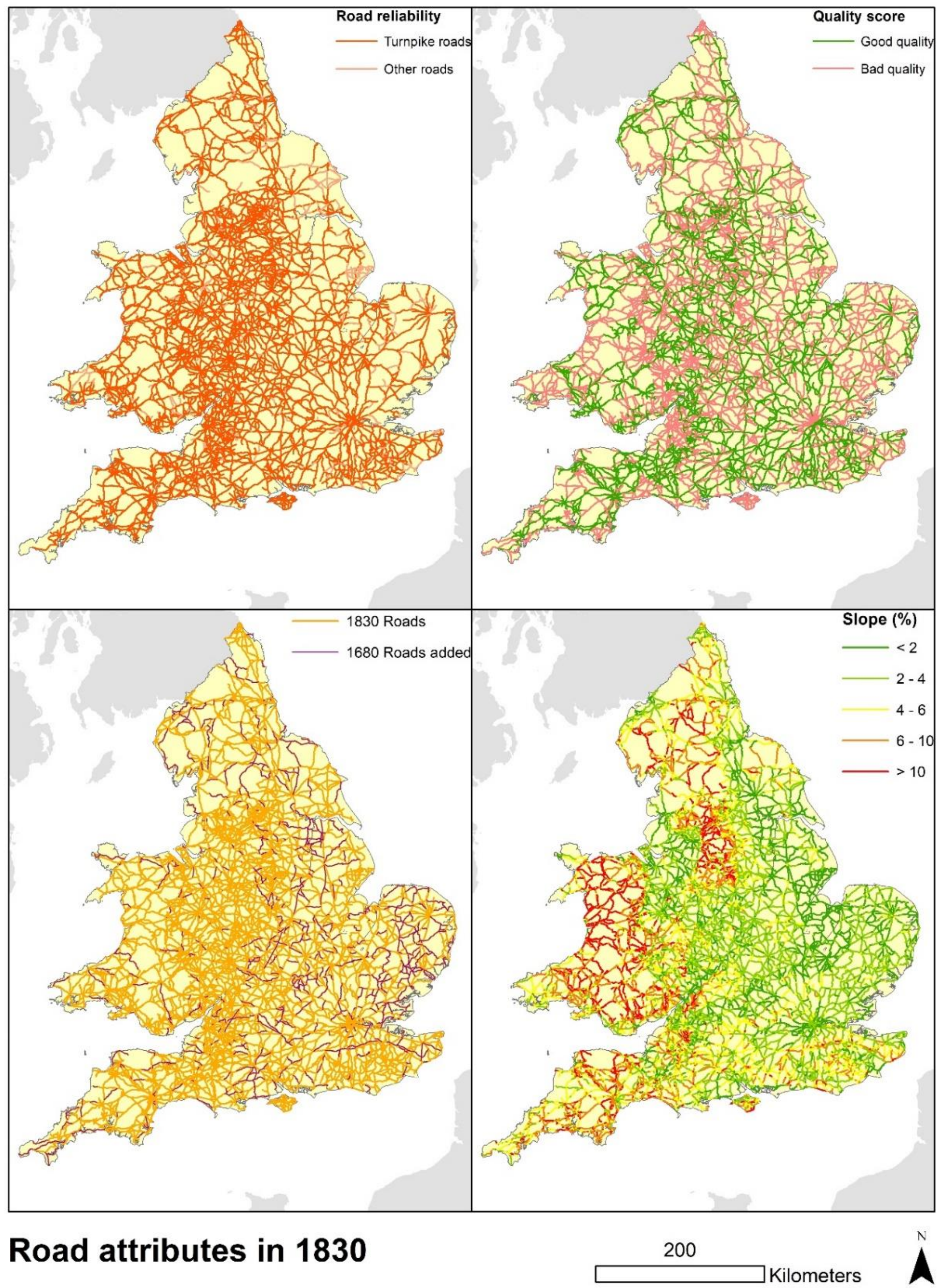


Figure A.2.d.1: Roads and attribute data in 1830

Source: author's creation using Rosevear, Satchell, Bogart, Shaw Taylor, Aidt, and Leon (2017) and other sources in text.

Bridges and Ferries were also plotted into the 1830 roads GIS files. We now explain the sources and strategy for plotting data on river crossings in the shape files used in the Cambridge Historic roads GIS.

Bridges

Only major river crossings are considered here – loosely defined as a structure requiring large capital cost for construction and likely to have significant maintenance costs. Roads crossed streams and small rivers on structures ranging from simple culverts to small single arched bridges – these are not considered significant in the context of costing travel or determining travel speed on the GIS road network and are not plotted individually.

There are four major categories of bridge to consider in building the roads GIS file.

- Toll Bridges are generally new structures built during the period when roads were being turnpiked. They may have been built by local trusts, Improvement Commissions or by a private company but were for public use. Each required an Act of Parliament to define powers of the Commissioners, Trustees or Proprietors and which limited lending for construction of the bridge and approach roads. Many of these were totally new bridge crossings; a few replaced older bridges, generally a little to the side of the earlier bridge. In many cases the new bridge replaced an ancient ferry and the "rights" of the ferry owner had to be purchased in order to close this down or compensate for the inevitable loss of business. A number of medieval bridges that had been administered by a charitable foundation (Bridgemasters or trustees) had powers to levy tolls for the upkeep of the bridge. Many of these were rebuilt in the 18th and early 19th century and were covered by Acts of Parliament as with new toll bridges. These bridges may abut turnpiked roads but are separately administered; some have approach roads that were not turnpikes. (these toll bridges are designated TB in the database file field "was turnpike" and are given a Trust or Company name)

- County Bridges were old bridges that by 1700, were already the responsibility of the county or counties on the river bank (rivers often form civil administration boundaries). Finance for repairs and any rebuilding fell on the counties, raised through local taxation and administered through the Magistrates. This category included medieval bridges that had originally been the responsibility of Charities or Foundations but had subsequently fallen on the county as well as important crossings that had been built by the civil administration prior to the 18th century. These bridges were toll free, and may be replaced by a new toll bridge during the turnpike period. (these County Bridges are designated CB in the database file field “was turnpike”)

- Free Bridges is a category covering bridges which were built by a trust or a Commission that did not levy a toll on users. Some were ancient charities which had been bequeathed property or given the revenues from a source of taxation (e.g. coal) to cover maintenance costs or were under an Improvement Commission for town or river. Later this category included bridges which had been freed from toll when the civil administration took over the bridge or bought out the original proprietors (e.g. all London bridges by the late 19th century) (these Free Bridges are designated B in the database file field “was turnpike”).

- Turnpike Road Bridges were new bridges built under the Act authorising a new turnpike trust. In some instances they were fully incorporated into the road administration and there was no specific toll related to the crossing. In others (e.g. Shillingford) the Act included a specific toll for the bridge crossing. The subsequent administration of these bridges generally followed that of the associated turnpike road. (these are designated T in the database file field “was turnpike” and are assigned to the relevant turnpike Trust)

Most new bridges required a new approach road on either bank. Generally these were the responsibility of the bridge administrators; some approach roads could be long, stretching for a mile or more. The bridge toll usually covered travel on the approach road. Where it was clear that the road was administered with the bridge it is given the trust name, otherwise it is designated as an Urban Link Road.

Recording and plotting the bridges

The Chadwick archive of Parliamentary Acts (covers 1799 to ca 1833) was searched through the Welcome Library web site for Acts that concerned the building of bridges. The Acts identified when a bridge would be a toll bridge (coded TB in the “was turnpike” field of the Arc GIS File) or when bridges were toll-free (coded B). Some bridges required several Acts of Parliament to increase the approval limit of building costs, and a number of bridges required new Acts for rebuilding soon after construction of a first bridge, due to collapse of the initial structure. Wikipedia entries were checked to confirm the most likely date of the first successful bridge being built – the default date used was the latest Act for building a first bridge at the site.

A google search was made for bridges on the major rivers and estuaries of England and Wales – all entries that identified a toll bridge built before 1900 were recorded and the date at which tolls were lifted was noted.

Finally, a visual inspection was made of all points where a turnpike road crossed a major river and any instances of a toll bridge recorded. Not all County Bridges have been separately identified in the present version of the Roads GIS.

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 alinement where possible. All bridges that were not part of a turnpike trust were plotted as discrete items 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 particular location, the bridge in use in 1830 was given priority as the straight line joining the abutting roads.

Ferries

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 (fords were free) and it was one of the more lucrative Manorial rights that could be leased out. Ferries varied in size from a simple punt carrying a few passengers to sizable boats capable of carrying a coach or a wagons as well as passengers, livestock and horses. Ferries were able to offer crossings at deeper and wider sections of river than was the case with fords but they were still vulnerable to extremes of weather and so could be unreliable and sometimes fatally dangerous. As traffic along the roads increased, ferries became significant bottlenecks in the flow of traffic and were progressively replaced by bridges. As bridge building technology improved, the sequential replacement of ferries along the major rivers moved downstream to span wider and wider sections of river.

Recording and plotting the ferries

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 taken from Campbell and georeferenced by Max Satchell – these points were 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.

An Excel sheet (ferries v10.xls) containing basic information was set up the record the common name of the ferry, the stretch of water crossed, the most probable date of its first use and the date the ferry was closed (if not still operating). Ferries were designated F in the database file field “was turnpike” but larger ferries that were known to carry horses were designated HF and the largest ferries thought to have carried vehicles were designated FXL)

In the Roads GIS, ferries were plotted as polylines joining roads on the adjoining banks. The OS 6inch first edition was used to locate the ferry alinement where possible. 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)

III. Maps of planned canals

The following is a conceptual illustration of the Grand Cross. The contours 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. For the remaining of this appendix we describe the detailed maps of canals in the Cross Plan and the Cross Plan itself.

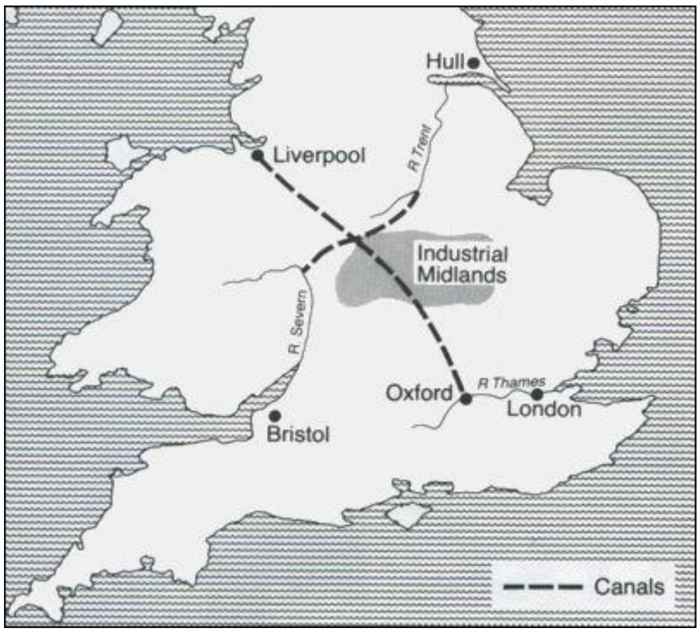


Figure A.3.1: Conceptual illustration of the Grand Cross

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

The following is a map of the plan for the Trent and Mersey Canal c.1766.

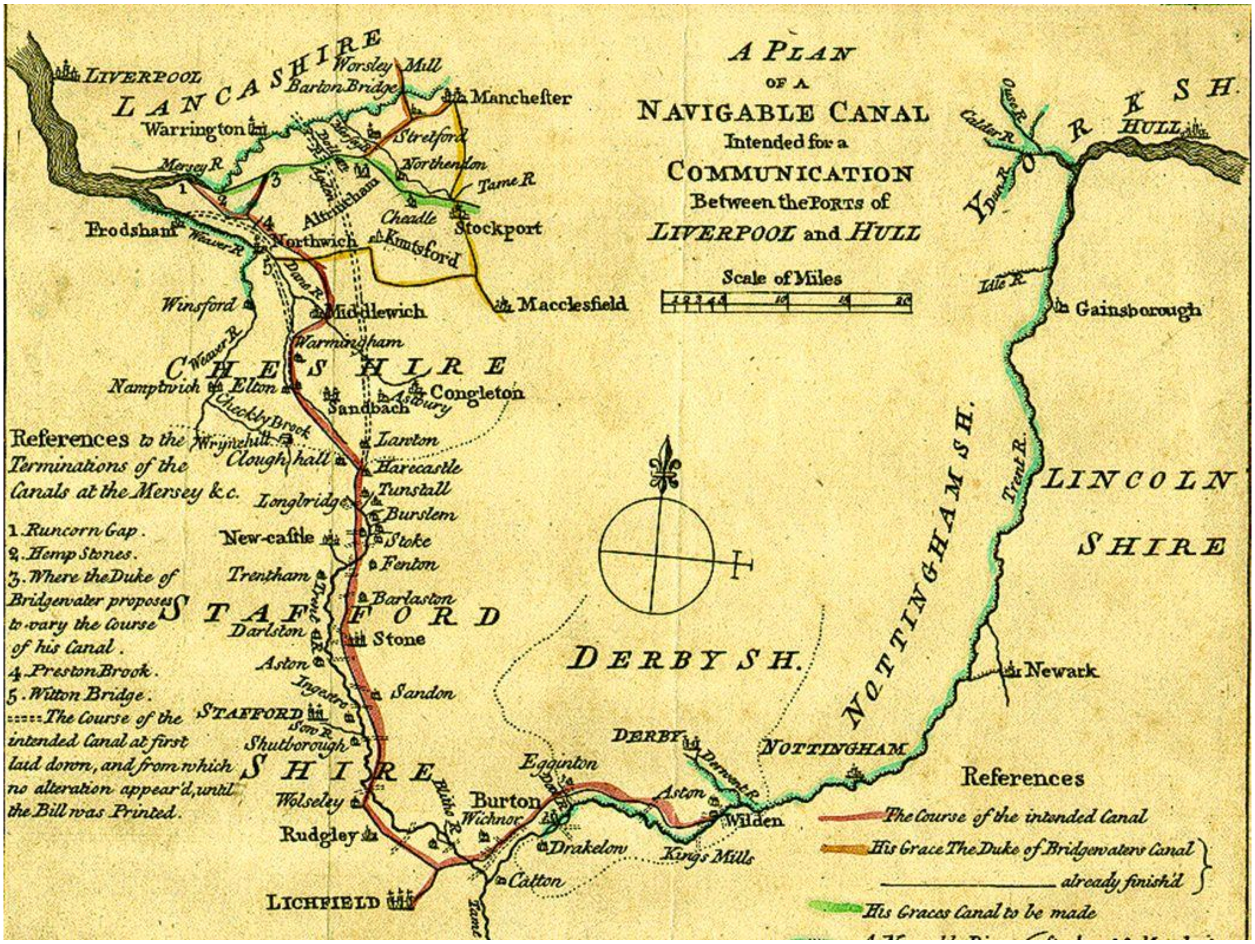


Figure A.3.2: A plan of a navigable canal intended for a communication between Liverpool and Hull, c.1766

Source: "British Canal Systems Holzmann & Mummert"
https://images.slideplayer.com/24/7368308/slides/slide_8.jpg

The following is a map a plan of the canals authorized to be made in different parts of England, which we think was made around 1769 based on the canals in the map. It is an early version of the Cross Plan.

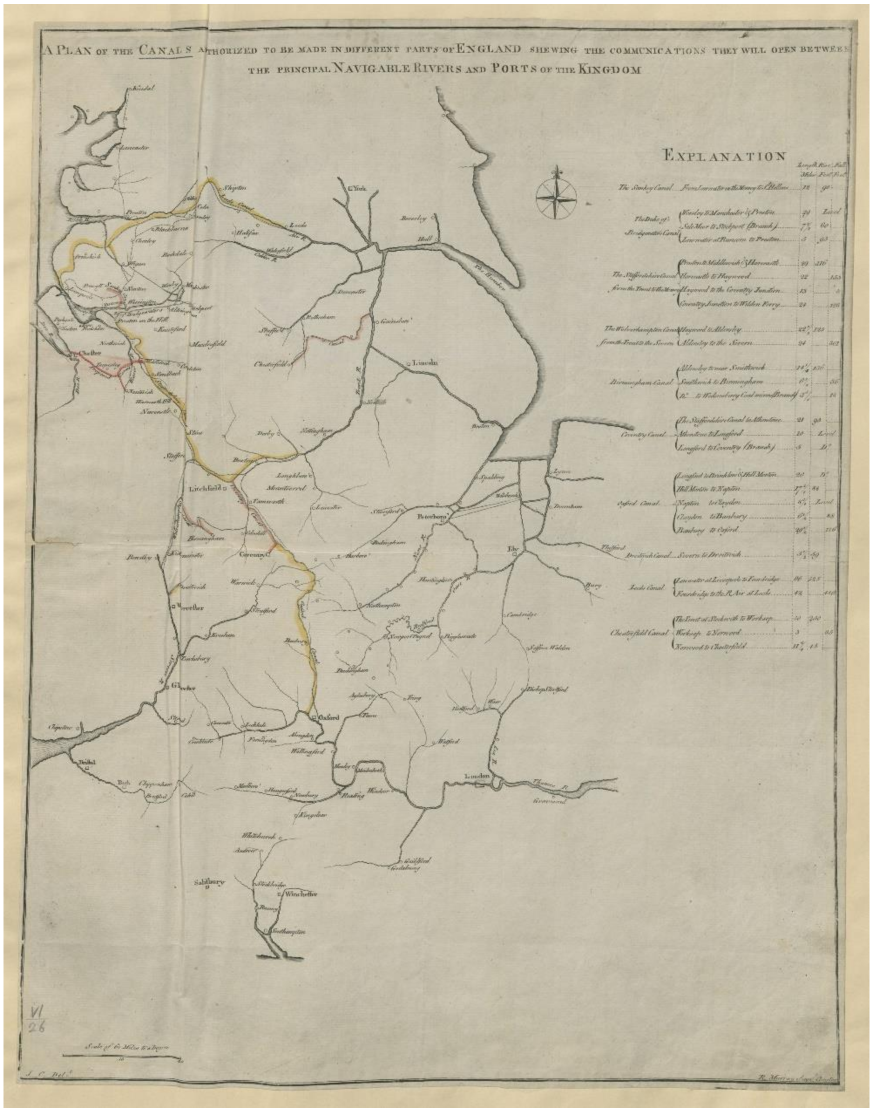


Figure A.3.3: A plan of the canals authorized to be made in different parts of England

Source: The British Library, King's Topographical Collection, Maps K.Top.6.26. See https://www.flickr.com/photos/britishlibrary/50264082542/in/photostream/

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

Figure A.3.4: A plan of the navigable canals made and now making in England, 1779 by Hugh Henshall and John Cary

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

While we do not use in the main text, the following is our representation and classification of the c.1769 map of a Plan of canals authorized to be made.

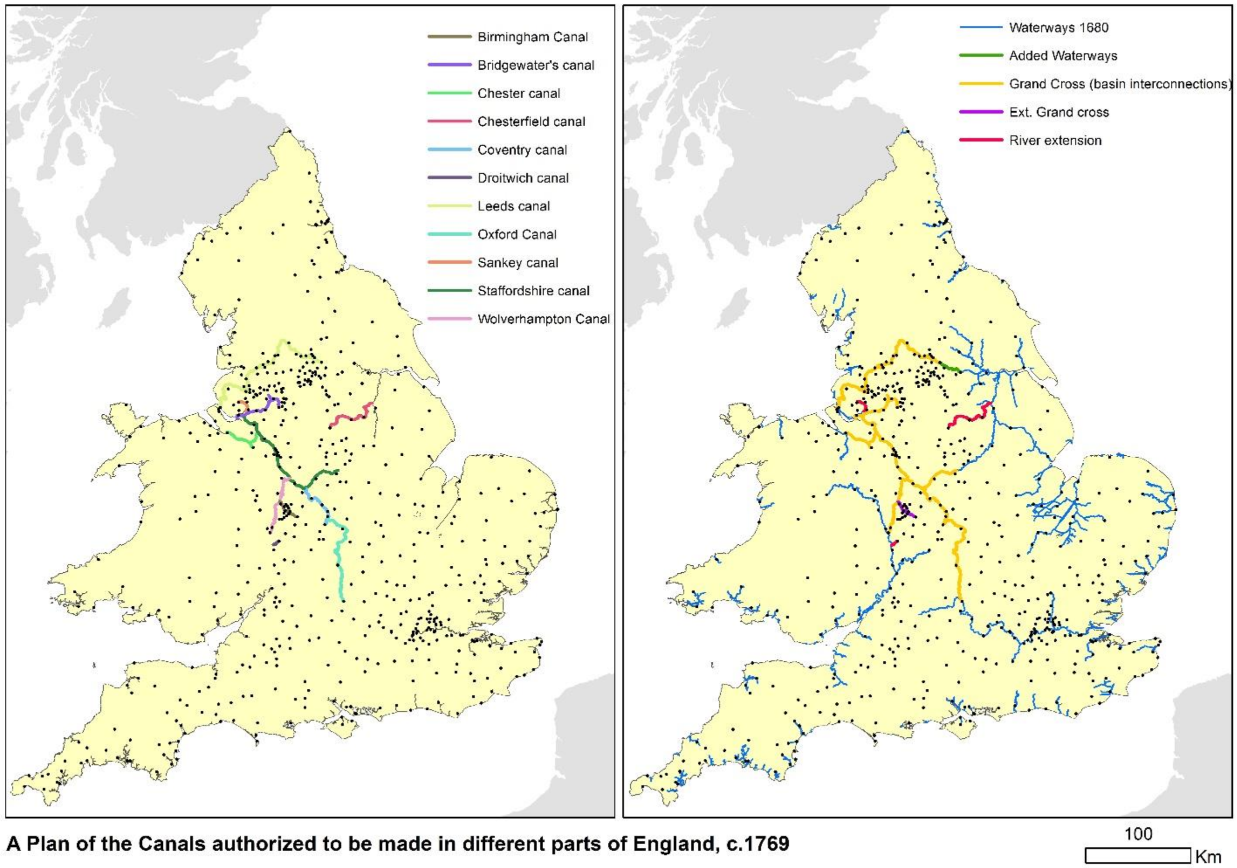


Figure A.3.5: Towns and representation of all canals authorized to be made c. 1769 (left), with classification and network connections (right).

Source: Authors creation based on The British Library, King's Topographical Collection, Maps K.Top.6.26. See https://www.flickr.com/photos/britishlibrary/50264082542/in/photostream/

Notes: 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 to towns, river extensions were river navigations unrelated to Grand Cross.

IV. Historic town controls

The historic controls come from Blome's Britannia published in 1673. They have been digitized and used in Bogart (2018). From Blome's town description, the following 11 indicator variables are created equal to 1 if the town (1) had cloth manufacturing, (2) had brewing, (3) had other manufacturing, (4) had mining, (5) had a harbour, (6) had an almshouse, (7) had a free school, (8) had municipal government, which, for simplicity, is one if the town had at least one type of official like mayors or council members, (9) was represented by MPs, (10) was on a navigable river, and (11) was on the coast. Blome also described the town's market including the number of days. We create a 12th variable for number of market days. Blome also describe the market anywhere from small and poor to medium, good, large, and impressive. We use these words to code a dummy variable equal to 1 if the market was described with words like large and zero otherwise. We also a create variable if the market was described with words like small and zero otherwise. The omitted group are markets described with words like medium. We use 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, we also supplement Blome with Robert Morden's, The New Description of the State of England. Morden (1701) provides maps of roads in each county in the 17th century before turnpikes. Here we define another indicator variable for being on the 1700 road network.

In total there are 16 historic controls drawn from Blome. As an illustration Figure A.4.2 shows towns identified has having cloth manufacturing and mining.

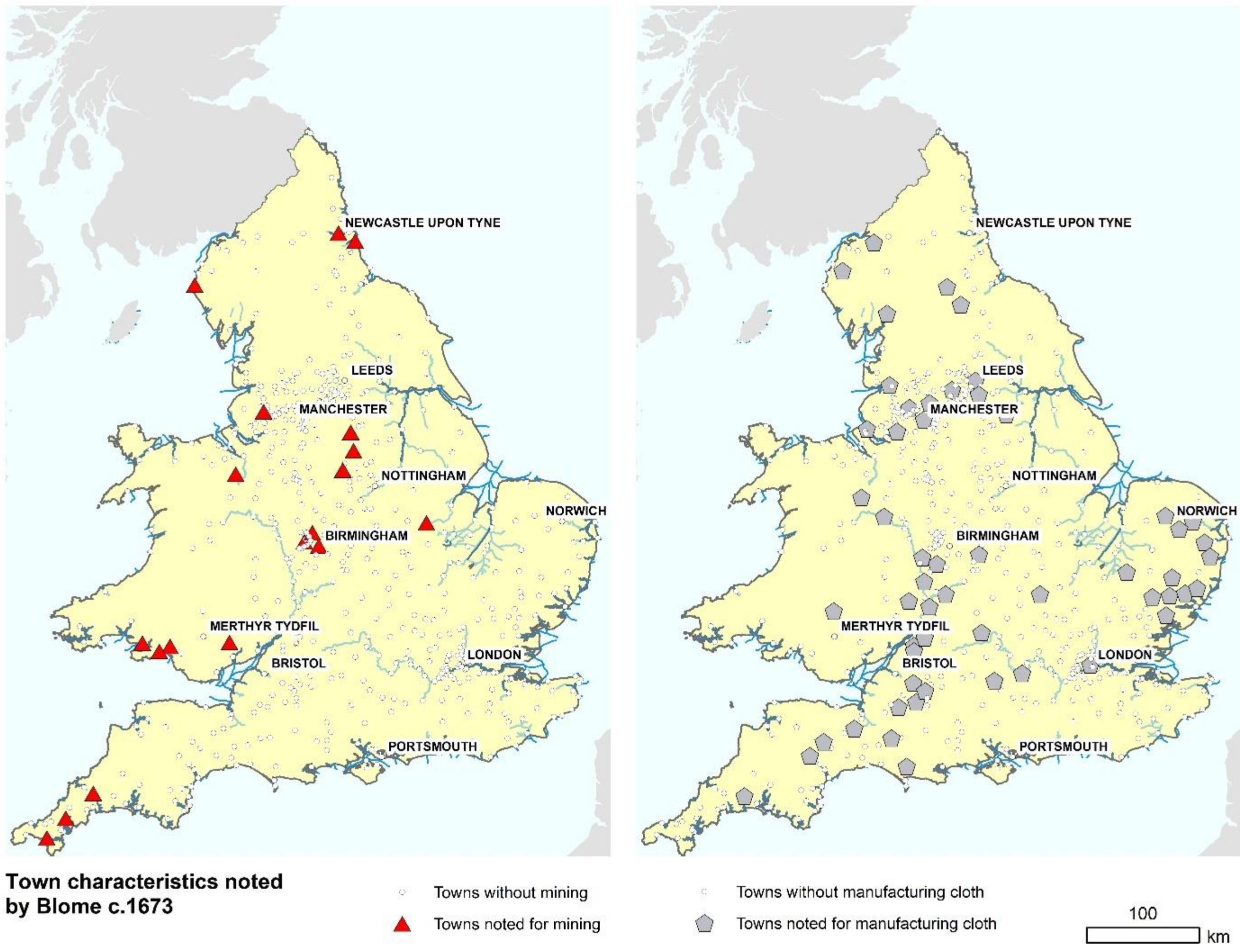


Figure A.4.2: 1680-1801-1841 sample towns noted for mining and cloth manufacturing specialties by Blome's Britannia in 1673

Source: Author's creation based on digitization of Blome variables.

V. The Multi-modal model

The creation of the historical GIS transport networks presented in section III 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 all the different networks in just 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.

We assembled the multimodal model by coding a python script specifically designed to implement the following steps in ArcGIS:

1. Determine the XY coordinates of all towns and ports.
2. Create straight line connections between towns and the nearest road.
3. Create straight line connections between towns and the nearest waterway, with a 2km threshold.
4. Create straight line connections between towns and the nearest port, with a 2km threshold.
5. Create straight line connections between ports and the nearest road.
6. Create straight line connections between ports and the nearest waterway.
7. Integrate all the previous features: roads, coastal routes, waterways, ferries, ports, towns and XY connections (calculated in steps 2 to 6).
8. Create points at the intersection between roads and waterways.
9. Create points at the intersection between roads and coastal routes (if any).
10. Create points at the intersection between waterways and coastal routes.
11. Create points at the intersection between roads and ferries.

12. Compile all intersection points in one layer, keeping the attributes.

13. Determine XY coordinates of all intersection points.

14. Create small by-passes to circumscribe intersection points when needed.

15. Integrate roads and ferries.

16. Integrate roads, road by-passes and ferries.

17. Integrate waterways and waterway by-passes.

Once the multi-modal networks were ensembled, we proceed to create a GIS feature dataset containing a copy of all the previous features. Then we proceeded to create a network dataset including all features, allowing global turns, applying the appropriate connectivity policies (one independent group for each mode of transport), avoid elevation data (already included in the features) and defining the appropriate freight cost parameters. Figure A.5.1 illustrates roads, waterways, coastal routes, towns, ports and their interpolated interconnections in Norfolk.

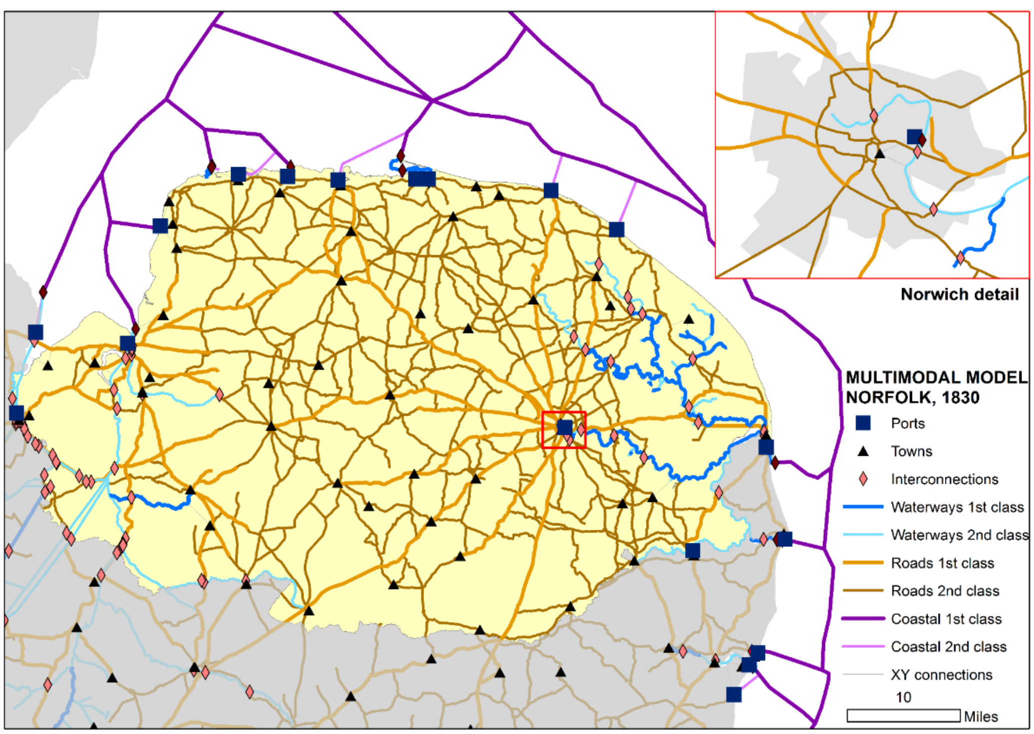


Figure A.5.1 Multi-modal model framework: roads, waterways, coastal routes, towns, ports and their interpolated interconnections.

Table A.5.1 gives the modal parameter values and the source basis. We now explain how they are created. 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.[74] For 1836, we use a parliamentary report on the coastal coal trade (BPP 1836, State of Coal trade, p.76). One of the most often-cited witnesses in the reports, Bentley, gives figures for loading costs and coastal freights at that time (see Ville 1986). Comparing with 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 coast fell from 27.1 to 22.9 pence.

Table A.5.1: Per ton mile costs for multi modal models in 1680 and 1830.

Year	1680		1830	
	parameter	source basis	parameter	source basis
coastal, pence per ton mile	0.211	Nef (1979), p. 412	0.168	Bentley in BPP
Sea port fee in pence per ton	27.1	Nef (1979), p. 404	22.9	Bentley in BPP
Trans-shipment fee, road to water in pence per ton	17.14	Nef (1979), p. 404	13.9	Bentley in BPP
inland waterways in pence per ton mile	1	Willan (1964)	2.25	Allnut (1810), p. 20
lock fee in pence per ton	n.a.		1	Priestly (1831)
Low quality road, 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)
High quality road 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)

[74] 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.

ferry pence per ton	1	Willan (1964)	2.25	Allnut (1810), p. 20

Notes: (h/l) means height/length of the segment or slope. 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 a contemporary, Allnut, summarized freight rates on the river Thames as being 2.25 pence per ton mile.[75] 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) 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 2.25 per mile cost of using canals.

Road freight rates in the late seventeenth century are generally summarized in Gerhold (2005) 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 a 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. 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 as explained below. The quality metrics were described above. Slope was obtained by extracting elevation values in the vertices of the road segment and dividing by the length between them. Our elevation raster is the Shuttle Radar Topography Mission (SRTM 90x90m), created in 2000 from a radar system on-board the Space Shuttle Endeavor by the National Geospatial Intelligence Agency (NGA) and NASA (Jarvis et. al. 2008).

John MacNeil was a civil engineer who was an expert in road building. MacNeil testified before parliament on the value of building better roads, in particular reducing draught animal power.

[75] Bogart, Lefors, and Satchell (2019) discuss Allnut as source in more detail.

The testimony was given on 20 May 1833 (BPP 1833, Second report from the Select Committee of the House of Lords appointed to examine the turnpike returns, p. 129). MacNeil proposed empirical formula for draught. The formula was the following:

$$P = \frac{W'+w}{93} + \frac{w}{40} + c * v + \frac{h}{l}(W' + w)$$

Where P is draught, W' is the weight of the wagon, w is the load, c is a parameter for the quality of the road, v is the velocity in feet per second, $\frac{h}{l}$ is the slope where h is height and l is length. MaCNeil p.129 gives 6 values for c. $c = 2$ on a paved road, $c = 5$ on a well made broken stone road in a dry state, $c = 8$ on a well made broken stone road with dust, $c = 10$ on a well made broke stone road covered with mud, $c = 13$ on a gravel or flint road when wet, and $c = 32$ on a gravel or flint road when covered with mud. From this formula we can calculate draught P given a wagon load, a weight, a road type, a speed, and slope and calculate draught.

We want to estimate road transport costs under different conditions. This requires a calibration. First, we assume P is energy required in road transport. The cost of energy in monetary terms is some constant β times P. Gerhold (1996) has evidence that energy costs [feeding horses] were 75% of total freight transport costs TC. The rest were labor and capital costs like paying for the wagon and horse. Gerhold's evidence implies the formula: $0.75 * TC = \beta P$. We need to solve for β in 1680 and 1830 to get TC. We use observed transport costs under known road conditions, loads, and speeds at zero slope. In the 1680 calibration, we consider a wagon of 2240 pounds, a load of 4 times 2240 pounds, a velocity of 3.7 feet per second (which MacNeil used), and a road quality $c = 8$, which is well made broken stone with dust. Our road quality may appear arbitrary however, we can estimate relative c for packhorses roads since we observe a freight cost for packhorse and wagon from Gerhold (11.9 and 10.6). We solve the following equation for β in 1680.

$$\beta\left(\frac{2240 + 4 * 2240}{93} + \frac{4 * 2240}{40} + 8 * 3.7\right) = 0.75 * 10.6$$

Given this $\beta = 0.02$, we can solve for the packhorse road quality that gives a packhorse freight transport cost of 11.9 using the following equation.

$$0.02 * \left(\frac{2240 + 4 * 2240}{93} + \frac{4 * 2240}{40} + c * 3.7\right) = 0.75 * 11.9$$

The final formula for packhorse roads in 1680 as a function of slope is

$$0.02 * \frac{4}{3}\left(\frac{2240 + 4 * 2240}{93} + \frac{4 * 2240}{40} + 20.4 * 3.7 + \frac{h}{l}(2240 + 4 * 2240)\right) = TC$$

Or

$$11.2 + \frac{h}{l}(298.67) = TC$$

The final formula for wagon roads in 1680 as a function of slope is

$$0.02 * \frac{4}{3}\left(\frac{2240 + 4 * 2240}{93} + \frac{4 * 2240}{40} + 8 * 3.7 + \frac{h}{l}(2240 + 4 * 2240)\right) = TC$$

Or

$$9.97 + \frac{h}{l}(298.67) = TC$$

A related calibration is done for 1830, but here we have two qualities of road: good and bad. Again we assume energy costs were 75% of total road freight transport costs. In 1830 we only know transport costs for a good quality road, Leeds to London. The cost was 7.5 pptm from Gerhold (1996). We assume that the Leeds to London road quality was $c = 2$, equivalent to a paved a road. Therefore, we can solve for β using the following formula

$$\beta\left(\frac{2240 + 4 * 2240}{93} + \frac{4 * 2240}{40} + 2 * 3.7\right) = 0.75 * 7.5$$

The solution is β=0.016. With this β we can calculate a transport cost on bad roads if we assume a quality coefficient $c = 32$, which in MacNeil's framework is a gravel or flint road with mud.

The final formula for good roads in 1830 as a function of slope is

$$0.016 * \frac{4}{3}\left(\frac{2240 + 4 * 2240}{93} + \frac{4 * 2240}{40} + 2 * 3.7 + \frac{h}{l}(2240 + 4 * 2240)\right) = TC$$

Or

$$7.5 + \frac{h}{l}(238.93) = TC$$

The final formula for bad roads in 1830 as a function of slope is

$$0.016 * \frac{4}{3}\left(\frac{2240 + 4 * 2240}{93} + \frac{4 * 2240}{40} + 32 * 3.7 + \frac{h}{l}(2240 + 4 * 2240)\right) = TC$$

Or

$$9.87 + \frac{h}{l}(238.93) = TC$$

Finally, a trans-shipment cost is need in our model to switch from inland waterways to roads and vice versa. We use the labor component from coastal loading costs as detailed by Nef (1979), which implies inland trans-shipment costs were about half as large as seaport costs. This makes sense as in ports there were additional charges for infrastructure.

VI. Producer prices and estimates of trade costs

This section explains how we determine average producer prices starting with the pithead price of coal. The ideal is to identify the average coal price across the coal fields, since these were production centers. Also ideal is to compare the coal prices from the same coalfields over time as there could be differences between coalfields. One can find references to the price of coal in Newcastle in the 1600s and early 1700s but on the other coalfields it is scarce. We looked at Houghton's data in 1701 which was a year of peace. There we find prices for coal in Newcastle and near Carlisle and Penrith in Cumberland (CU). The price of Newcastle coal is very stable at around 46 pence per ton. The price in Cumberland is also stable around 70 pence a ton. We then find coal prices in the same two locations from the PLU data c.1843 which shows that coal prices in Newcastle and in Cumberland were 63.6 and 108 pence a ton respectively.[76] 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.

As a baseline, for each town in our sample we calculate its average trade costs to all other towns $\overline{\tau_i}$. These are shown in figure A.6.1. In 1680, inland towns faced very high average trade costs, generally above 20. Towns near the coast or navigable rivers had average trade costs generally less than 10. In 1830, the differences in average trade costs across towns declined dramatically. Many towns had an average trade cost around 6, the overall average.

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

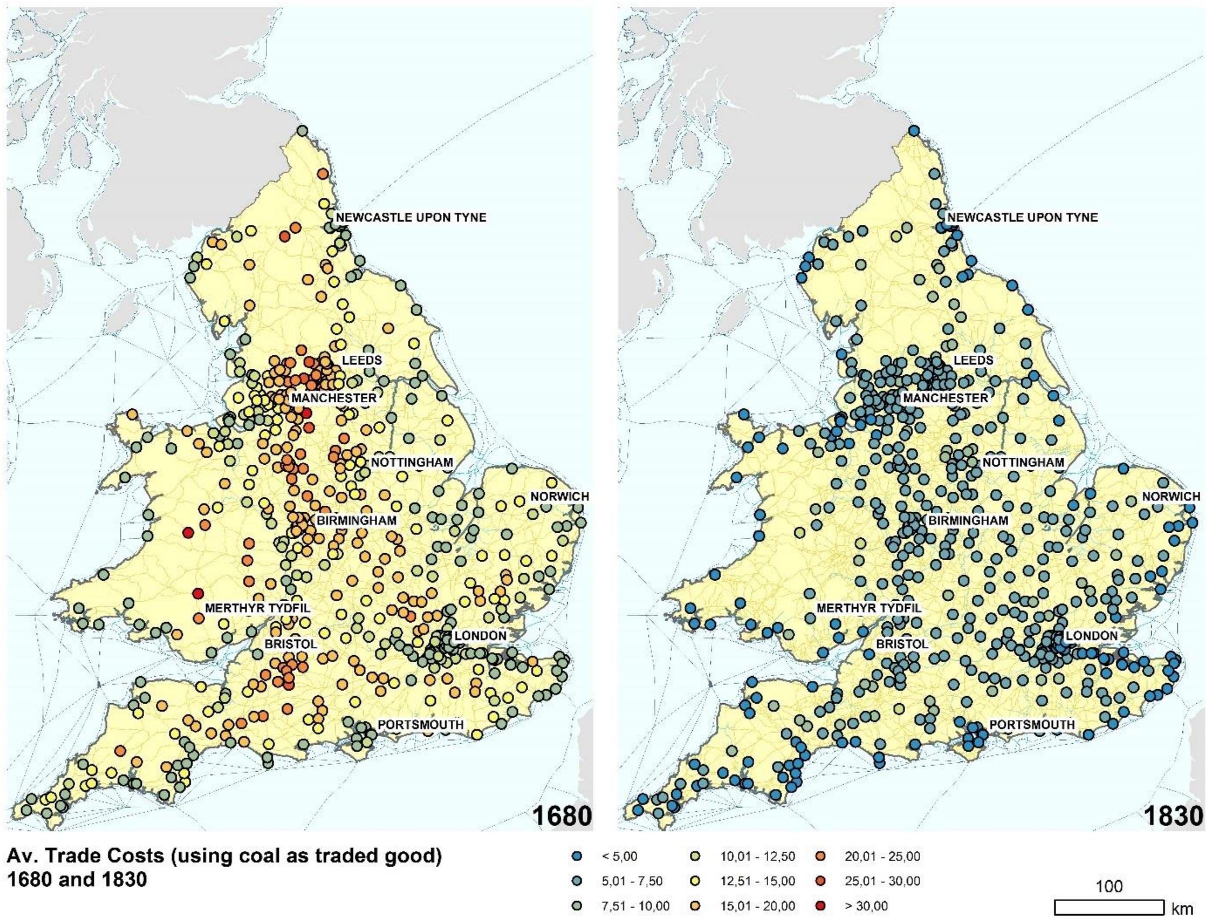


Figure A.6.1: Average trade costs for each town to all other towns in our sample
Source: Author's creation based on multimodal model and coal prices.

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

Let us say more about these two commodities. We know from the coastal shipping data that the top two commodities shipped coastwise were coal and grain. Within grain we can break grain into wheat, barley, and oats. Armstrong and Bagwell (1983 pp. 154-156) report coastal tonnage in these commodities between 1819 and 1825. From their data, we made the following calculations on tonnage:

Table A.6.1: Commodities carried coastwise c1830.

Commodity	Tons carried coastwise c1830 in 000s tons
wheat	169.7
barley	125.5
oats	110.6
coal	4761.0

Now coastal shipping is not all transport, but it is probably a good share of it. So, we think it is defensible to use these figures to calculate shares of trade goods (i.e. $\alpha's$). The alpha for coal would be 0.921 and the alphas for wheat, barley, and oats would be 0.032, 0.024, and 0.021 or in total 0.079.

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

The next task is to find the grain prices in these counties c.1680 and c.1830. Again, we want to compare the exact same places across time. For c.1680 we consulted Houghton in the peace year 1701. Houghton has wheat prices in the several of these places. We focus on the following markets: Chichester, Andover, Chelmsford, Lewes, Southampton, Rumford

Next, we looked at the corn returns https://www.cornreturnsonline.org/ where one can find grain prices across space. We were able to find prices in the above 'wheat' markets for 1830. The average wheat price in 1701 in the markets above was 3.07 shillings a bushel or 1179 pence a ton. The average wheat price in 1830 in the markets above was 7.38 shillings a bushel or 2834 pence a ton. For barley we could find prices in 1701 and 1830 in Andover, St. Ives, and Stamford. The average barley price in 1701 was 624 pence a ton and in 1830 the average barley price was 1461 pence a ton. For oats, we could find prices in 1701 and 1830 in Nottingham and Ripon. The average oats price in 1701 was 360 pence a ton and in 1830 it was 1162 pence a ton.

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

$$\alpha * avcoalprice^{1680} + (1-\alpha) * avgrainprice^{1680} = 115$$
$$\alpha * avcoalprice^{1830} + (1-\alpha) * avgrainprice^{1830} = 233$$

We now compare coal prices across 35 towns with data in both our periods. These are reported in table A.6.2. We focus on the coefficient of variation which declines.

Table A.6.2: Coal prices in 35 towns c.1700 and 1842.

TOWN.COUNTY	Average coal price 1691 to 1703 in pence per ton	Average coal price 1842 in pence per ton
ABINGDON.BERKSHIRE	324	262
BEDFORD.BEDFORDSHIRE	193	346
BERKHAMSTEAD.HERTFORDSHIRE	411	285
BERWICK UPON TWEED.NORTHUMBERLAND	86	84
BRENTFORD.MIDDLESEX	300	223.5
BURY ST EDMUNDS.SUFFOLK	190	343
CAMBRIDGE.CAMBRIDGESHIRE	238	294
CHICHESTER.SUSSEX	426	288
COLCHESTER.ESSEX	235	288
DARTFORD.KENT	226	300
DERBY.DERBYSHIRE	50	98
DEVIZES.WILTSHIRE	253	224.5
EXETER.DEVONSHIRE	240	268.5
GUILDFORD.SURREY	286	402
HERTFORD.HERTFORDSHIRE	380	354
HITCHIN.HERTFORDSHIRE	463	396
HULL.YORKSHIRE EAST RIDING	235	192
IPSWICH.SUFFOLK	214	252
KINGS LYNN.NORFOLK	193	328
LEWES.SUSSEX	264	303

LONDON.MIDDLESEX	279	211.5
MONMOUTH.MONMOUTHSHIRE	252	129
NORTHAMPTON.NORTHAMPTONSHIRE	336	240
NORWICH.NORFOLK	209	249
NOTTINGHAM.NOTTINGHAMSHIRE	86	117
OAKHAM.RUTLANDSHIRE	171	219
OXFORD.OXFORDSHIRE	354	318
PEMBROKE.PEMBROKESHIRE	125	143
PETERBOROUGH.NORTHAMPTONSHIRE	214	293
READING.BERKSHIRE	303	300
ROMFORD.ESSEX	273	306
SOUTHAMPTON.HAMPSHIRE	303	342
STAMFORD.LINCOLNSHIRE	241	286.5
WALLINGFORD.BERKSHIRE	309	342
YORK.YORKSHIRE NORTH RIDING	183	150.0563
Average price	252.71	262.22
Std. dev. In price	92.82	81.87
Coefficient of variation	0.37	0.31

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

Next, we report the ratio of London to Newcastle coal prices from 1805 to 1845. Once can see that the price ratio fell over time (see figure A.6.2) supporting the argument actual trade costs fell.

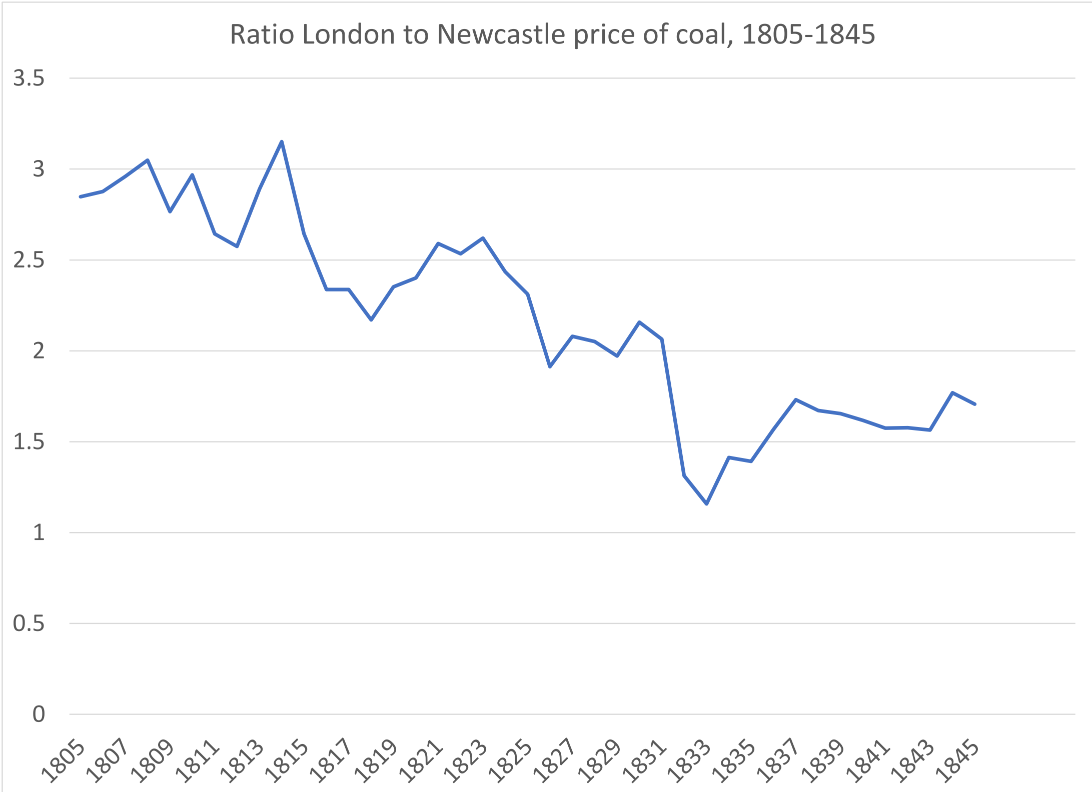


Figure A.6.2 The ratio of London to Newcastle coal prices

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

Finally, we report the price of coal in coastal towns relative to their coastal supplier and the estimated trade cost between the same two. Due to data limitations, we can only do this comparison for 8 coastal towns in 1680. See table A.6.3. But we can make the comparison for 51 towns n 1830/1842. See table A.6.4.

Table A.6.3: Coal prices in coastal towns and their supplier compared with estimated trade costs in 1680

	1	2	3	4
TOWN.COUNTY	Av. coastal town coal price, 1697_1702	Av. coastal supplier coal price, 1697_1702	ratio 1:2	estimated trade cost between coastal town and supplier 1680
SANDWICH.KENT	234	46	5.087	3.529

PLYMOUTH.DEVONSHIRE	216	137	1.577	2.943
SOUTHAMPTON.HAMPSHIRE	299	137	2.182	3.748
FALMOUTH.CORNWALL	189	137	1.380	2.788
LONDON.MIDDLESEX	237	46	5.152	4.241
HULL.YORKSHIRE EAST RIDING	192	46	4.174	3.150
CHICHESTER.SUSSEX	354	46	7.696	6.667
LEWES.SUSSEX	239	46	5.196	3.751
Correlation (3),(4)				0.82

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

Table A.6.4: Coal prices in coastal towns and their supplier 1842 compared with estimated trade costs in 1830

	1	2	3	4
TOWN.COUNTY	Av. coastal town coal price, 1842	Av. coastal supplier coal price, 1842	ratio 1:2	estimated trade cost between coastal town and supplier 1830
GREAT DUNMOW.ESSEX	363	63.6	5.708	5.378
WATCHET.SOMERSETSHIRE	255	80	3.188	1.91
ABERYSTWYTH.CARDIGANSHIRE	222	80	2.775	2.272
TRURO.CORNWALL	215.5	80	2.694	2.39
FAREHAM.HAMPSHIRE	370	80	4.625	2.839
BIDEFORD.DEVONSHIRE	174.5	80	2.181	2.219
PENZANCE.CORNWALL	196	80	2.45	2.262
ST IVES.CORNWALL	264	80	3.3	2.202
CARMARTHEN.CARMARTHENSHIRE	135	80	1.688	2.252
MAIDSTONE.KENT	289	63.6	4.544	3.403
KINGS LYNN.NORFOLK	328	63.6	5.157	2.832
CHEPSTOW.MONMOUTHSHIRE	150	80	1.875	2.643
IPSWICH.SUFFOLK	252	63.6	3.962	2.711
WEYMOUTH.DORSETSHIRE	278	80	3.475	2.58
MALDON.ESSEX	292.5	63.6	4.599	2.968
GATESHEAD.DURHAM	68	63.6	1.069	1.022
BECCLES.SUFFOLK	276	63.6	4.34	2.596
ST GERMANS.CORNWALL	203.25	80	2.541	2.498
WOODBRIDGE.SUFFOLK	285	63.6	4.481	2.69
SELBY.YORKSHIRE WEST RIDING	90	63.6	1.415	3.776

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

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

VII. Balance tests for incidentally connected towns

For the balance tests, we create a dummy variable for 25 sample towns that were incidentally connected to the 1779 canal plan. Specifically, they are within 2.5 km of 1779 planned canals and do not include the endpoint and through towns identified in the Plan. We also create a dummy variable for 22 sample towns that we consider as targeted by the 1779 Canal Plan. Specifically, they are within 2.5 km of 1779 planned canals and are named on the plan as the endpoint or through towns. To visualize the names see **Figure A.3.3.** Appendix III.

We compare 25 incidentally connected towns with all other towns, excluding targeted. An important first point is that the mean log 1680 population is 6.925 for incidentally connected towns, which is not statistically different from 7.029, the mean log 1680 population of all other non-targeted towns. In table A.7.1 we report differences in geographic controls. Several geographic variables, like log distance to coast, exposed coal, elevation, are statistically different from the other 398 towns in our sample. This is to be expected, since geography and exploitation of coal played a role in identifying the best routes. That said, we have controls for geography in our specification, so we are less concerned about this imbalance. There is no evidence that being an incidentally connected town meant greater selection into Blome's town summaries c.1670. Also, as shown in table A.7.4 there are few differences regarding the 16 Blome variables. This aspect is reassuring in that incidentally connected towns were no more likely to be early manufacturing towns.

Table A.7.1: Geographic covariate imbalance for incidentally connected towns vs. all non-targeted towns

	(1)	(2)	(3)
Variable	All non-targeted towns	incidentally connected towns	Difference
logdistcoastkm	-4.183	-2.951	1.232***
	(1.610)	(0.475)	(0.323)
exposedcoal	0.181	0.600	0.419***
	(0.385)	(0.500)	(0.081)
averagerain	782.037	848.100	66.063*
	(190.781)	(176.598)	(39.175)
averagetemp	8.979	8.700	-0.279*
	(0.718)	(0.540)	(0.146)
elevation_mean	80.896	109.412	28.516**

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

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

Also, as shown in table A.7.2 there is only one difference regarding the 16 Blome variables, having a 1700 road. Incidentally connected towns were also less likely to be coastal which make sense. Overall, these balance tests are reassuring in that incidentally connected towns were similar to non-targeted towns.

Table A.7.2: Blome covariate imbalance for incidentally connected towns vs. all non-targeted towns

Variable	(1) All non-targeted towns	(2) incidentally connected towns	(3) Difference
	economic & political vars.		
harbour1670	0.108	0.000	-0.108
	(0.311)	(0.000)	(0.072)
mining1670	0.045	0.053	0.007
	(0.208)	(0.229)	(0.049)
cloth1670	0.139	0.053	-0.086
	(0.346)	(0.229)	(0.080)
brewing1670	0.033	0.000	-0.033
	(0.179)	(0.000)	(0.041)
othermanuf1670	0.084	0.053	-0.032
	(0.278)	(0.229)	(0.065)
freeschool1670	0.096	0.053	-0.044
	(0.296)	(0.229)	(0.069)
alms1670	0.027	0.000	-0.027
	(0.163)	(0.000)	(0.037)
townofficials1670	0.367	0.316	-0.052
	(0.483)	(0.478)	(0.114)
hasmps1670	0.346	0.421	0.075
	(0.477)	(0.507)	(0.113)
marketdays1670	1.108	1.105	-0.003
	(0.555)	(0.567)	(0.131)
largemarket1670	0.343	0.211	-0.133

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

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

VIII. Summary statistics

The following table provide summary statistics for all the control variables. Variable labels should be clear from discussion in text and appendices.

Table A.8.1 Descriptive Statistics for instruments, and local infrastructure change

Variable	Obs	Mean	Std. Dev.	Min	Max
Diff. ln MA to towns incidentally connected to Cross Plan	448	1.708	0.681	0.383	3.788
Ln dist to nearest 1680 waterways	448	1.446	1.939	-3.367	3.907
Ln dist to nearest canal in 1779 Cross Plan	448	3.533	1.669	-2.006	5.662
Local infrastructure change					
Ln (dist 1830 waterway) -Ln (dist. 1680 waterway)	448	-1.378	1.721	-6.480	3.124
Ln (dist 1830 turnpike road) -Ln (dist. 1680 main road)	441	-2.280	3.360	-21.286	9.468

Table A.8.2: Descriptive Statistics: geographic control variables, region fixed effects, and Blome missing or no summary dummy variables

Variable	Obs	Mean	Std. Dev.	Min	Max
logdistcoastkm	448	-4.069	1.588	-9.596	-2.335
exposedcoal	448	.221	.415	0	1
averagerain	448	787.22	188.825	558	1372.5
averagetemp	448	8.949	.707	5.5	10
elevation mean	448	83.854	65.445	.326	401.49
elevation sd	448	29.713	27.454	.5	166.016
point x	448	429698.09	105696.06	147275.41	655050
pointxsq	448	1.958e+11	9.031e+10	2.169e+10	4.291e+11
point y	448	264245.97	131669.99	27475.902	652900.81
pointysq	448	8.712e+10	8.008e+10	7.549e+08	4.263e+11
pointxpointy	448	1.141e+11	5.726e+10	4.460e+09	2.612e+11
regionfe1	448	.203	.403	0	1
regionfe2	448	.188	.391	0	1
regionfe3	448	.132	.339	0	1
regionfe4	448	.112	.315	0	1
regionfe5	448	.096	.295	0	1
regionfe6	448	.098	.298	0	1
regionfe7	448	.076	.265	0	1

regionfe8	448	.036	.186	0	1
regionfe9	448	.06	.238	0	1
Blome nosummary	448	.074	.262	0	1
Blome missing	448	.089	.285	0	1

Table A.8.3: Descriptive Statistics historic controls, when Blome missing or no summary dummy variables are zero

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

IX. Additional estimates on effect of changes in market access

Table A.9.1 provides coefficient estimates for all variables in table 3.

Table A.9.1 Coefficient estimates for models in table 3

Dep. Var.	ln1841pop-ln1680pop			ln1841pop-ln1801pop	ln1680pop-ln1563pop	ln1841pop-ln1680pop
VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
$\Delta lnMA_i$, coal traded	0.0956*	0.179***	0.234***	0.0693**	-0.0970	
	(0.0494)	(0.0567)	(0.0633)	(0.0271)	(0.129)	
$\Delta lnMA_i$, coal, grain						0.260***
						(0.0790)
logdistcoastkm		-0.106***	-0.0600	-0.0179	-0.101	-0.0609*
		(0.0336)	(0.0365)	(0.0166)	(0.0829)	(0.0369)
exposedcoal		0.528***	0.422***	0.120**	-0.120	0.425***
		(0.122)	(0.128)	(0.0529)	(0.166)	(0.128)
averagerain		0.000524	0.000554	0.00059***	-0.000954	0.000560
		(0.00048)	(0.00048)	(0.000229)	(0.00108)	(0.000483)
averagetemp		0.173	0.0710	0.106*	0.191	0.0911
		(0.111)	(0.115)	(0.0568)	(0.180)	(0.114)
elevation_mean		0.000564	-0.000196	0.000508	0.0048***	-0.000189
		(0.00118)	(0.00113)	(0.000647)	(0.00176)	(0.00114)
elevation_sd		-0.00249	-0.00210	-0.00138	-0.00285	-0.00202
		(0.00201)	(0.00207)	(0.00103)	(0.00318)	(0.00209)
point_x	-3.06e-06	1.86e-06	3.36e-06	2.25e-06	-5.40e-06	3.38e-06
	(2.84e-06)	(3.28e-06)	(3.18e-06)	(1.84e-06)	(1.55e-05)	(3.17e-06)
pointxsq	0	-0	-0	-0	0	-0
	(0)	(0)	(0)	(0)	(0)	(0)
point_y	4.39e-06	4.77e-06	4.43e-06	-4.42e-07	-8.86e-06	4.47e-06
	(3.02e-06)	(3.03e-06)	(3.01e-06)	(1.86e-06)	(7.63e-06)	(3.01e-06)
pointysq	-0	-0	-0	-0	0	-0
	(0)	(0)	(0)	(0)	(0)	(0)
pointxpointy	-0	-0	-0	0*	0	-0
	(0)	(0)	(0)	(0)	(0)	(0)
regionfe1	-1.141**	-0.392	-0.416	-0.497***	0.834	-0.413
	(0.451)	(0.404)	(0.414)	(0.183)	(0.814)	(0.414)
regionfe2	-1.324***	-0.593	-0.576	-0.540**	0.714	-0.601
	(0.456)	(0.417)	(0.429)	(0.211)	(0.732)	(0.431)
regionfe3	-1.556***	-0.844**	-0.890**	-0.520***	0.506	-0.887**
	(0.436)	(0.381)	(0.381)	(0.173)	(0.747)	(0.382)
regionfe4	-1.169***	-0.765**	-0.820**	-0.522***	0.976	-0.834**
	(0.418)	(0.378)	(0.375)	(0.169)	(0.748)	(0.377)
regionfe5	-1.120***	-0.592*	-0.630*	-0.398**	0.598	-0.646**
	(0.382)	(0.332)	(0.326)	(0.160)	(0.640)	(0.328)
regionfe6	-0.132	0.00927	-0.0217	-0.194	0.790	-0.0221
	(0.323)	(0.320)	(0.315)	(0.166)	(0.684)	(0.316)
regionfe7	-0.436	-0.281	-0.345	-0.344**	0.124	-0.349
	(0.318)	(0.279)	(0.274)	(0.134)	(0.431)	(0.275)
regionfe9	-1.298***	-0.812*	-0.928*	-0.151		-0.945**
	(0.481)	(0.462)	(0.477)	(0.257)		(0.479)

harbour1670			-0.106	-0.0975		-0.101
			(0.172)	(0.0764)		(0.173)
mining1670			0.544**	0.0208		0.544**
			(0.240)	(0.0943)		(0.241)
cloth1670			0.215*	-0.00167		0.209
			(0.127)	(0.0425)		(0.127)
brewing1670			0.240	0.0269		0.237
			(0.187)	(0.0810)		(0.189)
othermanuf1670			0.135	0.0465		0.133
			(0.166)	(0.0616)		(0.166)
freeschool1670			-0.188	-0.0432		-0.183
			(0.146)	(0.0529)		(0.147)
alms1670			-0.329	0.00991		-0.314
			(0.235)	(0.101)		(0.238)
townofficials1670			0.127	0.0714*		0.127
			(0.0900)	(0.0423)		(0.0900)
hasmps1670			-0.128	-0.0514		-0.132
			(0.0934)	(0.0439)		(0.0933)
marketdays1670			-0.0235	0.00150		-0.0261
			(0.0602)	(0.0267)		(0.0608)
largemarket1670			-0.0206	-0.0222		-0.0186
			(0.0884)	(0.0434)		(0.0886)
smallmarket1670			0.0866	-0.0339		0.0848
			(0.136)	(0.0732)		(0.136)
mordenroad1700			-0.0468	-0.0322		-0.0442
			(0.0962)	(0.0431)		(0.0963)
rivernav1670			0.0527	0.100	0.487**	0.0530
			(0.135)	(0.0649)	(0.216)	(0.137)
stream1670			-0.0911	0.0583	0.180	-0.0846
			(0.101)	(0.0501)	(0.162)	(0.101)
coastal1670			0.398**	0.197**	0.0299	0.404**
			(0.171)	(0.0795)	(0.296)	(0.172)
Blome_nosummary			17.52*	5.090	14.29	18.03*
			(10.46)	(4.630)	(10.19)	(10.57)
Blome_missing			26.09*	7.585	21.83	26.84*
			(15.67)	(6.939)	(15.20)	(15.84)
Constant	3.023***	-1.487	-0.704	-1.227	-0.567	-0.968
	(0.735)	(1.760)	(1.842)	(0.920)	(5.090)	(1.841)
Observations	451	448	448	448	155	448
R-squared	0.236	0.310	0.366	0.237	0.311	0.364

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table A.9.2 provides coefficient estimates using the simplified market access formula with different values of theta. Standardized coefficients for a one-standard deviation change in market access in standard deviation units of the DV: 1680-1841 growth ($\Delta_{1841,1680}\ln\ pop_i$

Table A.9.2: Effect of market access on town population using different values of theta

	1	2	3	4
		DV: 1680-1841 growth ($\Delta_{1841,1680}\ln\ pop_i$)		
Alternative values of theta	$\theta = 1$	$\theta = 2$	$\theta = 4$	$\theta = 8$
	Coeff. (st. err.)	Coeff. (st. err.)	Coeff. (st. err.)	Coeff. (st. err.)
$\Delta lnMA_i$	0.459 (0.128)***	0.220 (0.057)***	0.096 (0.025)***	0.038 (0.012)***
		Standardized coefficient		
	0.227	0.240	0.231	0.181
Geo. controls	Y	Y	Y	Y
Historic controls	Y	Y	Y	Y
N	448	448	448	448
R-squared	0.368	0.369	0.367	0.363

Notes: All regressions include a 2nd order polynomial in latitude and longitude, region fixed effects, geographic controls, and historic controls from Blome. Simplified formulas for market access are used, $MA_i = \sum_j^J pop_j \tau_{ij}^{-\theta}$. Robust standard errors are reported. *, **, and *** represents statistical significance at the 10, 5, and 1% levels.

Table A.9.3 shows more extensions. It reports estimates of the effect of market access on town population change first with sample weights to match Langton full sample pop. growth distribution and second by adding a control for average distance to all towns.

Table A.9.3: Effect of market access on town population change: extensions with sample weights to match Langton full sample pop. growth distribution and adding a control for average distance to all towns.

	1	2	3	4
Traded good in MA_i		Coal		Coal & grain
	Obs. weighted to match growth in full Langton data		Obs. weighted to match growth in full Langton data	
	Coeff. (st. err.)	Coeff. (st. err.)	Coeff. (st. err.)	Coeff. (st. err.)
$\Delta lnMA_i$	0.196 (0.069)***	0.200 (0.067)***	0.210 (0.084)***	0.224 (0.083)***
Av. distance to towns in sample		-2.08e-08 (1.06e-08)*		-2.22e-08 (1.05e-08)**
Geo. controls	Y	Y	Y	Y

Historic controls	Y	Y	Y	Y
N	448	448	448	448
R-squared	0.341	0.373	0.337	0.371

Notes: The DV is ln1841pop - ln1680pop. All regressions include a 2nd order polynomial in latitude and longitude and 9 region fixed effects. Robust standard errors are reported. *, **, and *** represents statistical significance at the 10, 5, and 1% levels.

Table A.9.4 shows the full second stage estimates for the IV specifications in table 4.

Table A.9.4: Second stage estimates for market access in columns 2, 3, and 4 of table 4.

VARIABLES	Col. 2	Col. 3	Col. 4
	Coeff. (st. err.)	Coeff. (st. err.)	Coeff. (st. err.)
$\Delta lnMA_i$	0.264**	0.260**	0.274***
	(0.113)	(0.105)	(0.0821)
logdistcoastkm	-0.0619*	-0.0488	-0.0497
	(0.0353)	(0.0326)	(0.0326)
exposedcoal	0.423***	0.426***	0.427***
	(0.122)	(0.104)	(0.104)
averagerain	0.000542	0.000384	0.000379
	(0.000460)	(0.000422)	(0.000422)
averagetemp	0.0732	0.0189	0.0201
	(0.111)	(0.105)	(0.104)
elevation_mean	-0.000317	-0.000612	-0.000667
	(0.00115)	(0.00115)	(0.00112)
elevation_sd	-0.00195	-0.00110	-0.00103
	(0.00201)	(0.00203)	(0.00198)
point_x	3.28e-06	1.46e-06	1.43e-06
	(3.04e-06)	(2.91e-06)	(2.92e-06)
pointxsq	-0	-0	-0
	(0)	(0)	(0)
point_y	4.44e-06	4.11e-06	4.12e-06
	(2.89e-06)	(2.79e-06)	(2.80e-06)
pointysq	-0	-0*	-0*
	(0)	(0)	(0)
pointxpointy	-0	-0	-0
	(0)	(0)	(0)
regionfe1	0.520*	0.478*	0.482*
	(0.282)	(0.288)	(0.289)
regionfe2	0.359	0.311	0.315
	(0.259)	(0.264)	(0.267)
regionfe3	0.0361	-0.0150	-0.0154
	(0.292)	(0.294)	(0.295)
regionfe4	0.105	-0.0710	-0.0718
	(0.243)	(0.229)	(0.230)

regionfe5	0.295	0.248	0.247
	(0.279)	(0.276)	(0.276)
regionfe6	0.895***	0.949***	0.944***
	(0.319)	(0.268)	(0.267)
regionfe7	0.572	0.520	0.515
	(0.351)	(0.335)	(0.333)
regionfe8	0.913**	0.898**	0.891**
	(0.461)	(0.428)	(0.424)
harbour1670	-0.111	0.0111	0.00861
	(0.164)	(0.140)	(0.140)
mining1670	0.545**	0.415*	0.416*
	(0.230)	(0.213)	(0.213)
cloth1670	0.216*	0.0406	0.0412
	(0.122)	(0.106)	(0.106)
brewing1670	0.244	0.367**	0.368**
	(0.180)	(0.162)	(0.162)
othermanuf1670	0.137	0.0290	0.0295
	(0.158)	(0.134)	(0.134)
freeschool1670	-0.187	-0.270**	-0.269**
	(0.139)	(0.111)	(0.111)
alms1670	-0.336	-0.168	-0.171
	(0.223)	(0.219)	(0.218)
townofficials1670	0.128	0.157*	0.157*
	(0.0859)	(0.0817)	(0.0816)
hasmps1670	-0.127	-0.157*	-0.157*
	(0.0891)	(0.0867)	(0.0866)
marketdays1670	-0.0228	0.0113	0.0116
	(0.0576)	(0.0526)	(0.0526)
largemarket1670	-0.0202	-0.0442	-0.0441
	(0.0845)	(0.0815)	(0.0816)
smallmarket1670	0.0900	0.138	0.140
	(0.130)	(0.133)	(0.132)
mordenroad1700	-0.0483	-0.0209	-0.0218
	(0.0917)	(0.0818)	(0.0822)
rivernav1670	0.0688	0.0929	0.100
	(0.134)	(0.126)	(0.122)
stream1670	-0.0968	-0.0634	-0.0659
	(0.0974)	(0.0926)	(0.0902)
coastal1670	0.399**	0.325**	0.326**
	(0.163)	(0.143)	(0.143)
Blome_nosummary	17.80*	17.54*	17.69*
	(10.000)	(9.292)	(9.297)
Blome_missing	26.50*	26.09*	26.31*
	(14.98)	(13.93)	(13.94)
Constant	-1.688	-0.567	-0.597
	(1.692)	(1.587)	(1.577)
Observations	448	426	426

R-squared	0.366	0.379	0.379

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table A.9.5 shows the full first stage estimates.

Table A.9.5: first stage estimates for market access in columns 2, 3, and 4 in table 4.

	Col. 2 Coeff. (st. err.)	Col. 3 Coeff. (st. err.)	Col. 4 Coeff. (st. err.)
Diff. ln MA to towns incidentally connected	0.581***		0.563***
	(0.0574)		(0.0482)
Ln dist to nearest 1680 waterways		0.240***	0.145***
		(0.0168)	(0.0167)
Ln dist to nearest canal in 1779 Cross Plan		-0.0778***	-0.176***
		(0.0200)	(0.0252)
logdistcoastkm	0.0260	-0.0336*	-0.0325**
	(0.0160)	(0.0179)	(0.0153)
exposedcoal	-0.0534	-0.138**	-0.161***
	(0.0604)	(0.0647)	(0.0537)
averagerain	0.000289	0.000664***	0.000653***
	(0.000215)	(0.000246)	(0.000186)
averagetemp	0.0492	-0.0343	0.0140
	(0.0638)	(0.0839)	(0.0584)
elevation_mean	0.00257***	0.00101	2.85e-05
	(0.000669)	(0.000801)	(0.000549)
elevation_sd	-0.00312***	-0.00154	-0.000478
	(0.00115)	(0.00155)	(0.00100)
point_x	1.07e-06	6.64e-07	-2.19e-06*
	(1.32e-06)	(1.68e-06)	(1.26e-06)
pointxsq	-0	-0	0**
	(0)	(0)	(0)
point_y	-2.56e-06*	-2.85e-06	-6.61e-06***
	(1.41e-06)	(1.79e-06)	(1.33e-06)
pointysq	0	0	0***
	(0)	(0)	(0)
pointxpointy	0	-0	0
	(0)	(0)	(0)
regionfe1	-0.259	-0.430	0.0226
	(0.217)	(0.285)	(0.190)
regionfe2	-0.314	-0.602**	-0.182
	(0.199)	(0.272)	(0.171)
regionfe3	0.0182	-0.163	0.350**
	(0.187)	(0.259)	(0.167)
regionfe4	-0.110	-0.248	0.0285

	(0.172)	(0.235)	(0.146)
regionfe5	-0.195	-0.245	-0.0263
	(0.152)	(0.214)	(0.128)
regionfe6	0.0271	-0.328	-0.196
	(0.140)	(0.206)	(0.127)
regionfe7	-0.0760	-0.130	-0.0687
	(0.119)	(0.189)	(0.107)
o.regionfe8	-	-	-
regionfe9	-0.0687	-0.183	0.257
	(0.216)	(0.286)	(0.185)
harbour1670	0.0913	0.103	0.0977*
	(0.0626)	(0.0771)	(0.0587)
mining1670	0.00244	-0.0896	0.0143
	(0.0912)	(0.103)	(0.100)
cloth1670	-0.120**	-0.0304	-0.0992*
	(0.0562)	(0.0772)	(0.0513)
brewing1670	-0.338***	0.0333	-0.176**
	(0.110)	(0.110)	(0.0864)
othermanuf1670	-0.0592	0.0661	-0.00955
	(0.0680)	(0.0839)	(0.0618)
freeschool1670	-0.0421	-0.0431	-0.0694
	(0.0766)	(0.100)	(0.0727)
alms1670	0.181	0.111	0.167
	(0.148)	(0.161)	(0.143)
townofficials1670	0.0152	-0.0413	0.00252
	(0.0538)	(0.0604)	(0.0477)
hasmps1670	-0.00196	-0.0406	-0.0526
	(0.0541)	(0.0603)	(0.0472)
marketdays1670	-0.0240	-0.0657**	-0.0537**
	(0.0297)	(0.0331)	(0.0269)
largemarket1670	-0.0322	0.0234	0.0136
	(0.0488)	(0.0523)	(0.0439)
smallmarket1670	-0.0712	-0.153**	-0.116**
	(0.0695)	(0.0718)	(0.0554)
mordenroad1700	0.0364	0.0161	0.0613
	(0.0487)	(0.0525)	(0.0443)
rivernav1670	-0.323***	-0.0863	-0.0537
	(0.0579)	(0.0652)	(0.0552)
stream1670	0.126**	0.0653	0.0668
	(0.0579)	(0.0685)	(0.0506)
coastal1670	-0.0392	0.0243	-0.0214
	(0.0633)	(0.0730)	(0.0570)
Blome_nosummary	-12.02**	-2.240	-4.585
	(5.420)	(5.479)	(4.800)
Blome_missing	-18.02**	-3.272	-6.960

	(8.114)	(8.207)	(7.190)
Constant	0.168	1.927*	1.422*
	(0.846)	(1.164)	(0.838)
Observations	448	426	426
R-squared	0.698	0.656	0.784

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

X. Additional counterfactuals

A different counterfactual supposes infrastructure networks remained the same between 1680 and 1830, but per ton mile freight costs and fees evolved as shown in table 1 of the text. This scenario aims at quantifying the impact of adding inland waterways, especially canals, and building more roads. It also assumes that shipping and road transport continued to get more productive, which is reflected in the evolution of freight cost parameters. We follow the same steps as described in the main text, but we recalculate transport costs in the multi-modal model using 1680 networks and 1830 parameters, call these ${tc_{ij}}^{1680net}$. The counter factual trade costs are then $\tau_{ij}^{c} = \frac{{tc_{ij}}^{1680net}}{CoalPrice1830} + 1$.

Our first calculation in the no infrastructure change counterfactual uses the baseline market access estimate from table 3. It implies the total town population in E&W would have been 4.5% lower in 1841 or 0.32 million less. Col. 2 in table A.10.1 shows the counterfactual populations in 1841 for the top 20 towns. Those inland, like Birmingham, Wolverhampton, and Sheffield, lose the most population. They were especially dependent on the inland canal network. Coastal towns generally lose less population, and some like Liverpool are even larger. In the last calculation, we add the estimated interaction effect between $lnMA_i$ and coal. Here estimates show total town population would be 7.9% lower in 1841. Across the top 20 towns the population would have shifted dramatically from the inland coalfields to the coast (see col. 4). For example, Leeds would lose 30% of its population, while Bristol and Hull gain 3-5%.

Table A.10.1: Counterfactual 1841 populations for top 20 cities and towns if freight cost parameters change between 1680 and 1830 but networks do not

	(1)	(2)	(3)	(4)	(5)
		Baseline without interaction effect between $lnMA_i$ and coal		Extension with interaction effect between $lnMA_i$ and coal	
Town. County	Actual pop. 1841	Counterfactual pop. 1841	ratio (4) to (1)	Counterfactual pop. 1841	ratio (4) to (1)
LONDON	1948417	1828633	0.9385	1840376	0.9445
MANCHESTER	311269	278115	0.8930	236070	**0.7584**
LIVERPOOL	286487	295741	1.0323	294827	1.0291

BIRMINGHAM	182922	150144	0.8208	152315	0.8327
LEEDS	152074	131304	0.8634	106141	**0.6980**
BRISTOL	125146	129327	1.0334	128957	1.0305
SHEFFIELD	111091	95954	0.8637	78167	**0.7036**
WOLVERHAMPTON.	93245	80525	0.8635	65438	**0.7018**
NEWCASTLE U. TYNE	70337	75032	1.0667	82259	**1.1695**
HULL	67308	70938	1.0539	70603	1.0490
BRADFORD	66715	55675	0.8345	42497	**0.6370**
NORWICH	61846	66183	1.0701	65799	1.0639
NEWINGTON	54606	59793	1.0950	59363	1.0871
SUNDERLAND	53335	56954	1.0678	62527	**1.1723**
BATH	53196	46146	0.8674	46807	0.8799
PORTSMOUTH	53032	56617	1.0676	56303	1.0617
NOTTINGHAM	52360	52604	1.0046	52561	1.0038
BOLTON	51029	46025	0.901	39500	**0.7741**
PRESTON	50887	52745	1.0365	52562	1.0329
LEICESTER	50806	42049	0.8276	42816	0.8427

Notes: author’s calculations, see text. In col. 5, towns in bold are on the coalfield.

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