Market access and urban growth in the pre-steam age

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Abstract[5]

Before the modern era, urban growth was rare and contingent on factors like high market access. This paper estimates the effect of market access on urban population growth in England and Wales when it experienced a pre-steam transport revolution. We use several new datasets on the populations and characteristics of urban settlements, freight transport costs between these settlements, and prices for commodities like coal from the late 1600s to the mid-1800s. From these, new estimates of inter-urban trade costs and market access are made. We show (1) trade costs declined by more than 50% on average and (2) through greater market access they substantially increased urban population growth, especially in regions with cheap coal. We interpret the OLS estimates as causal using an IV strategy and other robustness checks. More broadly the findings illustrate how locally developed networks can have national effects by increasing market access and enhancing endowments.

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

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Urban populations have grown to levels not previously seen in human history during the modern era. Yet urban growth occurred earlier, including in the pre-steam age when most machines were operated by hand and trade was conducted on horseback or aboard sailing ships. Like the recent past, the fastest growing cities and towns in the pre-steam age usually had favorable natural resources or a 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. However, having good market access in the pre-steam age was more contingent. Along with access to the sea, there needed to be investment in ships, experienced seaman to use advanced shipping technologies, and strong navies to make coastal waters safe from privateers and pirates. Infrastructure investments were also needed, which was challenging because governments had limited fiscal and administrative capabilities in earlier centuries.

This paper estimates how market access increased urban population growth in England and Wales during the pre-steam age. This economy offers unique insights because it experienced a transportation revolution starting in the late 1600s. It developed and adopted new technologies for sailing ships and navigation. Extensive networks of navigable rivers, canals, high quality roads, and capable ports were also built to foster the movement of goods by wagon and barge, especially coal and grains. At this time, England and Wales also experienced extensive urban growth and spatial redistribution. From around 1650, its 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. Using several new datasets, we show (1) inter-urban trade costs declined by more than 50% on average between 1680 and 1830 and (2) through greater market access they substantially increased urban population growth between 1680 and 1841, especially for urban settlements on the coalfields.

More generally, our findings highlight a setting where market access was transformed by private, nonprofit, and municipal groups with a supporting role by the central government. This

[6] See Wrigley (1985), Bairoch (1988), DeVries (2013), Shaw-Taylor and Wrigley (2014), and Buringh (2020).

is unlike other settings, where the central government plays the leading role. We show that locally developed infrastructures have impacts on distant cities and towns through the network, making urban growth an inter-dependent process. Our findings also demonstrate interaction effects between market access and energy. It is commonly argued that low energy costs contribute to industrialization and development (e.g., Allen 2009, Wrigley 2010). However, as we show, there may be limited exploitation of energy resources without high market access.

This paper is the first to use several new datasets. One contains populations for nearly 500 England and Welsh cities and towns in 1680, 1801, and 1841 and a subset with populations as early as 1560.[7] There are also variables for economic, political, and infrastructural characteristics of cities and towns in 1673 and their resource, geographic, and climate characteristics. A second dataset contains new estimates of freight transport costs between 590 cities and towns in 1680 and 1830.[8] These link to the nearly 500 cities and towns with population data in 1680, 1801, and 1841. The third dataset includes coal prices in several markets around 1700 and 1842.[9] The markets are also linked to cities and towns with transport costs. The fourth is a map of planned canals in 1779. Most were part of the 'Grand Cross' Plan, devised by James Brindley in the 1760s and meant to interconnect the basins of distant rivers. We use this map in our identification strategy.

The first major contribution of this paper is to combine the freight cost data with coal prices to construct estimates of inter-urban trade costs at two dates 1680 and 1830. For the 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. The new estimates show that on average inter-urban trade costs declined by 57% between 1680 and 1830. Moreover, where data is available, we demonstrate that estimated trade costs correspond with predicted differences in coal prices between supplying and consuming towns along the coast, giving confidence for their accuracy.

[7] See Alvarez, Bogart, Satchell, and Shaw-Taylor (2022a). Unfortunately, the data on Scotland are less developed and so this British region is not included in our study.

[8] See Alvarez, Bogart, Satchell, and Shaw-Taylor (2022b) for details on the 1680 and 1830 multi-modal models.

[9] See Satchell, Bogart, Shaw-Taylor (2016) for coal prices.

The second major contribution is to estimate the effects of market access on urban population growth. Market access is calculated using our new trade cost estimates and drawing on the formulation provided by Donaldson and Hornbeck's (2016) general equilibrium model. We estimate 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. This issue is addressed with an instrumental variable related to the Grand Cross Canal Plan, largely intended to link distant river basins. The routes were shaped by geographic conditions and had few viable alternatives. As the plan was implemented, some towns got 'incidentally connected' with canals and the broader transport network. We identify incidentally connected towns as those within 2.5 km of the planned canals, but not named in the map from 1779. In terms of observables, like 1680 population, they are no different from towns away from the Plan. Building on this point, our main instrument is market access to incidentally connected towns more than 50 km away.[10] The requirement of 50 km distance reduces concerns of endogenous development between neighboring towns. In extensions, we also use distance to the nearest canal in the Plan and distance to 1680 inland waterways as additional instruments.

Our preferred ordinary least squares (OLS) estimate, which controls for resource, geographic, climate, and other pre-existing characteristics of towns, shows that increasing a town's market access significantly increased its population. The instrumental variable estimates are similar in magnitude, regardless of which IV we use. 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. Building on all these results, we interpret our preferred OLS estimates as causal. They imply that a 10% increase in market access would increase town population by approximately 2.5%.

[10] Redding and Turner (2015) discuss the 'inconsequential places' approach. For two applications see Faber (2014) and Bogart et al (2021). For a recent application in a market access framework, see Herzog (2021)

The main extension highlights the interaction effect between market access and a town being on a coalfield. Summarizing, 22% of the towns in our data were on coalfields, and on average their 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 quantify how the urban population would have changed if trade costs remained constant between 1680 and 1830. Our estimates imply that the total urban population would have been 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 had little loss or some increase. The reason is that inland areas experienced much greater trade cost reduction.

Our paper contributes to many literatures. The first uses history to study transport improvement and economic development.[11] The most related examine economy-wide effects of improving networks using a market access approach.[12] This paper is one of the first to analyze market access impacts before railways.[13] There are several studies highlighting new shipping technologies related to sailing.[14] Others focus on internal improvements, such as canals and roads, and innovation in the provision of freight services.[15] Yet these studies rarely emphasize inter-modality and network structure.[16] As we show, trade costs depended on improvements across transport modes and throughout the network.

Second, we shed new light on the causal factors explaining urban growth. The prior literature focusing on the pre-industrial era emphasizes skills, institutions, and contingencies

[11] See Atack et al. (2010), Tang (2014), Garcia-López (2015), Hornung (2015), Berger and Enflo (2017), Jedwab (2017), Bogart et al. (2022).

[12] 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).

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

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

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

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

associated with new technologies.[17] Here market access and endowments are highlighted as fundamental factors, consistent with some research on the modern era.[18]

Third, our paper contributes to the literature on the industrial revolution, especially its location within England.[19] One view is that endowments were a major factor, especially being on the coalfields since they gave energy cost advantages in home heating and steam powered manufacturing.[20] Another view is that economic specialties in the past had persistent effects on industrialization in the 1700s.[21] We advance this literature since most studies focus on county-level outcomes.[22] Also, we provide new estimates on the effect of reduced trade costs and increased market access, including their positive interaction with towns on coalfields.

The following section gives background on urban growth and how technological and infrastructural changes combined to fundamentally alter transport from the late-1600s to the mid-1800s. A more detailed discussion of inland waterways gives background for the instrumental variable. New trade cost estimates are given in section III, followed by estimates for the effect of market access changes on urban population growth detailed in sections IV and V. A counterfactual summarizes the overall effect of reduced trade costs in section VI.

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.

[17] Dittmar (2011), Bosker et al. (2013), Cantoni and Yuchtman (2014), Dittmar and Meisenzahl (2020).
[18] See Duranton and Turner (2012), Fabor (2014), Allen and Arkolakis (2022).
[19] See Shaw-Taylor and Wrigley (2014), Trew (2020), Heblich, Trew, and Zylberberg.(2021).
[20] See Wrigley (2010), Crafts and Wolf (2014), Stuetzer et al (2016), Warde (2018), Hanlon (2020), Fernihough and Hjortshøj O'Rourke (2021).
[21] See Heblich and Trew (2019), Kelly et al. (2020), Mokyr et al. (2021).
[22] The urban historical datasets presented here will be made available through this paper.

Migration and natural increase were both drivers of urban population growth in E&W.[23] We emphasize migration here as it is more closely related to market access. Urban areas attracted migrants by providing more employment in manufacturing, including textiles, food, household goods, and metal working (Shaw-Taylor and Wrigley 2014). The new factories were normally set up in or near towns, which brought increased employment opportunities (Berg 2005). In rural areas, mortality rates were lower, which created a surplus of labor. 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, 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.[24] 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. In the literature, there are several explanations for varying urban growth in this period.[25] 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 more 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 initial level of commercial activity is also thought to have been an

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

impetus to future growth, often through a financing channel. Urban institutional structures are also emphasized as they are linked with the absence of guilds or corporate governance.

Well-developed transport connections, allowing for extensive trade, are another factor highlighted in explaining urban growth. The literature emphasizes the potential for shipping two necessities: food and fuel for home heating (e.g., 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 inland waterways. This meant that many large urban areas were near the coast, where coal could be cheaply imported, or along inland waterways linking to the coast or an inland coalfield.

Grain was the second most important traded good in terms of weight and first when measured in value. Towns 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.[26] Having dense transport connections to nearby markets was most helpful for supplying food.

I.A Improvement of inland waterways

The development of inland waterways was a major factor in improving pre-steam transport. Nearly all waterway projects were approved in Parliament through special acts. Landowners and traders, along with county and city officials, were the main promoters, while engineers helped propose the routes. If the project was approved, 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.

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

River navigation projects, making short cuts and clearing obstructions, were the first phase of infrastructure development between 1660 and 1740.[27] A technological impetus came the pound lock, originally a Chinese invention. It was a chamber with gates at both ends that allowed boats to travel by water to higher elevations. Pound locks were installed on some E&W rivers, extending navigation inland and thereby increasing accessibility to the coast. Yet since locks were expensive, rivers with greater elevation changes were not improved. This meant many inland towns were not reached, and no navigation projects connected distant river basins.

Canals were the next phase of inland waterways, mainly from 1760 to 1830. Canals were like a straightened river with artificial cuts, and made more use of locks, tunnels, and reservoirs.[28] 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. Also at this early stage, Brindley promoted the Grand Cross Plan. 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 Online Appendix III for an illustration). The Cross Plan received support from the mining and manufacturing community, like the Bridgewater. Various links were approved by acts in the 1760s and 70s and several opened in the decades after.

The routes of Cross Plan canals will play an important role in our analysis. The Trent and Mersey Canal was the first major link. One endpoint was Runcorn, where barges could reach Liverpool and Manchester through the Bridgewater canal. The other was the navigation head of the river Trent. Next the Wolverhampton Canal was meant to link the Trent and Mersey with the river Severn. The endpoints, Stourport and Haywood, were both previously small settlements. The canal got its name because it passed through Wolverhampton, then a medium-sized industrial town. The Coventry and Oxford Canals provided a single Cross link from the Trent and Mersey to the river Thames and ultimately London. Their southernly route had few elevation

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

changes and terminated at Oxford, a prosperous university and market town. The Leeds and Liverpool Canal is worth noting as an expansion of the original Cross Plan. It would link the Mersey and Humber basins via the river Aire in West Yorkshire. Leeds and Liverpool served as endpoints because they were emerging industrial and trading towns. Most towns in between were selected for being on a favorable route through this rugged region. Finally, Birmingham gives an example of an emerging town not on the ideal route linking major basins. An early 1769 plan shows the 'Birmingham canal' as a branch of the Wolverhampton canal, with no through services.[29]

Canal promotion and building continued through the 1820s. Some of the later canals addressed limitations in the early Cross Plan. For example, the Grand Junction canal provided a more direct link between the Thames and Mersey basins, bypassing Oxford.[30] With time, canals were 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 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 other modes.

I.B Improvement of roads, ports, and shipping

Although it was the most expensive, road transport did improve during the 1700s with more powerful draft animals and logistical innovations among carriers. Road improvements from turnpike trusts were another factor.[31] 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

[29] See 'A plan of canals authorized to be made in England' available through the British Library King's Topographical Collection. https://www.flickr.com/photos/britishlibrary/50264082542/in/photostream/, assessed Aug. 22, 2022

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

[31] For the literature on turnpikes and their effects, see Gerhold (1996), Bogart (2005) and Rosevear et. al. (2022).

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. Trusts in these areas recruited better engineers, like McAdam who used advanced techniques. Also, it seems 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 key role. In the early sailing era, voyages had long and unpredictable travel times, which meant higher costs. Gradually, there were innovations, like copper sheathing and improved rigging, which increased speed and reliability.[32] 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.[33] For our purposes, the key point is that they lit up most of the E&W coastline by 1830, improving shipping.

For the rest of this paper, we focus on how trade costs dramatically fell due to the fundamental changes in transport from the late 1600s to the early 1800s. Trade costs capture the wedge between prices paid by consumers and prices received by firms. In theory they should affect urban population growth through market access as explained in section IV.

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[32] 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).

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

II. Data

II.A Urban historical data

We analyze a sample of cities and towns from a new and unique historical urban dataset for E&W.[34] The main features of the dataset are the following: (1) Population estimates for over 1000 urban settlements around 1680 linked with their census populations in 1801 and 1841. (2) Population estimates for a subset of settlements going back to 1560. (3) Economic, political, and infrastructure characteristics of 781 settlements around 1673. (4) Settlement locations based on historical structures and public spaces. (5) Settlement natural resources, geographic, and climate data. To give more details, settlement populations are derived from Langton (2000), Clark and Hosking (2005), and Wrigley (1985). These figures are estimates before 1801 and require assumptions about the sources. Nevertheless the 1680 estimates are very accurate in comparing town populations across counties (see Alvarez, Bogart, Satchell, Shaw-Taylor 2022a). Settlement location comes from Satchell, Potter, Shaw-Taylor, and Bogart (2017).

Economic, political, and infrastructure characteristics are derived from Bogart (2019)'s digitization of Richard Blome's *Britannia*, originally published in 1673 (see also Blome 1962). We use 16 of these 'historic' variables as detailed in Online Appendix I. Some of the most important are specialties in mining and cloth manufacturing. Resource, geographic, and climate variables are made from linking settlements to a rich database of 9700 spatial units in E&W, comprised of parishes and townships.[35] The resulting 'geographic' variables are: (i) an indicator for being on an exposed coalfield, (ii) average elevation, (iii), the standard deviation of elevation, (iv) average rainfall, (v) average temperature, and (vi) distance to nearest port in 1565.[36]

We have two population criteria for a settlement to be included in our sample. The first requires it to reach a population of at least 2500 in 1680, 1801, or 1841, reducing the sample size to 590. Many settlements in the dataset are small and a population of 2500 is often the lowest

[34] The dataset is described in Alvarez, Bogart, Satchell, Shaw-Taylor (2022a). see https://www.socsci.uci.edu/~dbogart/historicurbandatasetnov162022.pdf, last assessed Nov 28, 2022.

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

[36] 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.

standard for urban in historical studies (e.g., DeVries 2013).[37] The second restriction further requires settlements to have a recorded population in 1680, 1801, and 1841. It avoids the complication of modelling missing 1680 populations as zero. The second requirement reduces the sample size to 461. We also drop 13 small settlements which are linked to the same spatial unit as a larger settlement. The result is a baseline sample of 448 settlements with population in 1680, 1801, and 1841, of which 155 also have population in 1560. Going forward observations are referred to as towns generally and cities in specific cases.

There are some features to note about our baseline '1680-1801-1841 sample.' By design it is positively selected on 1680 population size and growth compared to the full list of over 1000 urban settlements in the dataset. We choose not to study those close to being rural throughout. Nevertheless, robustness tests later will reweight the sample to check the implications. Fortunately, the sub-sample with 1560 populations has a similar distribution of 1680 population and growth as the baseline sample (see Online Appendix I). Less fortunately, we can only link 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.

Figure 1 shows E&W town populations in 1680 and 1841. 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 have grown significantly. The latter regions have urban clusters in 1841 which are absent in 1680. For reference, Online Appendix I reports the list of the top 20 towns by population in 1680 and 1841.

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

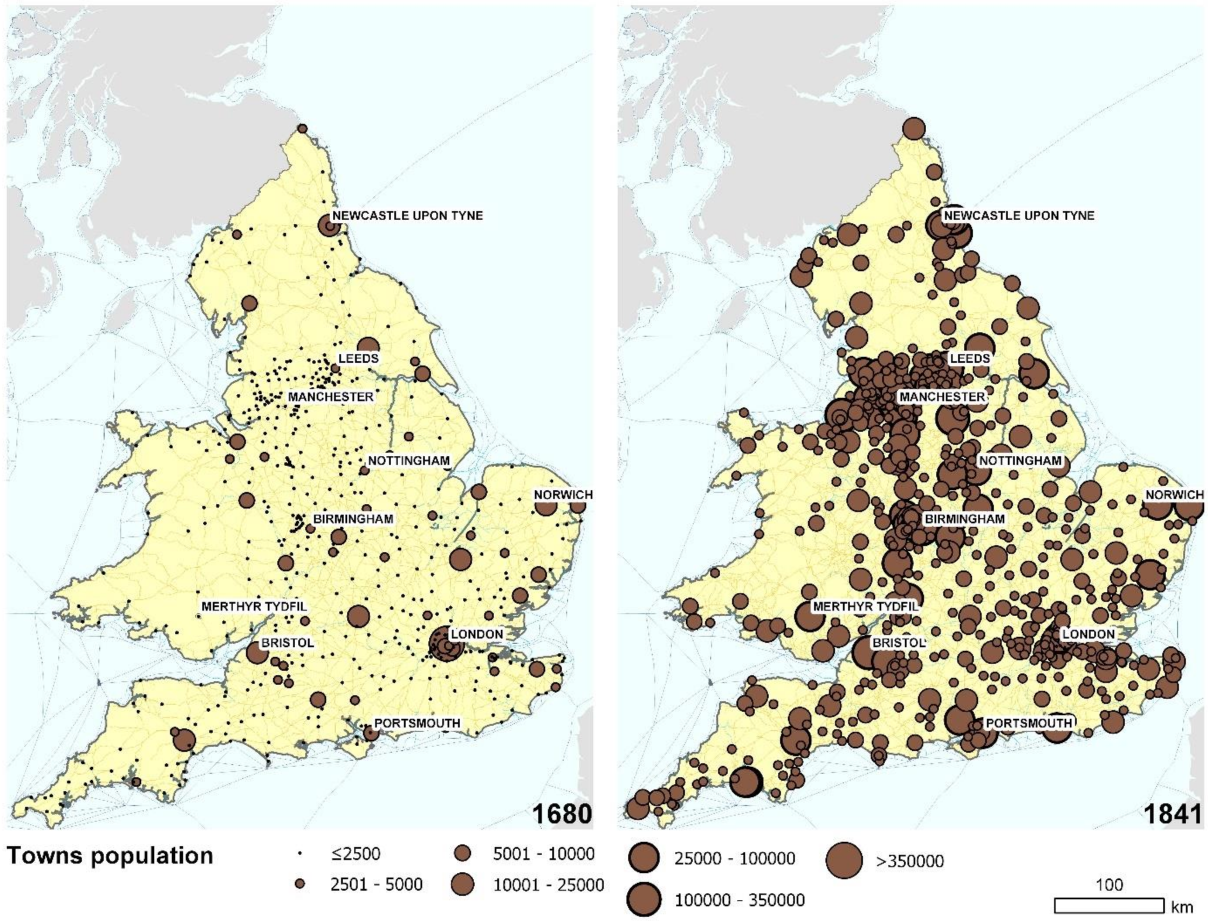

Figure 1: English and Welsh city and town populations in 1680 and 1841

Sources: Sample drawn from the Urban historical dataset made by Alvarez, Bogart, Satchell, and Shaw-Taylor (2022a).

II.B Inter-urban freight costs

We use Alvarez, Bogart, Satchell, and Shaw-Taylor (2022b)'s dataset on freight transport costs in pence per ton between 590 E&W towns in 1680 and 1830.[38] They are calculated from a freight transport model combining several modes to identify the least cost route between points. The points represent towns, which are a subset taken from the full urban historical data described in section II.A. Polylines represent specific transport modes like roads, waterways, and coastal routes and together they form a network. To ensure connectivity, interpolated straight lines between point layers and networks are created too. A 'global turns policy' is used, which

[38] See www.socsci.uci.edu/~dbogart/Multimodalmodel16801830nov162022.pdf, last assessed Nov 28, 2022.

means movements within and between each network are allowed. Dijkstra's algorithm finds the least cost route, minimizing a cost accessibility function between all towns i and j.

Historic transport networks are key data inputs for the multi-modal model.[39] They are derived from detailed historical sources. The definition of a port is broad and includes 479 recorded loading/unloading places in a variety of sources.[40] Coastal routes between ports were digitized according to the navigation charts of the era and physical geography. In 1680, inland navigation consists of the network of navigable rivers. In 1830, it also includes canals and river navigations made since 1680, all of which are traced in detail using historical maps and published sources.[41] The 1830 inland navigation data also includes locks, which allowed boats to travel by water to higher elevations for a fee often included in the toll. The road network in 1680 includes principal roads identified in John Ogilby's Atlas of 1675. It also includes important secondary roads identified from a military survey of 1686.[42] Information on terrain slope and vehicle accessibility, either packhorse or wagon, are also added. The principle and important secondary roads in 1830 are represented by a digitization of the turnpike trust road network.[43] Along with slope, road quality is incorporated based on a parliamentary survey of 1838.[44] Bridges and ferries are added as singular segments of roads digitized from the same sources.

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 by 1830 were often near the canals. Ports were common in both periods and therefore the regional differences in ports are not a major emphasis here.

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[39] They come from a wider project creating GIS maps of historic ports, coastal routes, inland waterways, and roads in E&W. See 'Transport, urbanization and economic development in England and Wales c.1670-1911' https://www.campop.geog.cam.ac.uk/research/projects/transport/.

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

[41] For a digitization of waterways open in 1680 and 1830, see Satchell, Shaw-Taylor, and Wrigley (2017a,b).

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

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

[44] 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).

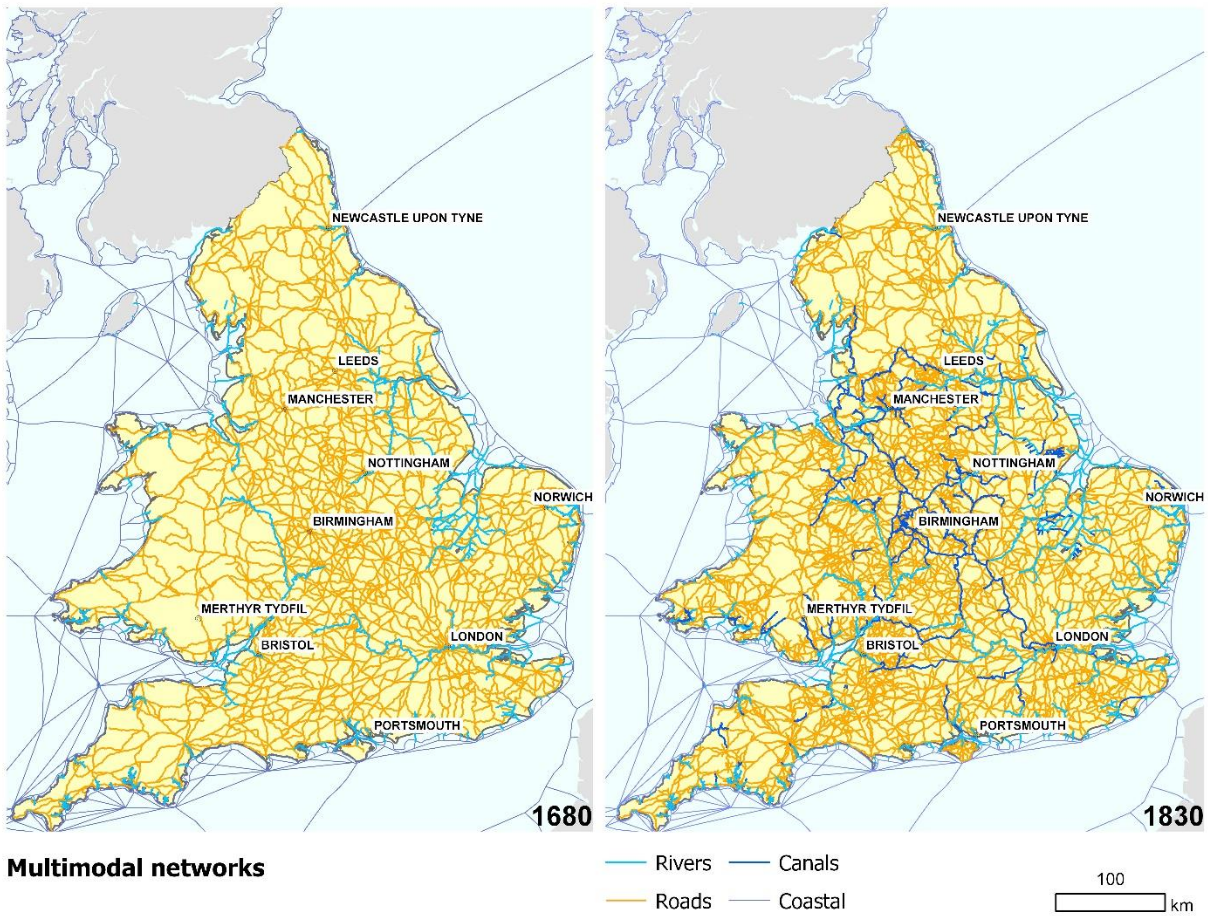

Figure 2. Transport networks in 1680 and 1830.

Source: Alvarez, Bogart, Satchell, and Shaw-Taylor (2022b).

Each transport mode in the model has been assigned a unique ton per mile cost and some have fixed fees along the route or varying costs due to terrain and quality. The modal costs are summarized in table 1. There are several features worth noting. First, inland waterway per ton mile costs were 4.7 times more than sea transport per ton mile costs in 1680. Inland waterways become relatively more expensive by 1830, mainly because canals charged tolls above any lock fee. Second, seaport fees declined reflecting improvement to ports. Nevertheless, they were non-trivial. In 1830, seaport fees 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, assuming zero slope, differences in quality can change road transport costs by approximately 30% in 1830. Fifth, road transport costs with the best quality and no slope were between 44 and 47 times more expensive than sea transport costs. It was always more economical to ship by sea.

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

	1680 cost	1830 cost
Sea transport, pence per ton mile	0.211	0.168
Sea port fee in pence per ton	27.1	22.9
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 Alvarez, Bogart, Satchell, and Shaw-Taylor (2022b).

It is worth emphasizing that historical inter-urban freight costs are generally unobserved and so the calculated freight costs represent new data based on detailed network, geographic, and logistic data. Even so, there are limitations. The assigned modal freight costs per mile are general and could vary locally for reasons we do not capture. The quality of the infrastructures embedded in the networks might be greater or less than is accounted for. Geography could have further effects than just slope. The reliability of the transport cost data will be examined more in section III, which introduces our trade cost estimates.

II.C Price and auxiliary 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 the urban settlement 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 urban settlement list 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.[45]

Ideally, we would also use data on traffic or flows in the pre-steam age. However, this is generally not available. One exception concerns the ports, where numbers of ships and their tonnage are available in various years. For one of our later access variables, we link the tonnage of ships involved in foreign trade that went inwards and outwards from each customs port in 1791.[46] Online Appendix II provides a map of ports and their involvement in foreign trade.

As a final data input, we use 'A plan of navigable canals made and now making,' created by Hugh Henshall in 1779.[47] The original Plan map is shown in Online Appendix III and has not been studied to our knowledge. It closely corresponds to an earlier Plan map in 1769 except for a few canals.[48] 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 many were being made or proposed in 1779.

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 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 instrumental variable approach.

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[45] See Online Appendix VI for more details.

[46] These are contained in CUST-17-13 through the National Archive. See Online Appendix II for details.

[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] This one 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. See https://www.flickr.com/photos/britishlibrary/50264082542/in/photostream/, last assessed Aug. 22, 2022.

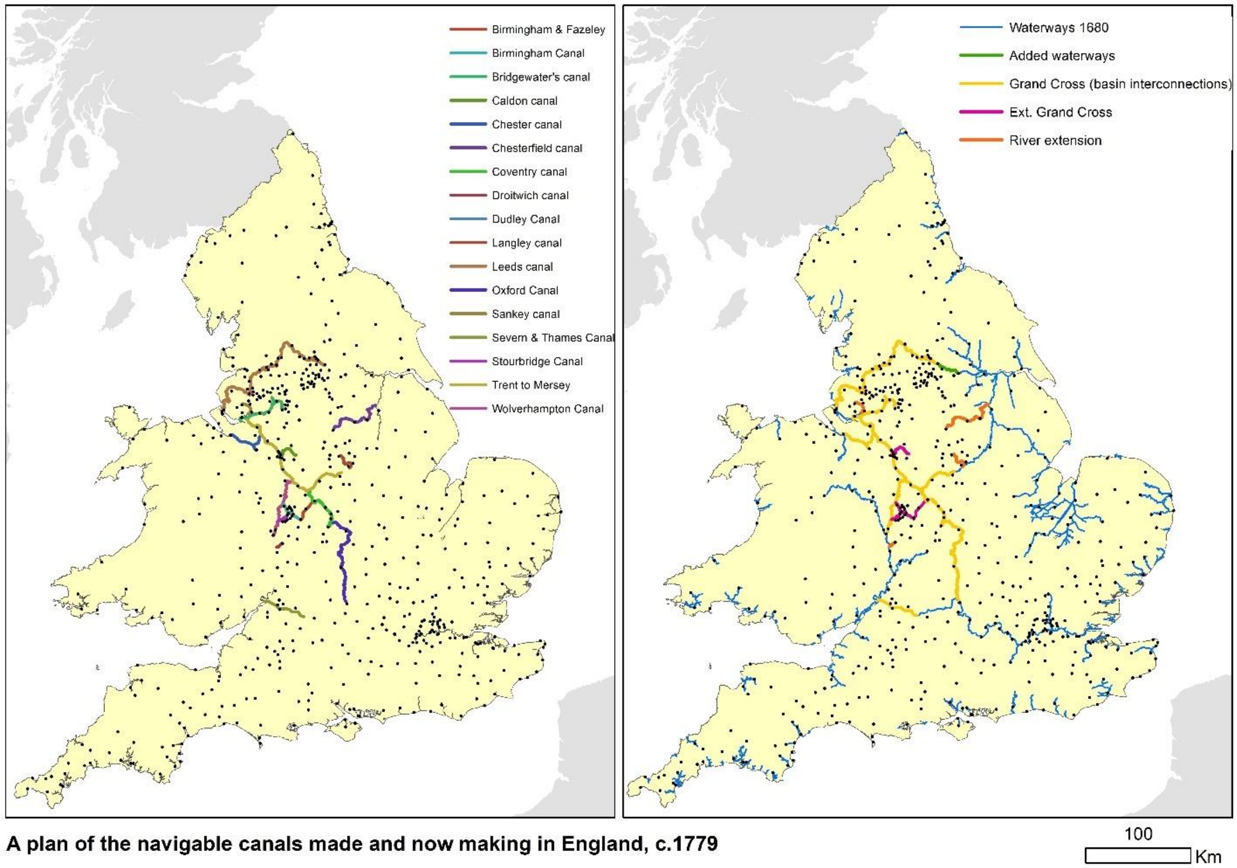

Figure 3: Towns and representation of canals in Henshall's plan 1779 (left), with classification and waterway connections (right)

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.

III. New trade cost estimates in 1680 and 1830

In the 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 freight transport cost in pence per ton and $CoalPrice$ is the average pit head price of coal. 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. 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. An extension recalculates trade costs τ_{ij} using coal and grain as the 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. Online Appendix IV explains the prices of these baskets.

To illustrate the estimates, for each town in our sample we calculate its average trade costs to all other towns $\overline{\tau_i}$. These are shown in figure 4 for both years. 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. The average across all town pairs 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 differences in average trade costs across towns declined dramatically. They were still lower near the coast, but not so much lower as before. The 1830 average across all town pairs 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. We find a similar change in trade costs using coal and grain as the traded good. They averaged 7.6 across all town pairs in 1680 and 2.8 in 1830, representing a 63% decrease.

Our estimates imply a large reduction in trade costs during the pre-steam era. How plausible are they? We use data on coal prices, where available, to support the accuracy of these estimates. One testable implication is that markets for coal should have become more integrated. Due to data limitations, we can only provide partial evidence. First, in the early 1800s coal prices in London, the largest consuming market, declined by 50% relative to Newcastle upon Tyne, the largest supplying market. Second, there is evidence that coal price variation across 35 markets was less in 1842 than in 1700 (see Online Appendix V for details).

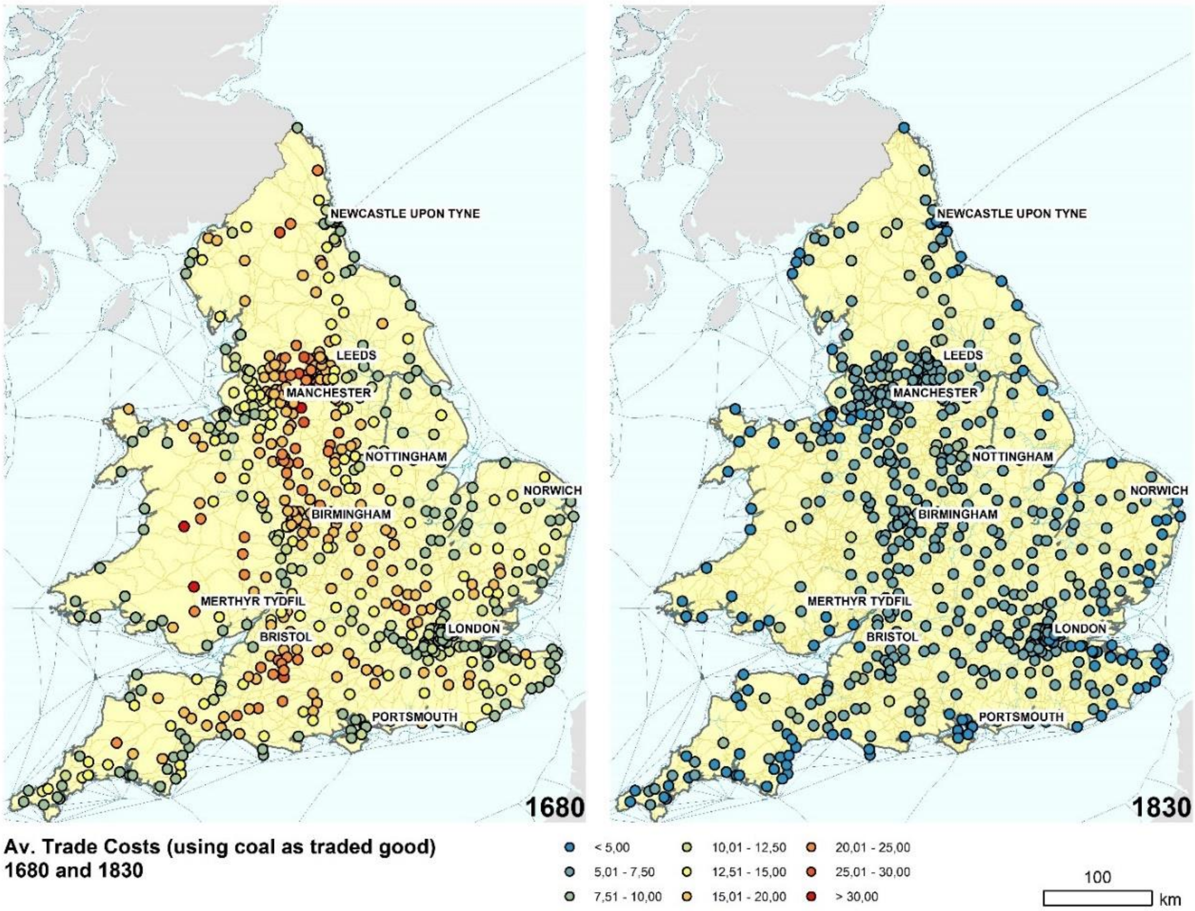

Figure 4: Average trade costs for each town to all other towns in the sample
Source: Author's creation. See text for details

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 Online Appendix V, 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.

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 Online Appendix V). 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 estimate effects of market access

To estimate how trade costs affected town population in our context we build on well used general equilibrium trade models.[49] In these models, households choose their location based on wages, goods prices, and rents. Goods prices are generally lower in locations where consumers have greater access to low-cost firms producing in other markets. This will attract households supplying labor. Firms will want to produce in locations where wages are lower and where they can sell to more consumers and/or face less competition. The degree of consumer and firm market access will depend on the structure of trade costs between all locations. We use Donaldson and Hornbeck's (2016) model to formulate market access. 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 fits our setting because production in the 1700s was mostly based on agricultural or raw material processing and economies of scale were limited.[50]

Donaldson and Hornbeck (2016) derive a tractable expression for locational population as a function of market access and other variables.[51] Letting towns be locations in their framework, town $i's$ market access is given by equation (1):

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

[49] Some foundational models are provided by Eaton and Kortum (2002) and Redding and Venables (2004).
[50] 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.
[51] 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.

where κ is a constant, 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.[52] 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.[53] 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 figure 5. In 1680 market access was highest near London and along the east coast. By 1830 market access had changed dramatically, growing most inland and in the northwest. Comparing with figure 4, one can see that market access increased substantially in the north and west, which is where trade costs decreased the most between 1680 and 1830.

Our main estimating equation is given by (2):

$$\Delta_{1841,1680} \ln pop_i = \beta \Delta_{1830,1680} lnMA_i + \gamma \cdot x_i + \varepsilon_i \qquad (2)$$

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 is a vector including nine region fixed effects, a 2nd order polynomial in town latitude and longitude, geographic controls, and Blome historic controls from 1673, before population change in the dependent variable. As our data includes two time periods, equation (2) is equivalent to a two-period panel with town fixed effects.[54]

[52] 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.
[53] There is no analytical solution (2) so we use Matlab to solve for market access, setting $\kappa = 1$.
[54] Notice our spec. is like a changes-on-changes strategy for analyzing city growth (see Duranton and Puga 2014).

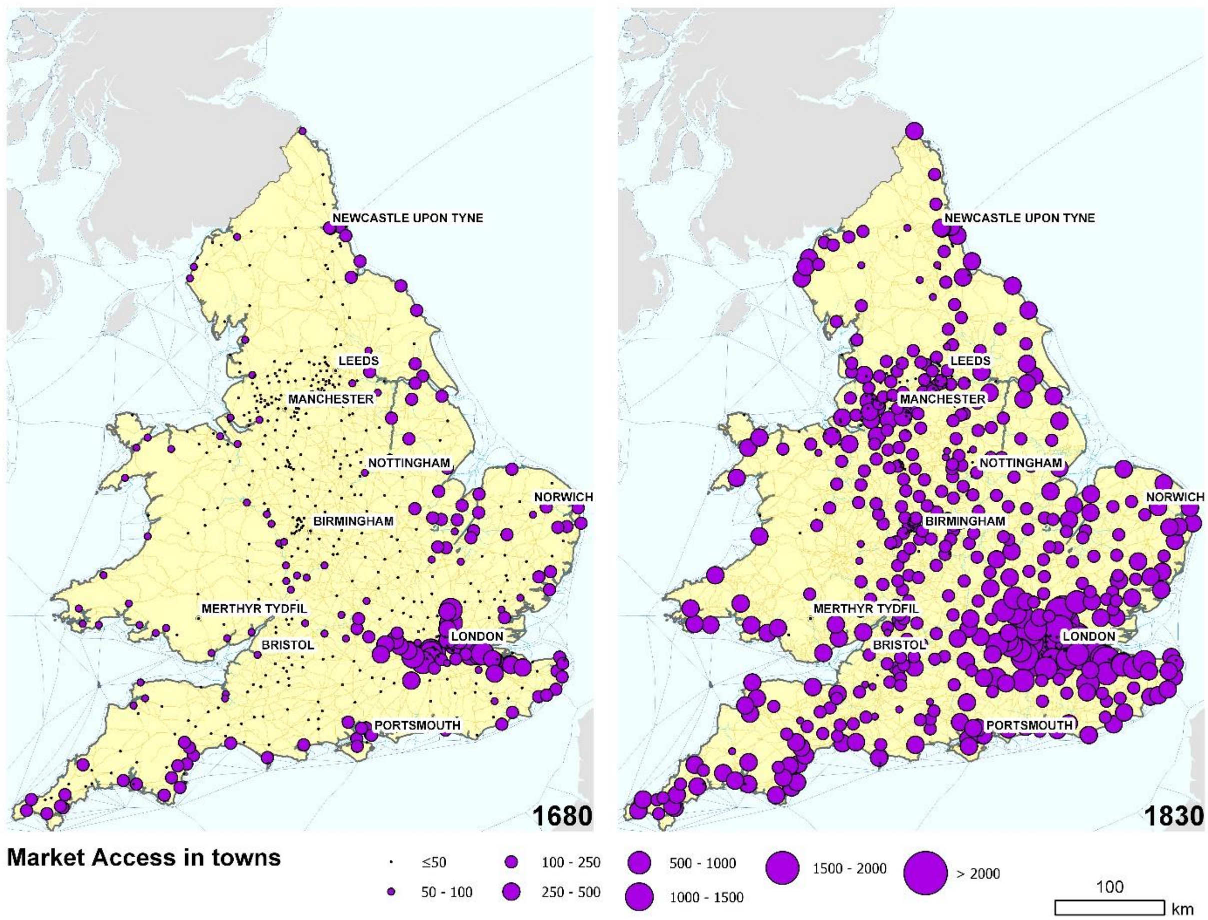

Figure 5: Estimated market access for towns in 1680 and 1830.

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

We think it is plausible 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 instrumental variables IVs. Our preferred 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.[55] More precisely, the IV is $\Delta \ln\,[\sum_j^J D_{ij}^{far} D_j^{plan,inc} pop_j \tau_{ij}{}^{-2}]$, 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

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

distance, $D_j^{plan,inc}$ is an indicator 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. Most weekly trade for towns about the size of the incidentally connected was with rural areas and other towns within 50 km.[56] 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.[57]

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 Online Appendix VI). 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.[58] 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

[56] 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.
[57] The key to the 1779 canal plan map lists 19 canal projects and their length. The average length was 52 km.
[58] 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.

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 the natural 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 $MA_i = \sum_j^J D_{ij}^{far} pop_j {\tau_{ij}}^{-2}$. It is meant to eliminate 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.[59]

Summary statistics for the main variables are shown in table 2. Online Appendix VII 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 similar 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.

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

Notice further that omitting towns within 50 km reduces market access growth marginally. Also, fixing 1680 population and isolating trade cost changes implies less market access growth.

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 (1) as the definition of MA_i, where coal is assumed to be the traded good when calculating τ_{ij}. Note that in the tables 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.[60] 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. These were described in section II.A (for coefficients see Online Appendix VIII). 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.

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.[61] In col. 5, the dependent variable is ln1680pop -

[60] 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.
[61] 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 sub-sample of towns with 1560 population. Under our identifying assumption, $\Delta lnMA_i$ should not affect population growth a century earlier. The OLS results confirm no precisely estimated effect.[62] 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 estimates. For the remainder of the paper, we analyze market access using coal as the only traded good.

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	0.179	0.234	0.069	-0.064	0.259
	(0.049)*	(0.056)***	(0.063)***	(0.027)**	(0.127)	(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.

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 Online Appendix VIII 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.

[62] The same results hold if we omit Blome historic controls dated in 1673.

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

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. Therefore, we think it is likely that the OLS estimate of 0.234 is a lower bound. It implies that a 10% increase in market access would increase town population by 2.63%.[63] 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

[63] 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.

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 more 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 $\Delta lnMA_i$.

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.

In Online Appendix VIII, 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.[64] Also, specifications are reported that weight observations to match the distribution of population growth in the full Langton dataset with 925 towns. Other reported

[64] Maximum likelihood estimates over different parameter values also suggest $\theta = 2$ provides the best model fit.

specifications add a variable for average distance to all towns in our sample. The coefficient on $\Delta lnMA_i$ is a bit smaller in both extensions, but still positive and precisely estimated.

V.A Heterogenous effects of Market access on the coalfields

Figure 6 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 several OLS estimates using our preferred specification. The coefficient 0.421 implies that being on a coalfield increased annual 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.

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 90^{th} 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.

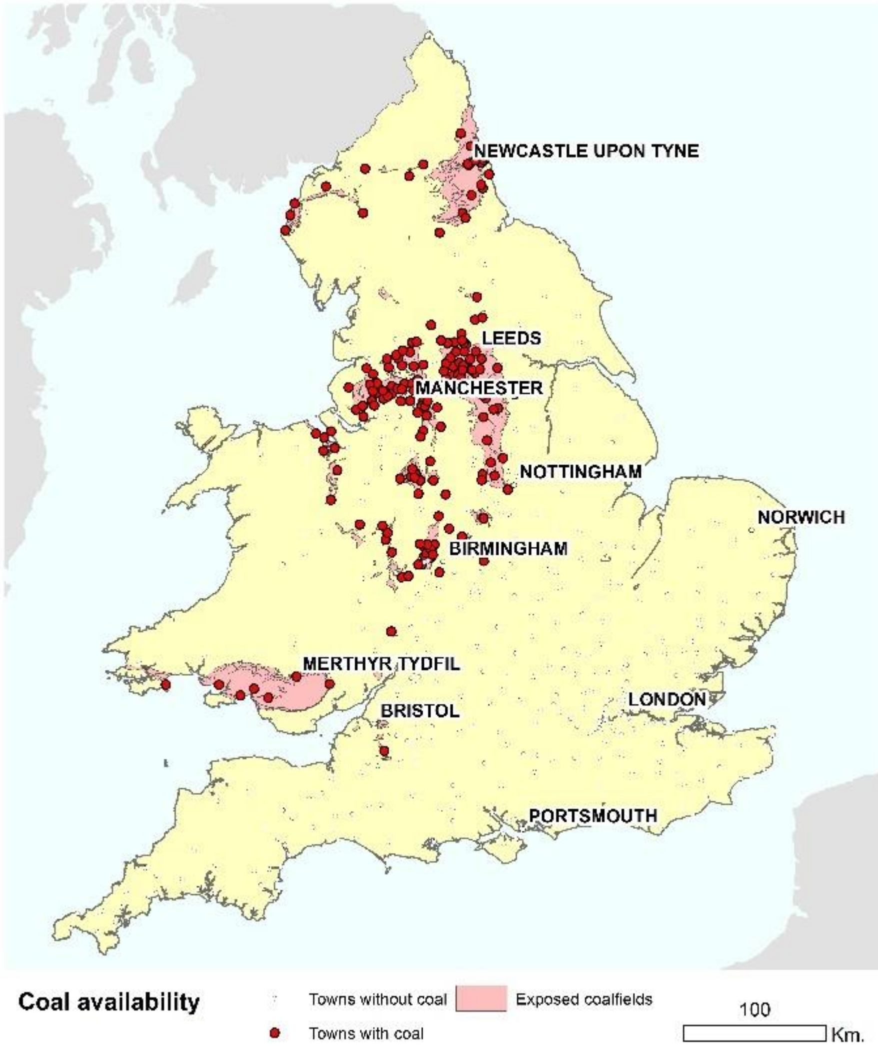

Figure 6: Sample Towns on the exposed coalfield along with major towns
Source: Author's creation based on exposed coal data from Satchell and Shaw-Taylor (2013).

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.[65]

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)***
Coalfield dummy	0.421	-0.144	0.308
	(0.127)***	(0.283)	(0.133)***
$\Delta lnMA_i$*Coalfield		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.

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 use the fact that our estimating equation (2) is equivalent to the two-period panel specification in (3):

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

[65] 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.

where α_i is a town fixed effect and δ_t is the time fixed effect equal to 1 in 1841 and zero in 1680. Assuming $t = 1841$, we rewrite (3) as $lnpop_{i1841} = \beta lnMA_{i1841} + e_{i1841}$, where $e_{i1841} = \alpha_i + \delta_{1841} + \delta_{1841}(\gamma \cdot x_i) + \varepsilon_{i1841}$ and captures residual factors explaining 1841 log town population in i. This says that counter-factual 1841 log town population is given by $lnpop^C_{i1841} = \beta lnMA^C_i + e_{i1841}$, where counterfactual market access is $MA^C_i = \kappa \sum_j^J \tau_{ij}{}^{-\theta} pop^C_{i1841} MA_j^{C^{-(1+\theta)/\theta}}$ with τ_{ij} fixed at 1680 trade costs. We use $\theta = 2$ and $\beta = 0.214$, which is conservative following our earlier estimates. The constant κ continues to be normalized to 1. One caveat is that κ is a function of worker utility in the Donaldson and Hornbeck (2016) model, which means there is an implicit assumption of constant worker utility. This assumption could be justified if urban workers were elastically supplied by rural areas, which beyond E&W could include Scotland, Ireland, Europe, and the new world. In this larger economy, utility appeared more fixed and plausibly independent of E&W trade costs. Finally, we think it is reasonable to assume that $e_{i1841} = \ln\ pop_{i1841} - 0.214 \ln MA_{i1841}$, that is actual log 1841 population minus the estimated effect of actual market access. The difference captures the effects of all our control variables, 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 $pop^C_{i1841} = MA_i^{C^{\beta}} \exp(e_{i1841})$ into the equation for counterfactual market access. The substitution yields a system of n non-linear equations, $MA^C_i = \sum_{j \neq i}^J \tau_{ij}{}^{-\theta} MA_i^{C^{\beta}} \exp(e_{i1841})\, MA_j^{C^{-(\theta+1)/\theta}}$, in n unknown variables MA^C_i. We solve this system for MA^C_i. In the second step, $pop^C_{i1841}$is obtained through substitution into $MA_i^{C^{\beta}} \exp(e_{i1841})$.

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 (1), but we modify expressions for pop_{i1841}^{C} and e_{i1841} based on estimates in col. 2 of table 6.[66] 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 not 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 Online Appendix IX). 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

This paper offers new insights on the effects of market access on urban growth by studying one of the most advanced economies in the pre-steam age. We use several new datasets to make new estimates of trade costs between over 500 English and Welsh towns in 1680 and 1830. They show a dramatic decline over time, which is indicative of the significant technological and infrastructure changes in transport over this period. We then estimate how lower trade costs affected town population growth through market access after controlling for a variety of town characteristics. We find large, positive effects of greater market access. An IV for changes in access to towns incidentally connected to planned canals yields similar estimates as our preferred OLS. Building on these results, we interpret our estimates as causal. Using them in a counter-

[66] Precisely, $e_{i1841} = \ln\ pop_{i1841} - 0.192 \ln MA_{i1841} - 0.316 \ln MA_{i1841} * exposedcoal$ and $pop^C_{i1841} = \exp(0.192 lnMA^C_i + 0.316 lnMA^C_i * exposedcoal + e_{i1841})$.

factual calculation, implies the total urban population in England and Wales would have been 12.2% lower if trade costs remained unchanged between 1680 and 1830. To compare with the effects of 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. Lower trade costs 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.

Our findings accord with previous scholars, who have noted the importance of transport improvements for the big events of world history, like 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)."

In this paper, we confirm the importance of canals, but go much further in estimating how trade costs changed due to all transport innovations and how they affected market access. We also illustrate the more contingent nature of expanding market access in the pre-steam age. It depended on a variety of technological and infrastructure developments. Not surprisingly, few economies in the pre-steam age had the conditions to support a large increase in market access.

More generally, our findings highlight a setting where private, nonprofit, and municipal actors take the lead in developing infrastructure with support from the central government. This is unlike other settings, where the latter plays the leading role, as in the development of the US inter-state highway system. We emphasize that locally developed infrastructure has impacts on distant cities and towns through the network, showing that urban growth can be an inter-dependent process. Finally, our findings demonstrate interaction effects between market access and energy. Energy is known to be crucial for production, while also generating negative externalities. We show there is much greater exploitation of energy resources with high market access.

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Online Appendix for Market access and urban growth in the pre-steam age

I. Historical Urban population data and sample properties

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

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

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

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

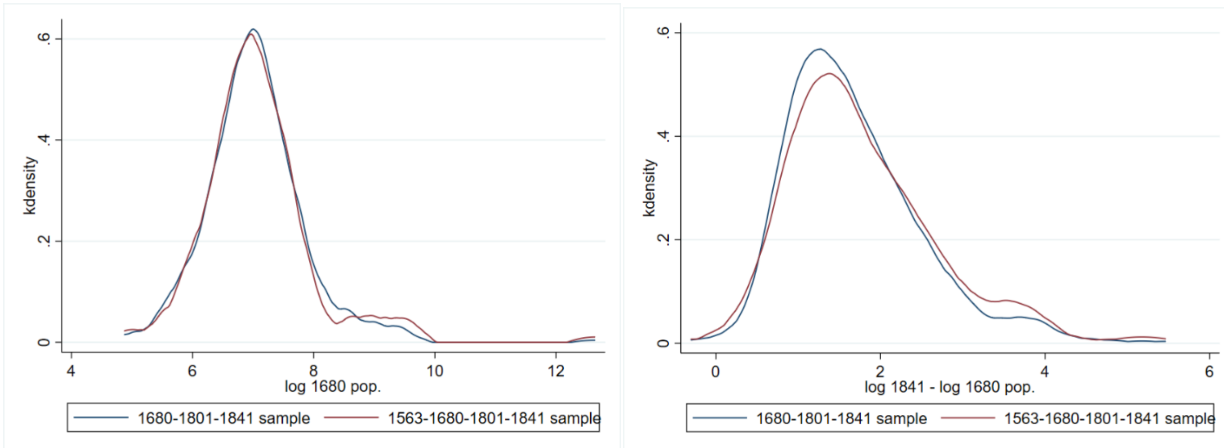
Appendix table A.1.2 shows the population of the largest 20 towns in 1841 and their population estimates at the two dates. London is again at the top. But interestingly the next two, Manchester and Liverpool, are not large towns in 1680. Liverpool is not even in the top 100 in in 1680. Bradford is another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

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

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

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

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



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

Source: author's calculations based Alverez, Bogart, Satchell, and Shaw-Taylor (2022a).

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

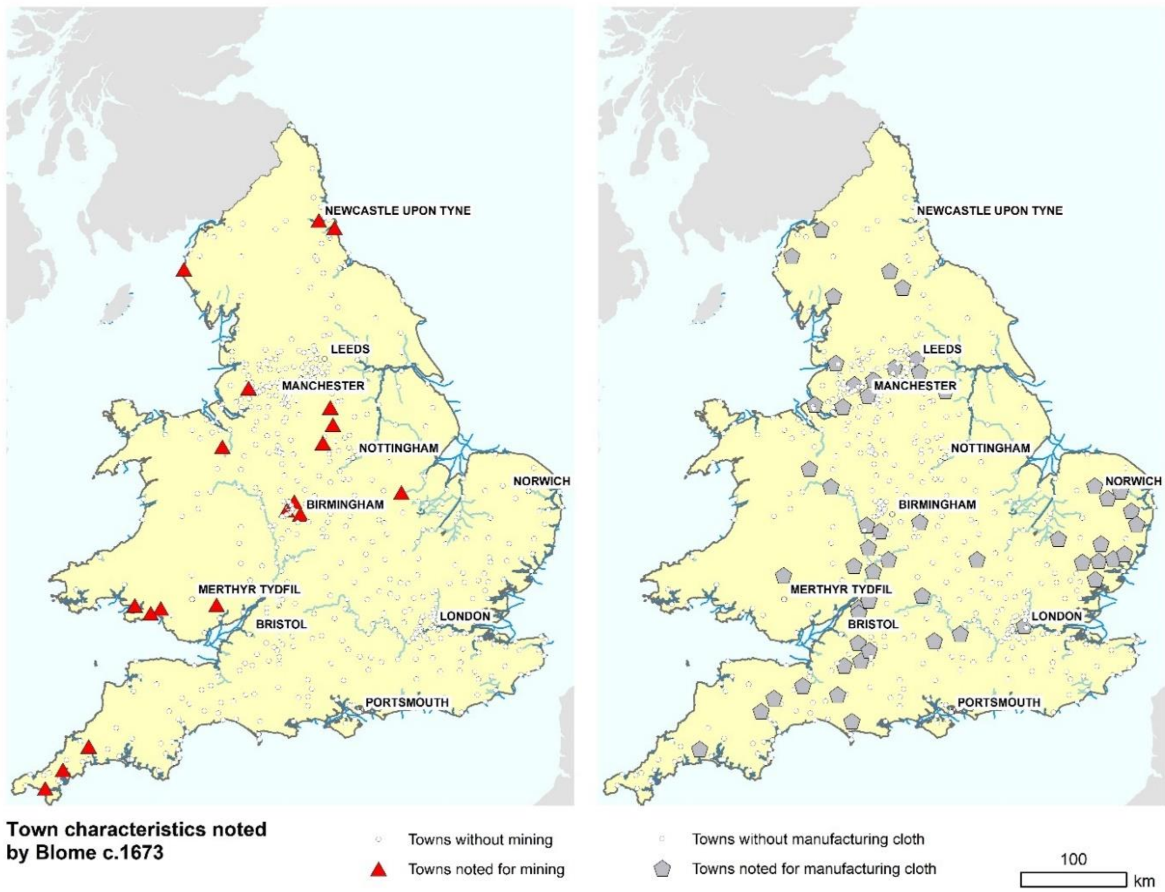


Figure A.1.2: 1680-1801-1841 sample towns noted for mining and cloth manufacturing specialties by Blome's Britannia in 1673

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

II. Ports and foreign trade volumes in 1791

For this paper we add tonnage data associated with head customs ports. 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. Specifically, we measure 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.2.1, along with towns and 1680 roads in our dataset. As tonnage captures weight it mainly captures the coal trade. That is why London's tonnage is like other leading ports.

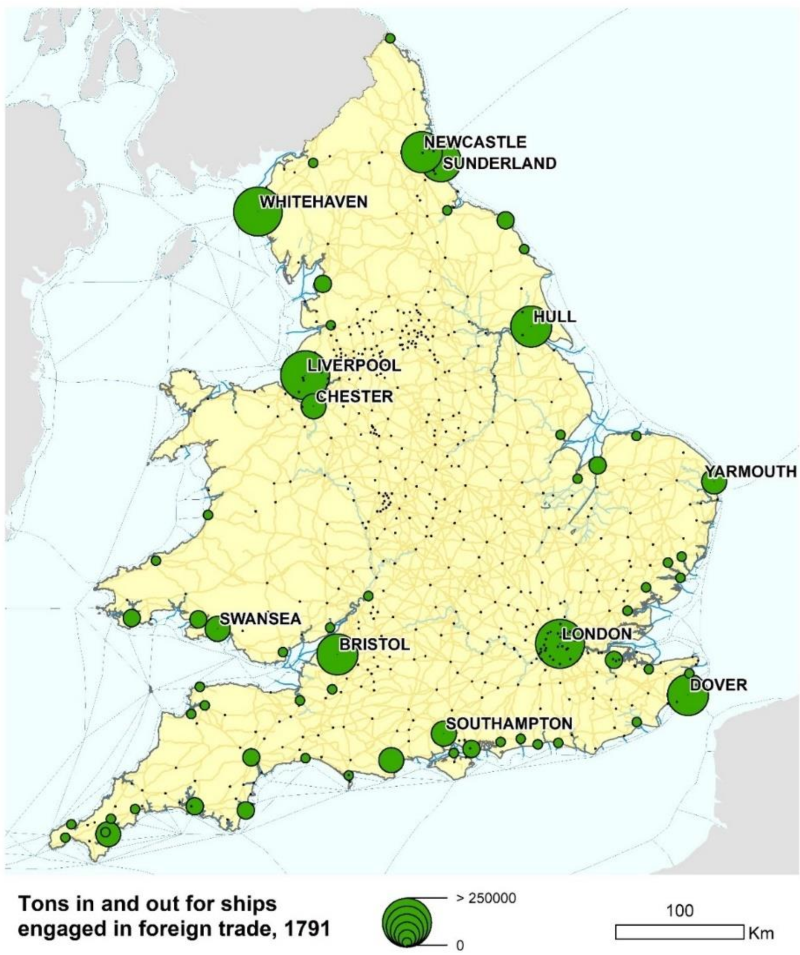


Figure A.2.1: Tons in and out for ships engaged in foreign trade in 1791.

Source: authors creation using CUST 17/13 records at the National Archive.

III. Maps of Grand Cross and planned canals

Figure A.3.1 shows a conceptual illustration of the canals associated with the Grand Cross Plan. The contoured routes reflect hilly terrain in some areas. Notice also that the industrial midlands were connected by the Cross, but its towns were not the main targets. While this was largely the case, there were exceptions as the main text explains.

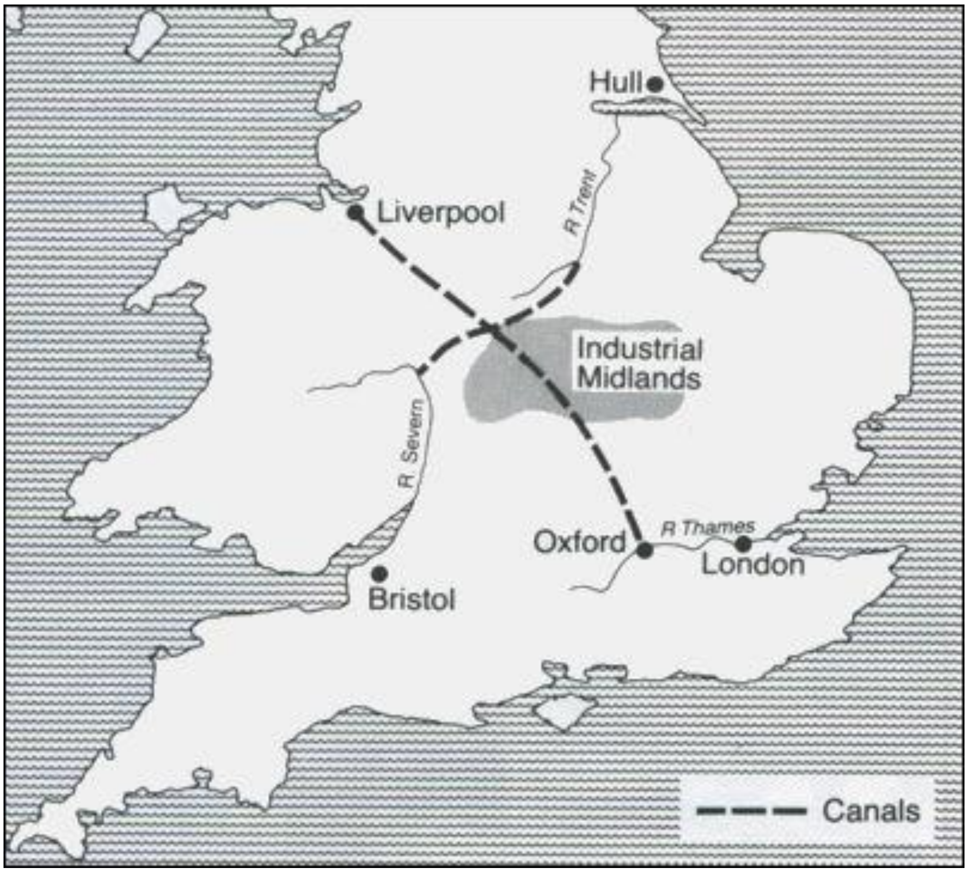


Figure A.3.1: Conceptual illustration of the Grand Cross Plan

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

Figure A.3.2 is a map of planned canals around 1779 by Hugh Henshall and John Cary. We use this map as the basis for our instrument.

Figure A.3.2: A plan of the navigable canals made and now making in England, 1779 by Hugh Henshall and John Cary

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

IV. Producer prices for trade costs

This appendix explains how we determine average producer prices starting with the pithead price of coal. One can find references to the price of coal in Newcastle in the 1600s and early 1700s but on the other coalfields it is scarce. We looked at Houghton's price data in 1701 which was a year of peace (See Rogers 1987). There we find prices for coal in Newcastle and near Carlisle and Penrith in Cumberland (CU). The price of Newcastle coal is very stable at around 46 pence per ton. The price in Cumberland is also stable around 70 pence a ton. We then find coal prices in the same two locations from the PLU data c.1843 which shows that coal prices in Newcastle and in Cumberland were 63.6 and 108 pence a ton respectively.[67] We then take the average price of the two coalfields. For our calculation, the average pithead coal price in 1680 would be 58 pence a ton and the average coal price in 1830 would be 86 pence a ton.

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

We know from the coastal shipping data that the top two commodities shipped coastwise were coal and grain. Within grain we can break grain into wheat, barley, and oats. Armstrong and Bagwell (1983 pp. 154-156) report coastal tonnage in these commodities between 1819 and 1825 (see Table A.4.1). Coastal shipping represents a good share of all transport, so we think it is defensible to use these figures to calculate shares of trade goods (i.e. $\alpha's$). The alpha for coal would be 0.921 and the alphas for wheat, barley, and oats would be 0.032, 0.024, and 0.021 or in total 0.079.

Table A.4.1: Commodities carried coastwise c1830.

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

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

oats	110.6
coal	4761.0

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

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

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

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

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

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

V. The reliability of trade cost estimates

Reliability is examined using spatial data on coal prices. The first exercise it so to give evidence on coal market integration. We compare coal prices across 35 towns with data in both our periods. These are reported in table A.5.1. We calculate the average coal price between 1691 and 1703 in those 35 towns. The coefficient of coal price variation, CV, was 0.37. The CV across the same 35 towns in 1842 was 0.31. The lower CV is one indication of greater market integration, with the caveat that the 35-town sample is not necessarily representative.

Table A.5.1: Coal prices in 35 towns c.1700 and 1842.

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

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

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

Next, we report the ratio of London to Newcastle coal prices from 1805 to 1845. Once can see that the price ratio fell over time (see figure A.5.1) supporting the argument actual trade costs fell.

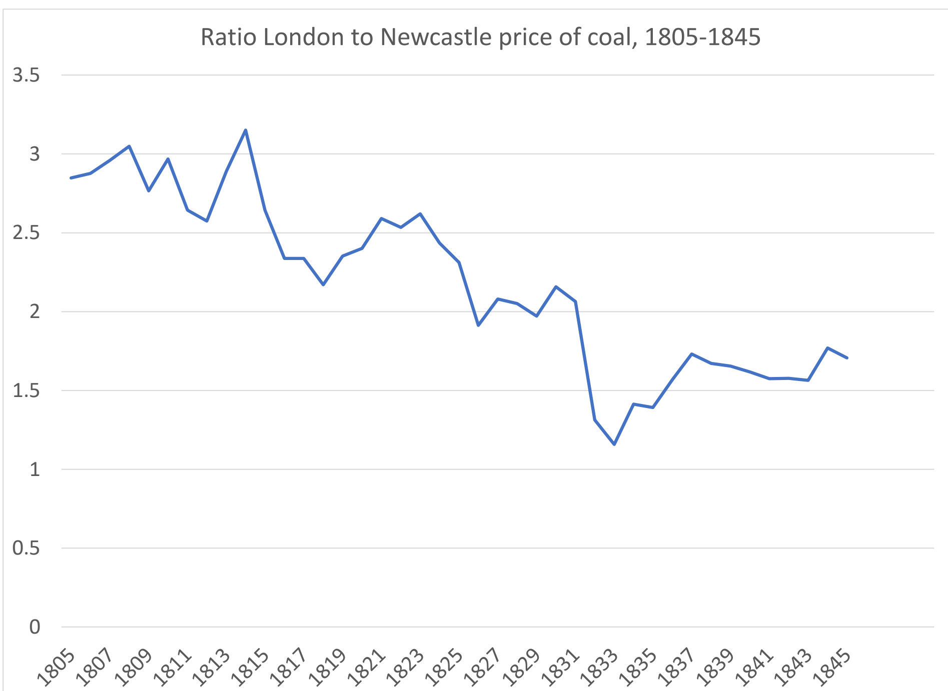


Figure A.5.1 The ratio of London to Newcastle coal prices

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

The next step is to show that our estimated trade costs are similar to observations of actual trade costs. We report the price of coal in coastal towns relative to their coastal supplier and the estimated trade cost between the same two. Due to data limitations, we can only do this comparison for 8 coastal towns in 1680. See table A.5.2. But we can make the comparison for 51 towns n 1830/1842. See table A.5.3.

Table A.5.2: Coal prices in coastal towns and their supplier compared with estimated trade costs in 1680

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

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

Table A.5.3: Coal prices in coastal towns and their supplier 1842 compared with estimated trade costs in 1830

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

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

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

VI. 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.3.2 in 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.6.1 we report differences in geographic controls. Several geographic variables, like log distance to coast, exposed coal, elevation, are statistically different from the other 398 towns in our sample. This is to be expected, since geography and exploitation of coal played a role in identifying the best routes. That said, we have controls for geography in our specification, so we are less concerned about this imbalance. There is no evidence that being an incidentally connected town meant greater selection into Blome's town summaries c.1670. Also, as shown in table A.6.4 there are few differences regarding the 16 Blome variables. This aspect is reassuring in that incidentally connected towns were no more likely to be early manufacturing towns.

Table A.6.1: Geographic covariate imbalance for incidentally connected towns vs. all non-targeted towns

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

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

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

Also, as shown in table A.6.2 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.6.2: Blome covariate imbalance for incidentally connected towns vs. all non-targeted towns

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

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

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

VII. 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.7.1 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.7.2: 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.7.3: 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

VIII. Additional estimates on effect of changes in market access

Table A.8.1 provides coefficient estimates for all variables in table 3.

Table A.8.1 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.8.2 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.8.2: 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.	Coeff.	Coeff.	Coeff.

	(st. err.)	(st. err.)	(st. err.)	(st. err.)
$\Delta lnMA_i$	0.459	0.220	0.096	0.038
	(0.128)***	(0.057)***	(0.025)***	(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 2^{nd} 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.8.3 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.8.3: 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.	Coeff.	Coeff.	Coeff.
	(st. err.)	(st. err.)	(st. err.)	(st. err.)
$\Delta lnMA_i$	0.196	0.200	0.210	0.224
	(0.069)***	(0.067)***	(0.084)***	(0.083)***
Av. distance to towns in sample		-2.08e-08		-2.22e-08
		(1.06e-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 2^{nd} 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.8.4 shows the full second stage estimates for the IV specifications in table 4.

Table A.8.4: Second stage estimates for market access in columns 2, 3, and 4 of table 4.

VARIABLES	Col. 2	Col. 3	Col. 4
	Coeff.	Coeff.	Coeff.
	(st. err.)	(st. err.)	(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.8.5 shows the full first stage estimates.

Table A.8.5: 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

IX. 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.9.1 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.9.1: 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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