Market access and urban growth in England and Wales during the pre-steam era

Preliminary Draft

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Abstract

The English and Welsh economy underwent a structural and spatial transformation between the late 17th and early 19th century. It became highly urbanized and, apart from London, its urban center shifted to the northwest. What caused these developments? This paper examines the role of market access. Market access changed greatly with infrastructure improvements and technological and organizational changes in transport. Many of these developments occurred before the era of railways and steam ships, when wagons, canals, and sail ships were dominant. We construct a measure of market access for nearly 150 towns in 1680 and 1830 using a new multi-modal transport model. We then estimate the effects of changes in market access and levels of market access on population growth. Our regression model controls for various town characteristics, including coal endowments. The results show that market access explains about 25% of the urban growth from 1680 to 1830 and nearly all the urban growth from 1831 to 1851. The results have implications for the drivers of the industrial revolution and more generally on economic growth.

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I. Introduction

It is well known that highly productive cities and regions can co-exist with less productive ones. Why is this so? Why does economic development not happen everywhere even when institutions are similar? One theory states that differences in market access cause differences in development and growth. Market access is a combination of the costs faced by consumers when they buy from producers in theirs and other locations and similarly, the costs faced by producers when they sell to consumers in theirs and other locations.

Several empirical studies have shown that market access is a key driver of economic density in the modern era of railways and highways.[2] However, little is known about whether market access influenced economic activity in the pre-steam era. Lack of data is one reason. Geographic information software (GIS) data on canal, wagon road, and sailing networks have not been available. Thus, it has been impossible to simulate transport costs are a large scale. This paper studies the role of market access for one of the most precocious economies in history: England and Wales between 1680 and 1830. In this economy, there is abundant evidence for transport improvements before steam.[3] Road surfaces and gradients were improved, the inland waterway network expanded, and technology evolved in sailing ships and passenger coaches. The institutional environment also changed with wars and new methods of public finance.

In this paper, we present new estimates of market access in 1680 and 1830 for 146 of the most populous towns. Market access is calculated using the measures of transport costs derived from the multi-modal transport model, including separate measures for passenger costs, freight costs, passenger times, and freight times (see Alvarez-Palau et. Al. 2017). The changes in log market access between 1680 and 1830 are then related to the changes in log urban population between 1680 and 1830 using a regression framework. There are control variables for endowments, like coal and being located on the coast, and for unobserved factors at the regional or county level. The results show that market access measured through freight

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[2] See Donaldson (2010), Donaldson and Hornbeck (2016), Jaworski and Kitchens (2016), Alder (2014) and Faber (2014),

[3] See Gerhold (1996, 2014), Bogart (2005), Turnbull (1987), Harley (1988), Armstrong (1991), and Solar (2013).

costs robustly affects population growth. Using growth from 1680 to 1830, we find the elasticity of market access with respect to town population is 0.57. Measured in terms of the variation in urban population growth, an increase in market access growth from the 25 to 75% percentile is estimated to raise population growth by 0.49 log points. By comparison the mean urban population growth is 2.04 log points and the median is 1.77.

We also estimate the effects of market access in 1830 on population growth from 1831 to 1851. The results show that market access measured through passenger travel times is most important. The elasticity with respect to town population growth is large at around 0.25. Measured in terms of the variation in urban population growth, an increase in market access growth from the 25 to 75% percentile is estimated to raise urban population growth by 0.13 log points. The effects again are large considering that the mean and median urban population growth are 0.33 and 0.36.

Counter-factual calculations further illustrates the effects of market access. The counter-factual assumes there is no change in market access from 1680 to 1830 for all towns. Our estimates suggest there would have been 25 percentage points less urban growth from 1680 to 1830 and 97 percentage points less growth from 1831 to 1851. We take this as strong evidence that pre-steam transport improvements were a major engine of economic growth during the Industrial Revolution.

Our paper is related to the emerging literature which uses GIS tools to study transport and economic development. Closely related historical studies are Donaldson (2010), Donaldson and Hornbeck (2016), Jaworski and Kitchens (2016), which study railways and highways in India and the United states. Closely related contemporary studies are Alder (2014) and Faber (2014), who study highways in India and China around 2000. Our study is unique in that we are the first to analyse the period before 1850. Little is known about the effects of pre-motorized roads and pre-steam inland waterways in the market access literature. Our estimated effects are similar to studies despite very different contexts. Our findings along with others suggest the relationship between market access and growth is quite robust and consistent.

Our paper contributes to the literature on the drivers of growth during the industrial revolution. Transport improvements are thought to be one of the most important engines of economic growth in the English economy. The economic gains from steamships and railways are often discussed but far less is known about the extent of change in the pre-steam era and its effects (Leunig 2006, Crafts 2004). In our companion paper that details our multi-modal transport model (Alvarez-Palau et. al. 2017), the productivity growth of the domestic transport sector is estimated. We also estimate its contribution to national income using a social savings approach. We find that national income would have been 10.5% lower in 1830 had there been no transport innovations between 1680 and 1830. In this paper, we estimate that urban population growth would have decreased by 25% had market access remained constant between 1680 and 1830. This suggests that the social savings approach under-estimates the contribution to urban areas, which likely benefitted more from transport innovations than rural areas.

II. Background

II.A Urbanisation

The towns or urban settlements of England grew substantially from the 17th century to the early 19th century. Our current knowledge of urban growth is based on Langton (2000), which provides estimates of town population in the late 17th century. Towns populations from 1801 are taken from Law (1967) and Robson (2006).

Table shows 2 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 100 in 1841. Several other large towns in 1680 are not as exceptional in population by 1841. York, Oxford, and Cambridge are three examples.

Table 1: Population of the largest 20 towns in the c17th in comparison with its situation in 1841

Town Name.County	Pop 1680	Pop 1841	Rank 1841
LONDON.MIDDLESEX	500000	2051380	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

Table 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. Bradford is another example of a town that grows significantly by 1841.

Table 2: Population of the largest 20 towns in 1841 in comparison with its situation in the c17th

Town Name.County	Pop 1680	Pop 1841	Rank C17th
LONDON.MIDDLESEX	500000	2051380	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

Table 2: Population of the largest 20 towns in 1841 in comparison with its situation in the c17th			
Town Name.County	Pop 1680	Pop 1841	Rank C17th
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

Below we analyse the 100 most populous towns in 1680 and the same for 1830. There are 46 towns in the top 100 in 1680 which are not in the top in 1841. Thus, we add 46 additional towns to get the top 100 in 1841. In total, we study 146 towns in one or both lists. Also, sixteen towns in the top 100 in 1680 or 1841 do not have a population estimate for the other date. We estimate the population for these towns using the population growth of their nearest neighbours. For example, Heywood's population in Lancashire is estimated using the population growth of Bury it nearest neighbour in Lancashire.

The 146 towns are shown as proportional circles in the figure 1. The top ten regional towns in 1801 are shown as a reference. The rise in the overall level of urban populations between 1680 and 1841 is evident. But there is a clear northwestern shift in the center of urbanisation led by towns such as Manchester and Liverpool. Bristol and Birmingham also grow substantially, and of course, so does London. The maps also show the road and coastal network at the two dates. The density of the urban network and the transport network overlap greatly especially in 1830. The towns that are large in 1680 or became large by 1841 are well connected. Notably many of the towns in the northwest that became large by 1841 do not have good transport connections in 1680.

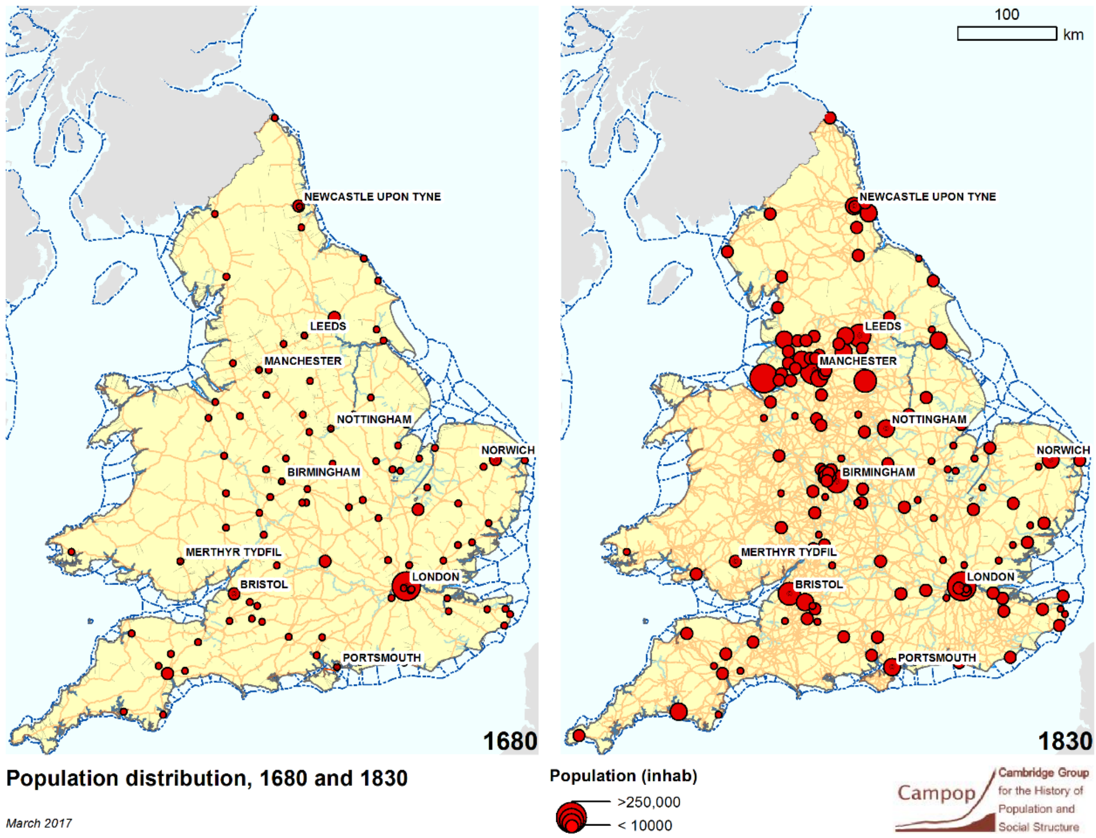

Figure 4. Population distribution in 1680 and 1830. The size of each settlement is proportional to their total population.

II.B Transport development

The domestic transport system in England and Wales substantially evolved between 1680 and 1830. This evolution was caused by several factors. The literature has mostly emphasized infrastructure construction, technological innovations and institutional changes. In this section, we briefly review these developments.

In 1680, inland communications were precarious. Roads were scarce and their state of maintenance made extremely difficult to reach large distances at a reasonable cost. Main rivers allowed the navigation of boats, but only in specific segments in deposited sediments did not restrict the draft in excess. Meteorological conditions also affected communications both in roads and rivers, adding even more uncertainty. Costal routes allowed the transport of heavy goods between ports and harbours at a reasonable cost. However, sailing boats showed high unpredictability in terms of travel time. Shipping casualties were annually reported in

Parliamentary Papers, giving an idea of the recurrence of sinking. All in all, this period was characterised by a clear lack of reliable transport infrastructure. This situation kept low speeds and high costs, maintaining distance as the main barrier for communications between settlements.

In 1830, transport infrastructure had evolved dramatically, especially the inland networks. Old roads started to be modernised using new paving materials. Innovations in vehicles and their characteristics were frequent. The increase in the number of services allowed labour specialization, emerging new occupations. And all the institutions had to adapt themselves to boost the market, to keep the infrastructure in good conditions and to finance new investments. Waterways were a network in which changes were crucial as well. From navigable rivers in the previous period, the construction of canals gave transport accessibility to remote and isolated locations. Coals mines could be exploited wherever the minerals emerged, and the new infrastructure allowed its transport to the cities or factories. In this case, technological and institutional innovations were also fundamental to compete with roads in inland transport. The coastal network was probably the one were changes were less visible. Port infrastructure developed considerably, as well as the design of ships and vessels. However, navigation techniques and the introduction of steam was not significant by the date.

While its clear transport changed qualitatively from 1680 to 1830, it is less obvious how the rate of change differed across space. Moreover, it is less clear whether urban areas that grew rapidly also experienced the greatest changes in transport costs. To address this issue it is first necessary to quantify the changes in transport across space. The following section develops our methodology.

III. Data and Methodology: multi modal networks

Our analysis of transport change is based on what we call a 'historical multi-modal network analysis.' The model is explained in detail in our companion paper (Alvarez-Palau et. al. 2017). Here we provide the brief details. The model combines several modes of transport to create an integrated model, which allows the identification of the most appropriate route between each pair of towns through all the networks. Time and cost parameters for both passengers and freight are used as the impedance of the model to solve the least-cost-path equation in two time-slices: 1680 and 1830.

The framework of the multi-modal model can be observed in the figure 2. The model integrates geographical information about transport and territory using points and polylines. In our case, we use points to represent towns, ports and the intersections between networks. Polylines are used to represent roads, waterways, coastal routes and the interpolated connections between the previous elements.

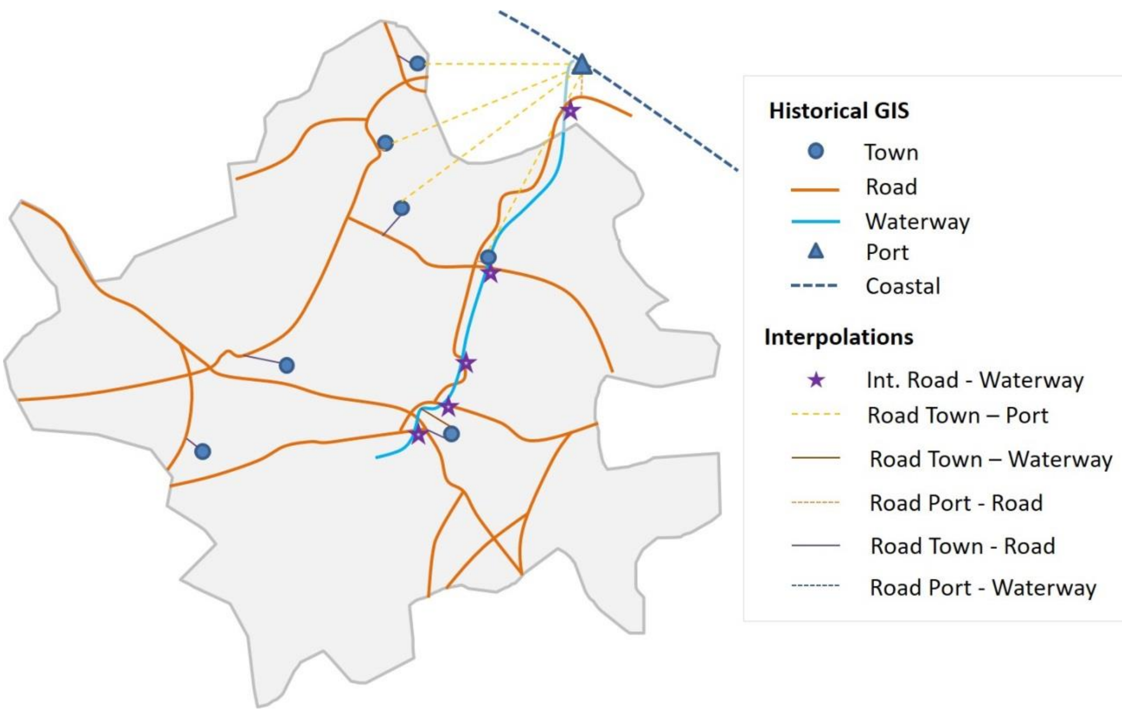

Figure 2. Multi-modal model framework: roads, waterways, coastal routes, towns, ports and their interpolated interconnections.

Networks of roads, navigable rivers and coastal routes have been digitised as polylines and incorporated as a basis of the model. The most populated towns and the historical ports have also been added with the aim to assign punctual information and determine specific routes between them. To ensure the connectivity of the model, and to avoid inconsistent routing problems, we create a set of interpolated lines between our point layers, towns and ports, and the respective polyline networks, namely roads, waterways and coastal.

Once the model is created, ESRI ArcGIS software is used to carry on with the analysis. The network analysis tools of ESRI are based on the Dijkstra's algorithm for finding the shortest paths. More specifically, we use the OD matrix solver for distance, time and cost. Each mode of transport has been assigned a unique speed or cost value for each time-slice, or what we call the parameter value. Dijkstra's algorithm uses the parameter values to estimate the shortest or least-cost-path between the origins and destinations supplied. The parameters are reported in constant per mile units and are linearly related to the length of the network segment. In terms of time, the length is multiplied by the average speed to obtain the time spent in each segment. In terms of cost, the length is multiplied by the unit cost of moving passengers or freight.

In choosing parameters our general approach was to identify costs and speeds reported in the secondary literature. The sources are described in Alvarez et. al. (2017). In the future, we plan to add archival sources, which will enrich the analysis.

Isochrone maps measure zones with similar travel times to a location and illustrate our model's results. The results are shown in figure 3 for passenger travel to London. In 1680, moving from the center of London to its surroundings is estimated to almost 10 hours. Almost 25 hours are needed to reach Cambridge or Oxford, and 50 to reach Bristol, Birmingham, Kings Lynn or Norwich. Reaching Liverpool is estimated to take over 100 hours, and almost 150 are needed to arrive to Newcastle. It gives an idea about how slow was to travel in that period. In 1830, however, the geographical landscape is completely different. Total travel times are divided almost by 4. Kings Lynn, Birmingham and Bristol can be reached within 15 hours and just 25 hours are needed to arrive Liverpool.

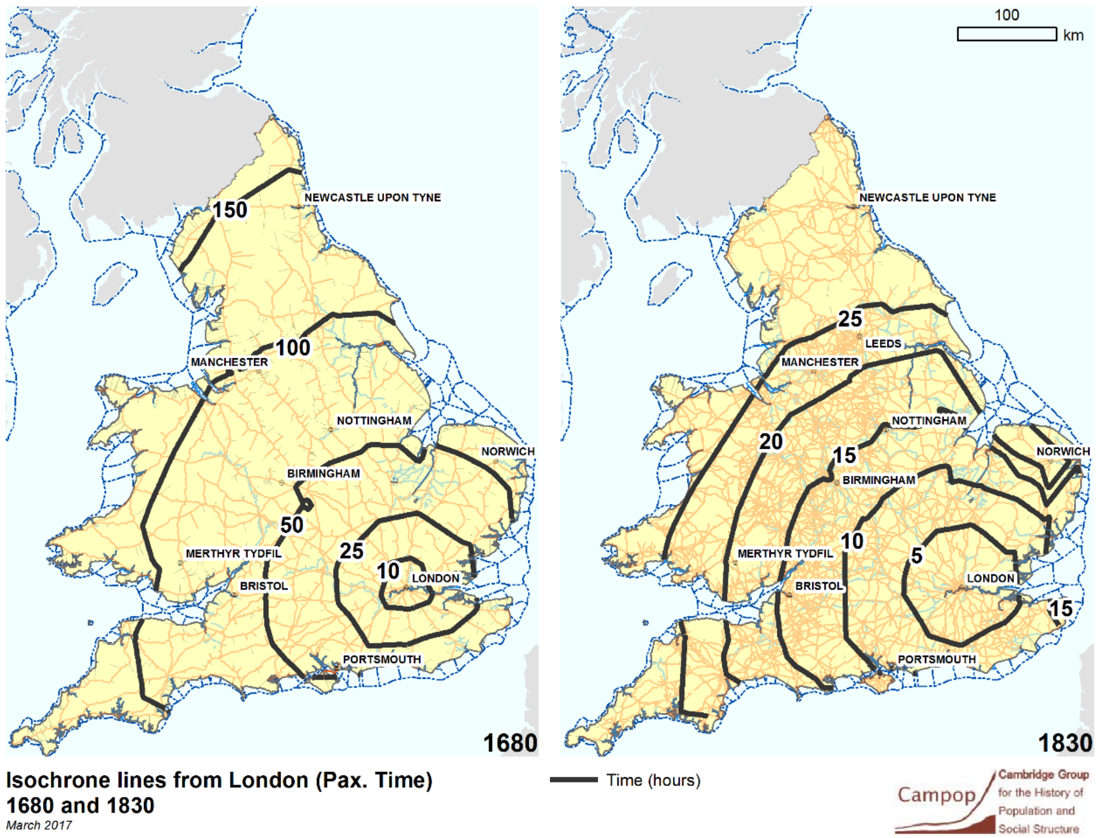

Figure 03. Isochrone lines from London for passenger time in 1680 and 1830.

Isocost maps measure zones with similar transport costs to a location. The results are shown in figure 4 for passenger travel to Manchester. In 1680, the shape of the isocost lines denote an apparent lack of connection. Manchester is relatively well connected with Beaumaris and Carlisle, but has problems to surpass the Pennines and to reach central Wales. The only direction with good connections is the corridor to Birmingham, that allows the connection with the centre of England. Another striking feature is the creation of islands of poor connectivity. This is the case of southern Wales or the Wiltshire country, remaining at poorer levels than their neighbours. By 1830 the landscape completely changes. The isocost lines are well defined, showing a homogeneous distribution of accessibility to Manchester across the country. This is a clear example of how the expansion of the road and canal network helped to improve inland transports, creating reliable connections and allowing the economy to benefit from this effect.

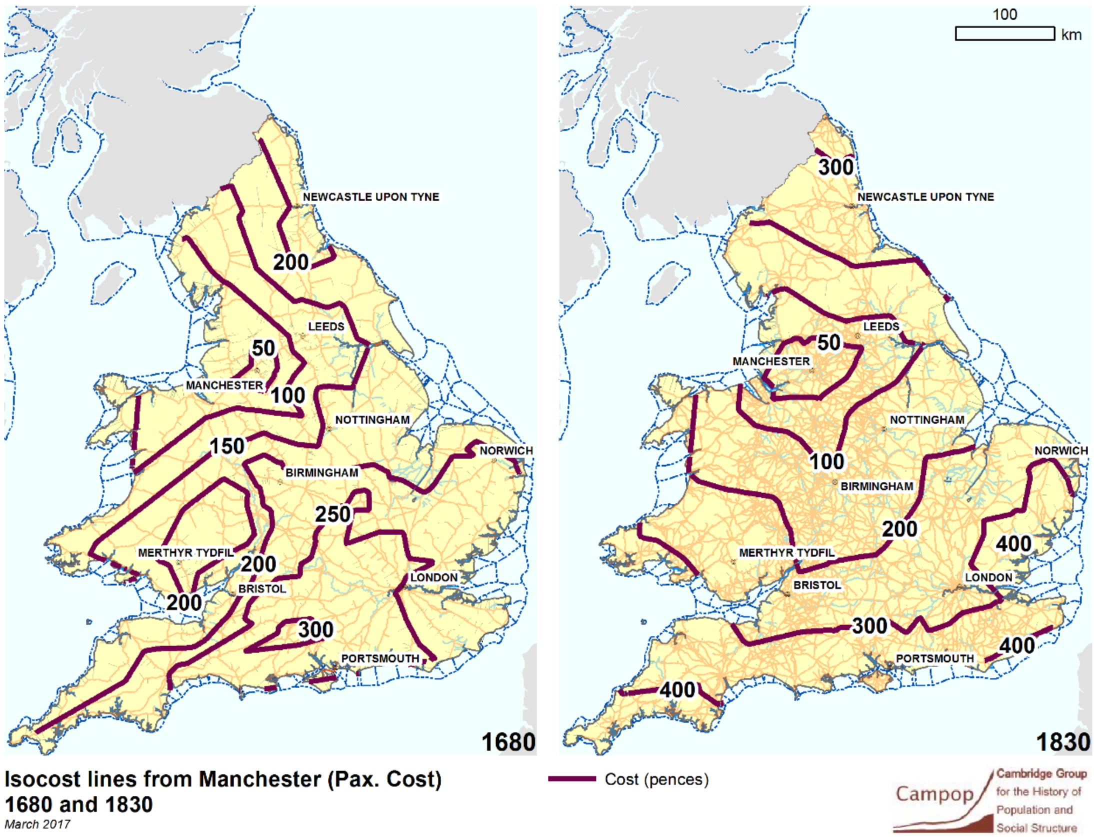

Figure 4: Isocost lines from Machester for passenger cost in 1680 and 1830.

III.A Model estimates of market access

In this section, we report our estimates of market access of English towns in 1830. Most models of economic geography emphasize the importance of market access for consumers and firms (e.g. Redding and Turner 2014). Importantly, consumer market access is a decreasing function of transport costs between a location and other locations supplying consumer goods. Producer market access is decreasing in transport costs between a location and other locations of demand. Most models imply that increasing market access raises the population in a location.

Follow Harris (1954), the most basic estimate of market access is the following, $MA_i = \sum_{j=1,\neq i}^{J} \frac{pop_j}{tc_{ij}}$, where MA_i is the market access of town i, pop_j is the population of town j, indexed from $j = 1, ..J, i \neq j$, and tc_{ij} is the transport cost from i to j. The Harris formula is often modified in two ways. First, the transport costs term has the exponent, θ, so that $MA_i = \sum_{j=1,\neq i}^{J} \frac{pop_j}{{tc_{ij}}^{\theta}}$. The parameter $\theta > 0$ captures the variation in productivity across locations, which has implications for the degree of comparative advantage in trade models.[4] Notice that the Harris formulation is equivalent to $\theta = 1$, which in theory corresponds to a situation where towns have very different productivity levels. In two important applications of market Access, Donaldson (2016) and Donaldson and Hornbeck use $\theta = 3.8$.

A second modification of the Harris formula incorporates the view that town's market access measures are inter-connected. The formula is derived from a general equilibrium trade model where $MA_i = \sum_{j=1,\neq i}^{J} \frac{pop_j}{tc_{ij}{}^{\theta} MA_j{}^{\frac{1+\theta}{\theta}}}$. Notice that greater market access of other towns j implies that the market access of town i is lower.

We construct new measures of market access for England using our model's estimates of transport costs between all towns, tc_{ij} in 1680 and 1830. The following expression using the Harris formula for market access in town i in year t using town i's freight cost:

$$MAFC_{it} = \sum_{j=1,\neq i}^{J} \frac{pop_{jt}}{freightcost_{ijt}}$$

Where pop_{jt} is the population of town j in year t and $freightcost_{ijt}$ is our freight cost estimate between town i and j in year t. A similar expression is used to calculate market access using passenger cost $MAPC_{it}$, freight time $MAFT_{it}$, and passenger time $MAPT_{it}$. For the moment, we use the Harris formulation only. In the future, we plan to estimate θ and construct inter-connected market access measures.

The $MAFC_{it}$ is shown in figure 5. In 1830 London has the highest market potential, but there are plenty of settlements with greater access to the national market. The clearest example is Manchester, where industrialisation created a textile cluster able to establish relations, not just at a national level but also internationally. Birmingham, Bristol or Newcastle are other examples of cities that created important markets capable of trade beyond their vicinities.

[4] According to Donaldson and Hornbeck (2016), the parameter θ captures, inversely, the (log) standard deviation of productivity, which corresponds to the scope for comparative advantage. In our case, a low θ means town productivity draws are dispersed, creating large incentives to trade on the basis of productivity differences.

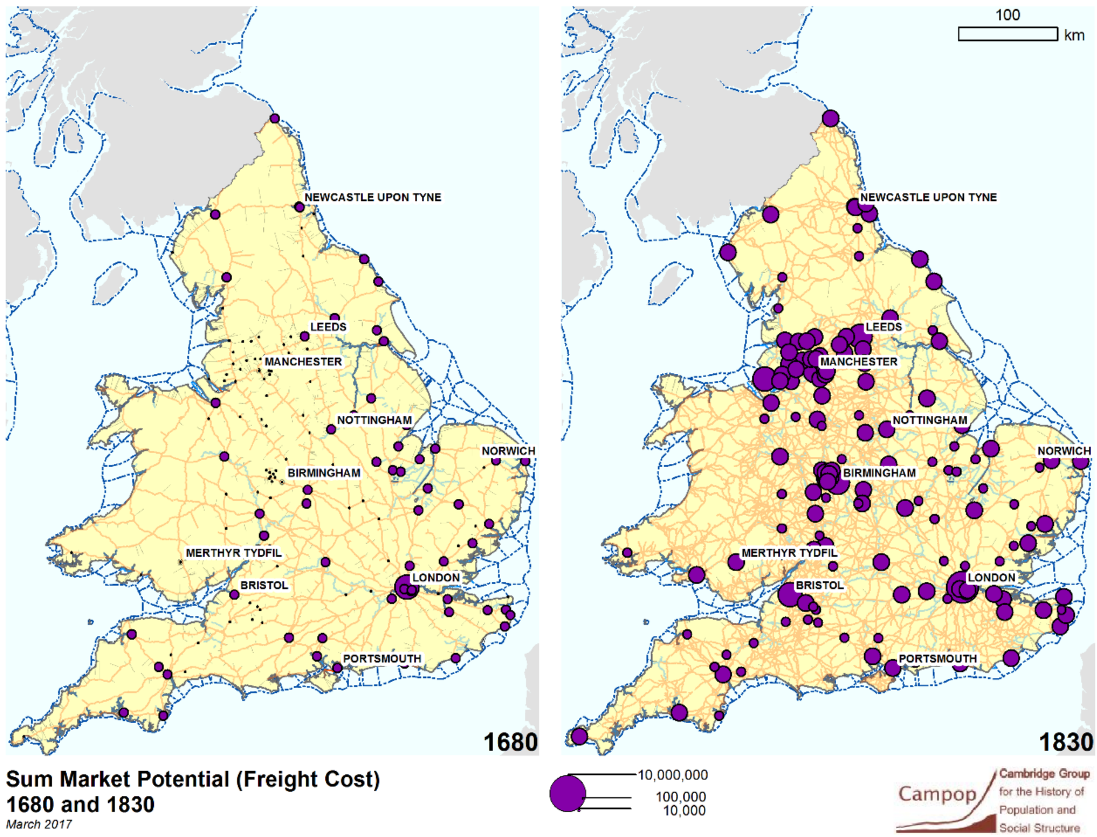

Figure 5. Market potential indicator in 1680 and 1830.

IV. Empirical framework

There are several estimating equations of interest for quantifying the effects of market access. We are interested in testing whether the population growth of towns was determined by levels of market access and/or changes in market access.

One specification examines the effects of changes in market access from 1680 to 1830 on population growth from 1680 to 1841. The model is the following:

$$\Delta\ln(pop_i)^{1841-1680} = \alpha + \beta_1 \Delta\ln(MA_i)^{1830-1680} + \beta_2 \ln(pop_{i1680}) + \beta_3 \cdot x_i + \varepsilon_i$$

where $\Delta\ln(pop_i)^{1841-1680} = \ln(Pop_{i1841}) - \ln(Pop_{i1680})$ is the log difference in town i's population from 1841 and 1680 and $\Delta\ln(MA_i)^{1830-1680} = \ln(MA_{i1830}) - \ln(MA_{i1680})$ is the log difference of market access from 1830 to 1680. The log of the initial population

$\ln(pop_{i1680})$ is included to capture convergence or divergence in populations levels across towns. The vector x_i includes indicators for coal, being on the coast, elevation, ruggedness, soil types, and distance to London and Manchester. These time-invariant control variables for town i capture other initial factors that can influence growth.[5] We call this specification the simultaneous growth equation, because it relates growth in population with growth in market access over the same time period.

Reverse causation is a concern in the simultaneous growth equation because growth in population could directly cause market access. For moment, we address this issue only partly. Our first approach is to include either a set of region dummy variables or county dummy variables. Since unobservable growth factors were often geographically specific, these fixed effects will lessen reverse causation concerns. Our second approach is to use 1680 town populations to measure market access in 1830. Our baseline model uses 1830 population to measure market access in 1830. This eliminates the potential endogenous feedback from town i's population growth to its neighbors j which would enter the formula: $MA_i = \sum_{j=1,\neq i}^{J} \frac{pop_j}{tc_{ij}}$.

A second specification examines the effects of the level of market access in 1830 on population growth from 1831 to 1851. The model is the following:

$$\Delta\ln(pop_i)^{1851-1831} = \alpha + \beta_1 \ln(MA_{i1830}) + \beta_2 \ln(pop_{i1831}) + \beta_3 \cdot x_i + \varepsilon_i$$

Where $\Delta\ln(pop_i)^{1851-1831} = \ln(Pop_{i1851}) - \ln(Pop_{i1831})$ is the log difference in town i's population between 1851 and 1831 and $\ln(MA_{i1830})$ is the log of market access in 1830. The log of town population and the vector x_i of controls are also included as before. Note the vector of controls will again include region or county fixed effects. We call this specification the lagged levels growth equation because it relates population growth from 1831 to 1851 century to levels of market access in 1830.

It is important to notice that in the lagged levels growth equation there is no concern about reverse causation. Growth in the period from 1831 to 1851 does not directly cause

[5] For more details on these sources see Bogart et. al. (2017a).

market development in previous years. Nevertheless, there is still a concern about endogeneity. Our plan in the future is to develop an instrument for market access using a least cost path (LCP) variable. Specifically, we calculate the distance between each town using natural geography plus a coastal route following bathymetry. We then construct an instrumental variable using these distances as the transport costs. See the formula below.

$$InstrumentMA_{it} = \sum_{j=1,\neq i}^{J} \frac{Pop_{jt}}{distanceusingLCP_{ijt}}$$

IV.A Summary statistics

The following table reports the summary statistics for the population variables, the market access variables, and control variables. Notice that urban population growth is large from 1680 to 1830. The average log difference in town population is 2.042, which implies that on average urban populations increased by an average of 671%. Much of this is driven by outliers such as Manchester that increased by 14,361% from 1680 to 1830. One should also keep in mind that the populations are measured 150 years apart, so the average annual urban growth rate is less equalling 1.4%. Urban population growth from 1831 to 1851 was larger in annual terms. The average log difference is 0.360, which implies an average annual increase of 1.8% over the twenty-year period.

Market access increased at more rapid rate than population growth in 3 of the 4 measures. The average log difference in market access based on freight costs is 2.556, which implies a 1188% average increase. In annual terms, market access based on freight costs grew at a rate of 1.71%. Market access based on passenger costs is the only case where market access grew less than population on average. The reason is that passenger costs rose in nominal terms from 1680 to 1830 (Alvarez-Palau et. al. 2017). In real terms passenger costs declined, and in the future we make adjustments for inflation.

Panel C reports summary stats for the remaining variables. Perhaps the most important are the indicators coal and coastal, which are key endowments.

Table 3: Summary Statistics

VARIABLES	(1) N	(2) mean	(3) sd	(4) min	(5) Max
Panel A: Population vars.					
ΔLn Town population 1830-1680	146	2.042	1.222	-0.307	5.574
ΔLn Town population 1851-1831	138	0.360	0.240	-0.113	1.284
Ln Town population 1680	146	7.716	0.948	5.521	13.12
Ln Town population 1831	138	9.616	0.990	7.983	14.37
Panel B: Market access vars.					
ΔLn MA Pass. Time 1830-1680	146	3.513	0.468	2.334	4.645
Ln MA Pass. Time 1830	146	13.26	0.506	11.96	15.45
ΔLn MA Freight Time 1830-1680	146	2.757	0.461	1.756	3.870
Ln MA Freight Time 1830	146	11.86	0.482	10.83	14.29
ΔLn MA Pass. Cost 1830-1680	146	1.710	0.684	0.518	3.232
Ln MA Pass. Cost 1830	146	10.66	0.509	9.645	13.03
ΔLn MA Freight Cost 1830-1680	146	2.556	0.643	1.406	4.061
Ln MA Freight Cost 1830	146	10.54	0.365	9.672	12.31
Panel C: control vars.					
Distance to London in m	137	179,153	98,130	594.4	424,871
Distance to Manchester in m	137	187,749	83,280	18,267	433,175
Coastal town	137	0.292	0.456	0	1
On exposed coal field	137	0.314	0.466	0	1
Percent soil type 2	137	0.00106	0.00888	0	0.0856
Percent soil type 3	137	4.241	15.20	0	92.57
Percent soil type 4	137	3.392	10.56	0	62.93
Percent soil type 6	137	2.255	5.866	0	36.61
Percent soil type 7	137	31.02	33.53	0	100
Percent soil type 8	137	15.93	27.39	0	100
Percent soil type 9	137	0.360	2.013	0	19.90
Percent soil type 10	137	1.722	5.855	0	44.76
Percent soil type other	137	0.895	1.865	0	11.93
Mean elevation	137	77.51	68.46	1.319	291.0
Mean elevation slope	137	4.420	2.927	0.697	14.11
Standard dev. elevation slope	137	3.214	2.200	0.0323	11.14

Sources: see text.

V. Results

The results from the simultaneous growth equation are shown in table 4. Panel A reports the results from a baseline model that includes fixed effects for 4 of the five regions: the North, the

Midlands, the Southeast, the Southwest, and Wales. All 4 market access variables are found to have a positive and significant effect on town population growth. The results provide some initial evidence that market access caused urban growth. The results for initial population are also reported. The negative sign on Ln pop1680 indicates a convergence process, whereby less populated towns in 1680 grew more up to 1830.

The results in panel B use 1680 population to calculate market access in 1830. The coefficients are larger for all 4 market access variables. The differences in coefficients are smaller for market access measured with freight costs and passenger costs, and larger for market access measured with passenger time.

Panel C repeats the specification of panel B but it replaces region fixed effects with 53 county fixed effects. In other words, we are identifying the effects of market access based on variation within counties. Given our sample size (n=137), we have fewer degrees of freedom to estimate market access, but the estimates are still useful because they reduce concerns about unobserved heterogeneity being correlated with market access. In this more stringent specification, we find that only market access using freight costs is positively and significantly associated with town population growth. The coefficient is reasonably large. The estimated elasticity of population with respect to market access is 0.57. Measured in terms of the variation in urban population growth, an increase in log difference in freight cost market access from the 25 to 75% percentile is estimated to raise population growth by 0.494 log points or 64%. By comparison, our estimates imply that being on the exposed coal fields raises urban population growth by 56% and being coastal raises urban population growth by 83%. (results not reported) Thus, the effect of market access appears to be broadly similar to the effects of endowments.

Another implication of our findings is that freight costs were the most significant determinant of population growth among all the measures of transport costs. Freight cost declines were driven by a combination of factors including the introduction of canals, better roads, and reorganization in coastal shipping. These changes would seem to spur manufacturing growth, which appears to be the main driver of urbanization in the eighteenth century.

Table 4: Growth in Population and Market Access

Panel A: baseline model

VARIABLES	(1) Model 1	(2) Model 2	(3) Model 3	(4) Model 4
Ln pop1680	-0.378***	-0.386***	-0.388***	-0.371***
	(0.0892)	(0.0821)	(0.0657)	(0.0620)
ΔLn MA Pass. Time	1.114***			
	(0.132)			
ΔLn MA Freight Time		1.008***		
		(0.140)		
ΔLn MA Pass. Cost			0.701***	
			(0.130)	
ΔLn MA Freight Cost				0.742***
				(0.0677)
Controls for Endowments	Y	Y	Y	Y
Region fixed effects	Y	Y	Y	Y
Observations	137	137	137	137
R-squared	0.605	0.597	0.616	0.617

Panel B: Market Access using 1680 population only

VARIABLES	(5) Model 1	(6) Model 2	(7) Model 3	(8) Model 4
logpop1680	-0.371**	-0.373***	-0.378***	-0.363***
	(0.106)	(0.0916)	(0.0725)	(0.0729)
ΔLn MA Pass. Time	1.572**			
	(0.458)			
ΔLn MA Freight Time		2.032*		
		(0.791)		
ΔLn MA Pass. Cost			0.863***	
			(0.106)	
ΔLn MA Freight Cost				0.897***
				(0.207)
1830 MA uses 1680 Pop	Y	Y	Y	Y
Controls for Endowments	Y	Y	Y	Y

Region fixed effects	Y	Y	Y	Y
Observations	137	137	137	137
R-squared	0.598	0.593	0.615	0.614

Panel C: Models with county FE				
	(9)	(10)	(11)	(12)
VARIABLES	Model 1	Model 2	Model 3	Model 4
logpop1680	-0.458***	-0.467***	-0.461***	-0.452***
	(0.136)	(0.142)	(0.143)	(0.137)
ΔLn MA Pass. Time	0.549			
	(1.128)			
ΔLn MA Freight Time		-0.0886		
		(1.426)		
ΔLn MA Pass. Cost			0.391	
			(0.392)	
ΔLn MA Freight Cost				0.572*
				(0.284)
1830 MA uses 1680 Pop	Y	Y	Y	Y
Controls for Endowments	Y	Y	Y	Y
County fixed effects	Y	Y	Y	Y
Observations	137	137	137	137
R-squared	0.725	0.724	0.726	0.731

Notes. The dependent variable is the log difference in population 1830 and 1680. Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

The results from the lagged levels growth equation are shown in table 5. Panel reports the baseline model. There is a positive and significant effect of market access for 3 of the 4 market access variables. Panel B replaces region fixed effects with county fixed effects. Again, this specification captures more unobserved heterogeneity but it also leaves fewer degrees of freedom to identify the effects of market access. The results indicate that only market access measured by passenger time is positively and significantly related to population growth. Its coefficient is large in magnitude. A one standard deviation increase in market access based on passenger travel time increases population growth by 0.41 standard deviations. Alternatively, an increase in passenger time market access from the 25th to the 75th percentile is estimated to raise population growth by 13%. By comparison, being coastal raises population growth by 8.9%

and having coal has zero effect in the model with county fixed effects. Thus, increases in passenger time market access are found to be more important than endowments in explaining urban population growth from 1831 to 1851. The significance of passenger times is interesting because it played a lesser role from 1680 to 1830. Passenger travel times were driven down by improvements in coaching and roads. It suggests that the value of time and communication became more important in the 19th century.

Table 5: Growth in Population 1831 to 1851 and Market Access in 1830

Panel A: baseline model VARIABLES	(1)	(2)	(3)	(4)
Ln pop1831	0.0570***	0.0500***	0.0554***	0.0538***
	(0.0107)	(0.0121)	(0.0128)	(0.0131)
Ln MA Freight Cost 1830	0.203			
	(0.127)			
Ln MA Pass. Cost 1830		0.199**		
		(0.0601)		
Ln MA Freight Time 1830			0.239***	
			(0.0494)	
Ln MA Pass. Time 1830				0.222***
				(0.0363)
Controls for Endowments	Y	Y	Y	Y
Region fixed effects	Y	Y	Y	Y
Observations	132	132	132	132
R-squared	0.380	0.398	0.406	0.416

Panel B: county FE VARIABLES	(4)	(5)	(6)	(7)
Ln pop1831	0.0381	0.0362	0.0393	0.0386
	(0.0296)	(0.0287)	(0.0292)	(0.0285)
Ln MA Freight Cost 1830	0.0539			
	(0.110)			
Ln MA Pass. Cost 1830		0.160		
		(0.168)		
Ln MA Freight Time 1830			0.254	
			(0.166)	
Ln MA Pass. Time 1830				0.245*
				(0.122)

Controls for Endowments	Y	Y	Y	Y
County fixed effects	Y	Y	Y	Y
Observations	132	132	132	132
R-squared	0.571	0.579	0.588	0.594

Notes. The dependent variable is the log difference in population 1831 and 1851. Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

The results from the simultaneous growth equation and the lagged levels growth equation suggest improvements in transport had large effects on the growth of urban populations. The effects are also seen in some counter-factuals. Suppose that market access in 1830 did not change and was the same as in 1680. How much lower would urban populations have been in 1830? The calculations in table 6 provide an answer. Using our simultaneous growth model, we predict that population growth would be 342% if market access stayed the same in 1680 and 1830 and 466% following its actual growth from 1680 to 1830. Thus, total population growth would have been 124 percentage points lower, equivalent to about 25% of the growth that occurred. Put differently annual urban population growth would have been 0.54% lower if market access stayed the same.

A similar counter-factual addresses how much lower urban population would have grown between 1831 and 1851 had market access in 1830 remained at its 1680 level. The results in table 6 suggest there would have been very little urban growth, only 3%, compared to our model's prediction of 50% growth given actual 1830 market access. In annualized terms, urban population growth would have been -1.97% lower.

Table 6: Counter-factual urban growth estimates

ITEMS for long 18th century	Outcomes
(1) Aggregate urban population growth between 1680 and 1830 predicted by the model	466%
(2) Counter-factual aggregate urban population growth between 1680 and 1830 predicted by the model if market access in 1830 remained at 1680 levels	342%
(3) Percentage point change in aggregate urban population growth between 1680 and 1830, (1)-(2)	-124%

(4) Annual percentage point change in aggregate urban population growth, (3) annualized over 1680 to 1830	-0.54%

ITEMS for mid-19th century	Outcomes
(1) Aggregate urban population growth between 1831 and 1851 predicted by the model	50%
(2) Counter-factual aggregate urban population growth between 1831 and 1851 predicted by the model if passenger travel times in 1830 remained at 1680 levels and population in 1830 remained at 1830 levels	3%
(3) Percentage point change in aggregate urban population growth between 1831 and 1851, (1)-(2)	-47%
(4) Annual percentage point change in aggregate urban population growth, (3) annualized over 1831 to 1851	-1.97%

VI. Conclusion

This paper studies the role of market access for one of the most precocious economies in history: England and Wales between 1680 and 1830. It present new estimates of market access in 1680 and 1830 for 146 of the most populous towns. Market access is calculated using the measures of transport costs derived from the multi-modal transport model, including separate measures for passenger costs, freight costs, passenger times, and freight times (see Alvarez-Palau et. Al. 2017). The changes in log market access between 1680 and 1830 are then related to the changes in log urban population between 1680 and 1830 using a regression framework. The results show that market access measured through freight costs robustly affects population growth. Measured in terms of the variation in urban population growth, an increase in market access growth from the 25 to 75% percentile is estimated to raise population growth by 0.49 log points. By comparison the mean urban population growth is 2.04 log points and the median is 1.77.

We also estimate the effects of market access in 1830 on population growth from 1831 to 1851. The results show that market access measured through passenger travel times is most important. Measured in terms of the variation in urban population growth, an increase in market access growth from the 25 to 75% percentile is estimated to raise urban population growth by 0.13 log points. The effects again are large considering that the mean and median urban population growth are 0.33 and 0.36.

Counter-factual calculations further illustrates the effects of market access. Our estimates suggest there would have been 25 percentage points less urban growth from 1680 to 1830 and 97 percentage points less growth from 1831 to 1851. We take this as strong evidence that pre-steam transport improvements were a major engine of economic growth during the Industrial Revolution.

Our paper is related to the emerging literature which uses GIS tools to study transport and economic development. Our study is unique in that we are the first to analyse the period before 1850. Our estimated effects are similar to studies despite very different contexts. Our findings along with others suggest the relationship between market access and growth is quite robust and consistent.

Finally, our paper contributes to the literature on the drivers of growth during the industrial revolution. Transport improvements are thought to be one of the most important engines of economic growth in the English economy. The economic gains from steamships and railways are often discussed but far less is known about the extent of change in the pre-steam era and its effects. In this paper, we show that pre-steam transport innovations were a significant driver of economic growth.

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