Speedier delivery:

coastal shipping times and speeds during the age of sail

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Abstract

Coastal shipping has been described as the ‘vital spark’ igniting economic growth in Britain. We provide the first quantitative analysis of long-term changes in journey times and speeds in English and Welsh coastal shipping during the age of sail. We use Board of Trade Crew Lists, which reveal timings for numerous coastal journeys from 1830 to 1845. Journey speeds are also calculated using a newly digitized coastal network. These are compared with journey times and speeds in the mid to late 1600s drawn from coastal Port Books and tax records. Our methodology compares journeys with similar observable characteristics, like port location and season of departure. We find evidence for significant differences in speed and time between the mid-1600s and the 1830s. Journey speeds are approximately 160% greater c.1835 and journey times are approximately half by this date. Similar differences are found for time spent in port and time for voyages cycling between two ports. Overall, there is consistent evidence that coastal shipping provided speedier delivery by the 1830s. This result contributes to a better understanding of productivity growth in coastal shipping and its impact on the long-term development of the British economy.

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Shipping is crucial for international and domestic trade. Much scholarly attention has been devoted to studying innovations during the age of sail from the 1500s to the mid-1800s. Researchers have argued that sailing vessels became larger and more durable with metaled hulls. Sails and rigging improved, giving vessels more power. Navigational tools and knowledge of coasts expanded, improving the capabilities of captains and crew. Ports increased in capacity and facilities for loading improved.[6] An important question is whether the cumulative effects of these innovations were large, and by extension, if they were significant compared to the move to steam ships in the mid-19th century.

There are several approaches to measuring shipping innovation. The first draws on the concept of total factor productivity, which is the amount of output produced by a firm or in some sector that cannot be explained by inputs, like labor and capital. While informative, studies estimating total factor productivity growth in shipping are not always definitive and a large debate has ensued on how to interpret the estimates. A second approach measures changes in shipping speed. Crews were often hired for a voyage, and therefore, faster sailing and lower port times meant lower labor costs per voyage. The fixed costs of owning a ship could also be spread across more voyages if speeds increased. Speed is also interesting because it is valued by merchants. If goods arrive more quickly, then merchants hold fewer inventories. Some of the cost savings are passed to households through lower prices, which raise real incomes.

Thus far the literature measuring shipping speed has focused on ocean-going ships.[7] There is almost no evidence on speeds in *coastal* shipping. In fact, for England, one of the

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[6] See North (1968), Shepherd and Walton (1972), Ville (1986), Hausman (1987), Harley (1988), Menard (1991), van Zanden and van Teilhof (2009), Solar (2013). There are also several valuable chapters on this topic in Unger (2011).
[7] Ronnback (2012), Solar and Hens (2015), Solar and Ronnback (2015), O'Grada and Kelly (2017), Solar and De Zwart (2017).

leading shipping economies, there is only scattered evidence on the annual number of roundtrip voyages in the English coal trade and a few anecdotes regarding daily sailing speeds.[8]

In this paper, we offer the first quantitative analysis on long-term changes in English and Welsh coastal shipping times and speeds. Our main question is whether coastal shipping times and speeds changed significantly between the mid-17th century and the second quarter of the 19th century. The interest in the mid-17th century stems from recent studies which show that England began its structural transformation around this date.[9] We focus on the 1830s because it was approximately the last decade when sailing ships still dominate the English coastal trade.

Several new sources are introduced in our analysis. For the 19th century, we use the Board of Trade Crew lists. It contains port locations and dates for individual ships between 1830 and 1845. From this source, we calculate three performance metrics: journey times (days to get from port A to port B), journey speeds (route miles from port A to Port B divided by journey days) and turnaround times in ports (days between arriving and departing from a port). The route miles between ports are calculated using a new historical GIS coastal network.[10]

The Board of Trade lists yield a fourth performance metric. Many ships sailed continuously between the same two ports in what we call a 'voyage cycle.' We measure the total time in the following steps: (i) sailing from an origin to a destination port, (ii) unloading and reloading at the destination port, (iii) returning to the origin port, and (iv) starting the next voyage to the same destination port. We also divide 365 days by average voyage cycle time to get the annual number of voyages, which is a useful statistic in the coastal shipping literature.

[8] See Hausman (1977), Ville (1984, 1986) for discussion of annual completed voyages. Armstrong (1991, p. 83) suggests that coastal speeds were high, perhaps 100 miles a day.
[9] See Shaw Taylor and Wrigley (2014), Wallis et. al. (2017).
[10] See https://www.campop.geog.cam.ac.uk/research/projects/transport/data/ports.html

Three other sources are compared with Board of Trade lists. The first is a sample of mid-17th century coastal port books collected and detailed by Dunn (2018). We reorganize the data to create a 'ship-level' panel and calculate journey times, turnaround times, and voyage cycle times in Port Books. The second source is what we call the Severn Port Books sample.[11] It contains data on voyages where the port of Gloucester is the origin or destination. We again reorganize observations as a ship panel to extract thousands of voyage cycle times. The third source are tax records from St. Paul's Church.[12] They yield information on voyage cycle times for ships involved in the north-east coal trade from 1689 to 1695.

Our methodology compares sample means and variance for times and speeds in the 17th and 19th century sources. We match journeys and voyages on observable characteristics like month of departure and the location of origin and destination ports. Matches are restricted to yield 'balanced' and therefore comparable samples.

The analysis reveals significant improvements in speed and time savings. Journey times were approximately 40% lower in the early 19th century compared to the mid-17th century. Journey speeds (miles per day) change more, increasing by 160% between these time periods. As we show below, the discrepancy in these two figures is due to speeds increasing more on long-distance voyages.

Voyage cycle times were significantly shorter by the early 19th century. Here we have several 17th century samples to compare, and the general finding is that voyage cycle times were approximately 50% lower in the 1830s. Also, nearly two thirds of voyage cycle time is spent in

[11] This data was collected and detailed by Wanklyn et. al. (1996). More details are given in Wanklyn (1996).
[12] We thank Callum Easton who kindly provided this data.

ports. This implies that port turnaround times declined significantly. We offer explanations for these findings below.

We also provide evidence on the timing of change. The Severn port books reveal some routes had lower cycle times by the mid-18th century. Data from the London to north-east coal trade also suggest that voyage cycle times changed significantly in the mid-18th century. However, evidence from a broader sample of routes indicates further improvements in speed occurred between 1797 and the 1830s. It appears that coastal shipping times and speeds changed incrementally in the aggregate leading to a large cumulative effect by the mid-19th century.

It is useful to compare our results with estimates for ocean-going vessels, where there is a consensus that journey speeds increased significantly from the late 17th to the early 19th century.[13] We document that a similar trend applied to English coastal shipping. That said, coastal ships were still slow in comparison. O'Grada and Kelly (2017) find that East India Company ships were moving at 5-6 knots per hour by 1830 (1 knot = 1.15 mph). We find that coastal ships travelled at 2-3 miles per hour by the 1830s. Coastal vessels were also much slower than coastal steam ships c.1850, which travelled at 10 miles an hour (Armstrong 2009, p. 66).

The results contribute to the literature on coastal shipping and productivity in the age of sail. There is a debate between Ville and Hausman on the rate of productivity growth in coastal shipping. Ville argues for a 0.45% average annual rate of productivity growth largely based on the assumption that the annual number of voyages increased by 100%. We provide robust evidence that annual voyages per year increased between 60 to 100%, implying productivity

[13] Ronnback (2012), Solar and Hens (2015), Solar and Ronnback (2015), O'Grada and Kelly (2017), Solar and De Zwart (2017).

growth in coastal shipping was relatively high. The implications for understanding the sources of aggregate productivity growth are large as we explain in the conclusion.

The paper is organized as follows. Section 1 outlines the sources. Section 2 examines journey times and speeds. Section 3 examines voyage cycle times. Section 4 decomposes voyage times and examines port turnaround times. Section 5 examines when voyage times declined between the 17th and early 19th century. Section 6 concludes.

Section 1. Sources

1.1 Board of Trade Crew Lists, 1830-45

Between 1830 and 1845, masters of coastal vessels were required to complete forms that record details of recent voyages and crews employed. The forms have survived and are available at the National Archives within the Board of Trade records (BT98).[14] The forms are arranged alphabetically by ship name for all 75 customs ports across England and Wales. We transcribed the first ten forms for each of the 75 customs ports to create our sample. As forms are arranged by ship name, we have close to a random sample within each customs port.

The voyage schedules come in various forms, but most give departure dates and arrival dates for a ship during a half year period. An example is the list for the Ann of Whitby between 30 June 1836 and 10 January 1837.[15] It describes 6 voyages all between the ports of Stockton on Tees in Durham and Rochester in Kent. It generally records the date of departure from Stockton and the date of arrival in Rochester. It also records when the ship returned to Stockton. Thus, there are several pieces of information. First, there is the journey time between origin and destination ports (i.e. Stockton to Rochester). Second, there is the time spent in port, in this case

[14] See BT98, Registry of Shipping and Seamen: Agreements and Crew Lists, Series I
[15] See Whitby BT98/ P7243333.

between the return date to the origin port Stockton and the next departure date from Stockton. Third, there is information on the time between starting one voyage from Stockton to Rochester and starting the next voyage from Stockton to Rochester. We call this the voyage cycle time.

It is worth noting that the Board of Trade records do not consistently report tonnage or cargo. Out of 2050 observed journey times, there is information on tonnage for 205 and on cargo for 325. Below we discuss what these small samples tell us about the relationship between speed, ship-size, and cargo.

1.2 Coastal ports books covering the mid seventeenth century

We compare journey and voyage times in Board of Trade records with several sources that reveal similar information in the mid to late 17th century. The first source is a sample of voyages from coastal Port Books. By way of background, when an English ship's cargo was bound for the domestic market merchants were obliged to post a bond at the nearest customs house that ensured they did not fraudulently export the goods. To facilitate the English system of coastal bonds, the Court of Exchequer required local customs officers to record ship's inward and outward journeys in vellum-bound accounts called Coast Port Books (hereafter Port Books).[16] Before final entry into the Port Books, a written receipt called the *cocket* (hereafter termed a 'manifest') listed goods designated for specified destination ports. Officers recorded the date of the manifest and confirmed the contents of the ship before departure. The master of a coastal voyage presented the manifest at the destination port, where officers made sure the written content of the document matched the arriving cargo. Sometimes the officer recorded the date of ship arrival in a port. Next a dated 'certificate' was given. The certificate was used to redeem the bond, which was later collected at the home port.

[16] The Coastal Port Books constituted a second dimension of government bureaucracy that subsisted alongside regular international Port Books. See Dunn (2015) for details.

As an illustration, there is an entry for the ship Providence in the Spalding Port Book from 1678.[17] A careful reading reveals that the Providence departed from London on 8 September 1678, arrived in Spalding on 26 September 1678, and was certified on 30 September 1678. In this case, we get a journey time from London to Spalding and a time to get certification.

Similar recording dates of manifests and certificates survive in thousands of Port Books. However, at the time of this research in 2016, the archival staff at The National Archives in London had removed most from public access due to mold ingress. Fortunately, we found a group that survived in Exchequer records (E122) containing details of duties paid at particular ports.[18] A new coastal shipping database created from this source covers the period from 1651 to 1683 and it contains over 4000 voyages. Details and analysis of this data are in Dunn (2018).

1.3 Severn port books, 1576-1765

We also make use of an enormous database of coastal shipping records created from the Gloucester Port Books.[19] It yields similar information to Port Books in Exchequer records. However, it is unique because voyages span years between 1585 and 1765. Unfortunately, only voyage departure dates are available due to the way the database was constructed. This limited the analysis to voyage cycles.

1.4 Church tax records, 1689-1695

We are also fortunate to have been provided with another source for the late 17th century. St. Paul's Church Records contain tolls collected on coal imported to London between 1689 and

[17] Spalding Port Book, E122/230/19.
[18] See TNA E122. Coast books were found and digitised for the head ports of Arundel 1656/1681, Barnstaple 1653, Cardiff 1654/1656, Colchester 1651/1656, Exeter 1655, Faversham 1656, Hastings 1656, Hull 1789 (not transcribed), Ilfracombe 1654, Looe 1653, Maldon 1650/1653, Plymouth 1652-4, Milford Haven 1651, Penryn 1650-1, Sandwich 1652, Scarborough 1655, Shoreham 1657, Spalding 1678/1681/1683, Sunderland 1784 (not transcribed) Port books from smaller member ports are often included.
[19] Wanklyn, M.D.G., Wakelin, P., Hussey, D., Milne, G. (1996). *Gloucester Port Books, 1575-1765*. [data collection]. UK Data Service. SN: 3218, http://doi.org/10.5255/UKDA-SN-3218-1

1695.[20] They were transcribed and digitised by Callum Easton, who kindly provided this data. The period covers the Nine Years War and French naval actions against coastal shipping and gives insights into the important north-east coal trade. The entries provide names of ships and masters, while giving the date of their entry into London and payment. Individual ships can be traced as returning to London with coal repeatedly. This allows for analysis of the voyage cycles of individual colliers operating between London and Newcastle or Sunderland.

1.5 Ports

Coasters landed at a wide range of locations, including beaches and large ports. We have created a port list drawn from published and primary sources. Sacks and Lynch (2016) produced a list of ports from 1540 to 1700. Hargreaves (1787) lists customs ports in 1680. Steele (1826) and Daniel (1836) produce lists of ports in the mid-19th century.

Our list of ports from before around 1790 follows the Tudor customs organisation of 'head' and 'member' ports, reflecting the location of customs houses and their jurisdiction over smaller landing places, including harbours, creeks and beaches. In the 19th century, the number of reported ports of all kinds increased due to better information and expansion of the network. Some of these ports were not in the four port lists described above, but are listed in the Board of Trade or Port Books. These were located and added to the database.

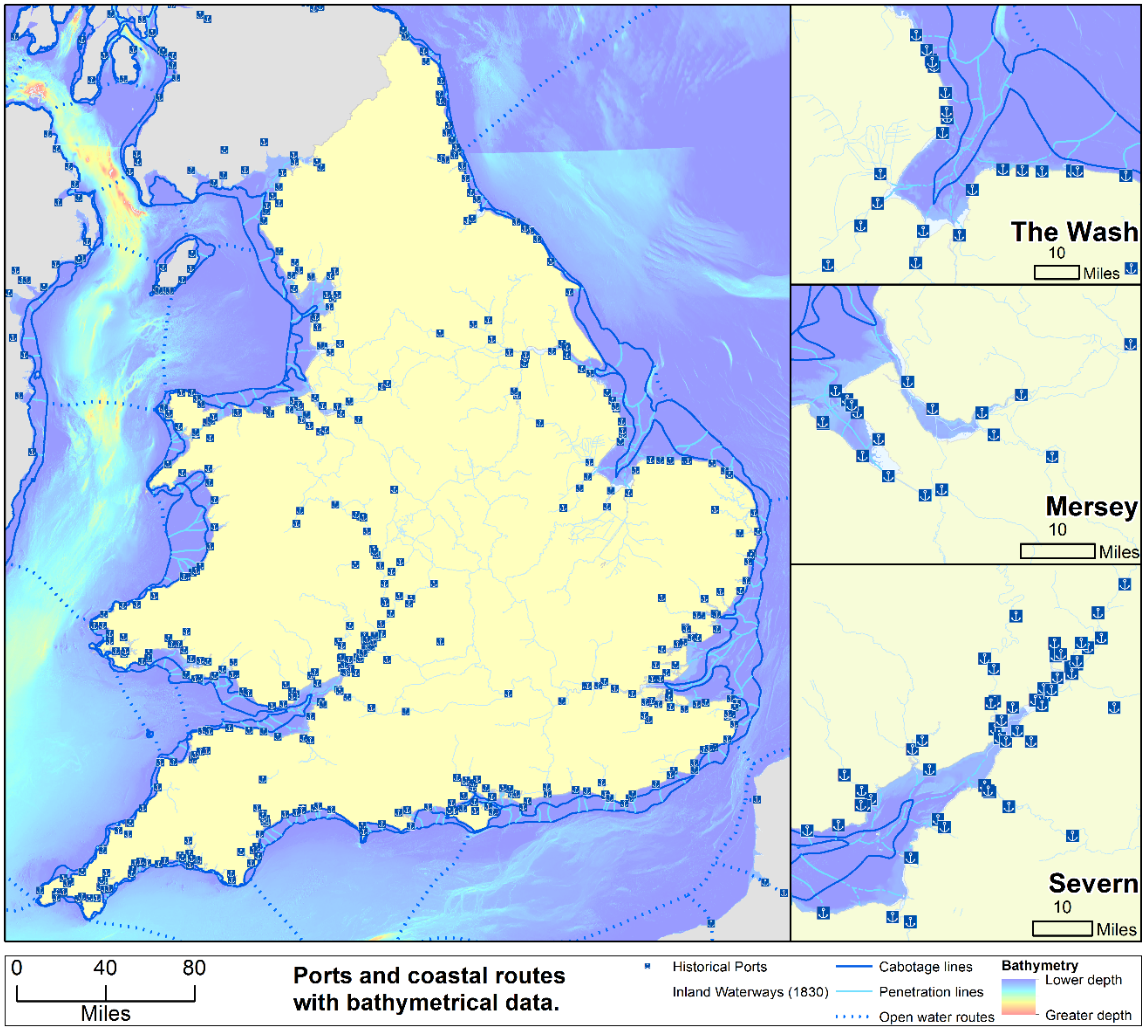
1.6 Coastal routes between ports

We collected and analysed new sources to recreate the historical coastal network using geographic information software (GIS). This geographical mapping program connects raw data with advanced geographical analysis tools. Using GIS, we have been able to digitise coastal trade routes using historical sources to model realistic coastal shipping networks from 1650 to 1840.

[20] These records are available at the London Metropolitan Archive, CLC/313/I/E. Registers of ships bringing coal from Newcastle to London, compiled in connection with the Coal Duty, 1687-95/6 & 1700-5 (Ms 25472/1-3)

Our intention with the network is to define a proximate route ships would take to avoid grounding or sailing dangerously far from the coast. We split our coastal routes into two main types: a national cabotage line, and from this, penetration, or entry lines connecting ports. Cabotage lines follow a 25-meter iso-depth curve that follows the British coastline. In some regions, this curve is naturally nearer the coast than others. Penetration/port-entry lines also employed bathymetrical data to establish the route between port and nearest cabotage line by the minimum depth it was possible to sail. The ports and coastal routes are shown in figure 1 along with ocean depths. The right-hand panels show the detail of our coastal routes in three estuaries: the Wash, the Mersey, and the Severn

Figure 1: The Ports and coastal routes GIS



Sources: see text.

Section 2: Journey times and speeds

Our first task is to identify how journey times and speeds changed between the mid-17th and the early 19th century. We first review methods for calculating journey speeds and times in each source, next basic facts are discussed, and then methods for comparing sources.

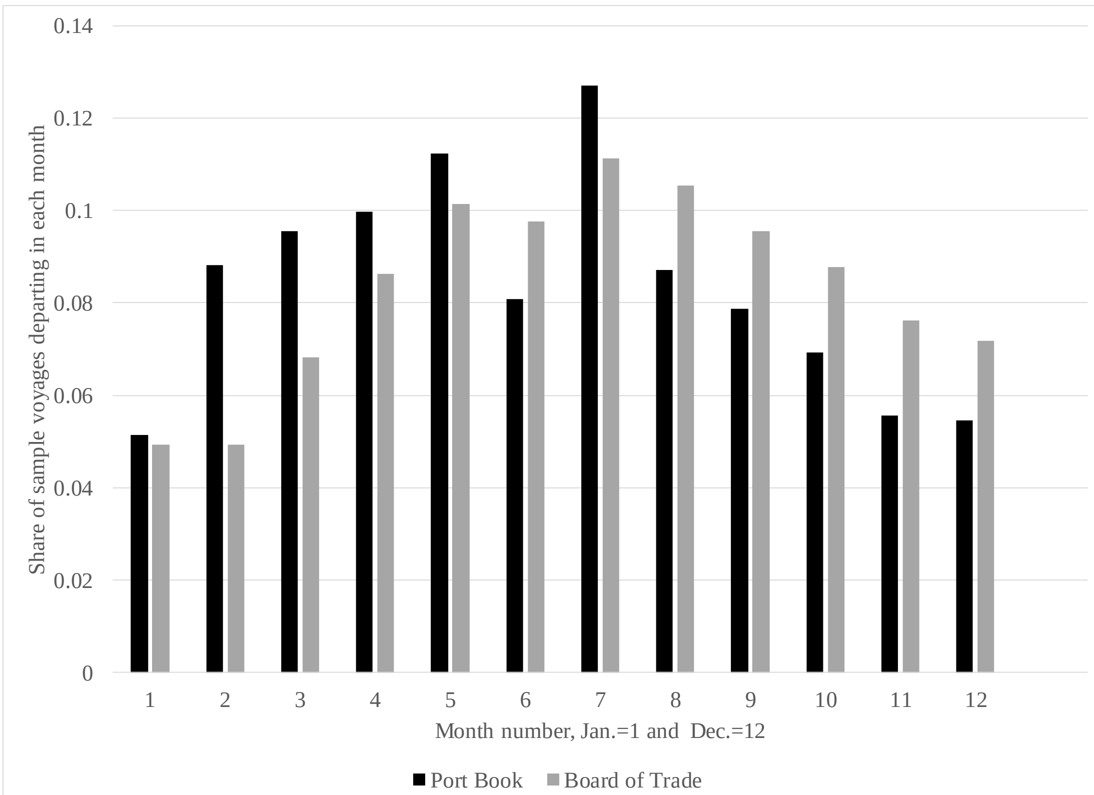
Our first source, the Board of Trade records (BT98), describes individual journeys taken by coastal ships between 1830 and 1845. In many cases, a record lists the day of journey departure and the day of arrival in the port. Therefore, it is straightforward to measure journey times by the number of days between departing an origin port and arriving at a destination port. Drawing on the full sample of Board of Trade records, we measure times for 2050 journeys between 826 port pairs. Journey speeds are measured by dividing route miles between ports by travel time in days. We call this statistic 'journey miles per day'.

The calculation of journey times is more involved in Port Books (E122), our second source. The database contains fields for the following information on each journey: the ports of origin and destination, the name of the ship, and three documented dates - the day of port departure, the day of arrival into the destination port, and the date of the certificate provided by customs officials at the final destination port. Arrival dates always follow departure dates for a journey and certification dates can equal or follow arrival dates. Journey times are most accurately measured by the difference in days between the departure and the arrival date. We observe arrival dates for 953 journeys between 101 port pairs in our baseline Port Book sample.

Certification dates are more common than arrival dates and could be used as another measure of journey times. The problem is that certification could happen within the same day of arrival, several days later, or several weeks later, introducing measurement error. Below we discuss how a larger sample based on certification compares to a smaller sample based on departure and arrival dates.

Seasonality is thought to be an important feature of coastal sailing. We find evidence for seasonality in the number of ship departures by month. Figure 2 shows the distribution for the Board of Trade and the Port Book samples. There is a clear seasonal pyramid. July has the most journeys in both samples. May, August and September are second, third, and fourth. January and February have the fewest journeys. June is the one month that deviates in having fewer journeys than neighboring months. The pattern is especially strong in the Port Books. Robinson (2006) argues that sailings were less common in mid-summer because masters and crew worked the harvest. Perhaps this could explain the low June sailings in the Port Books.

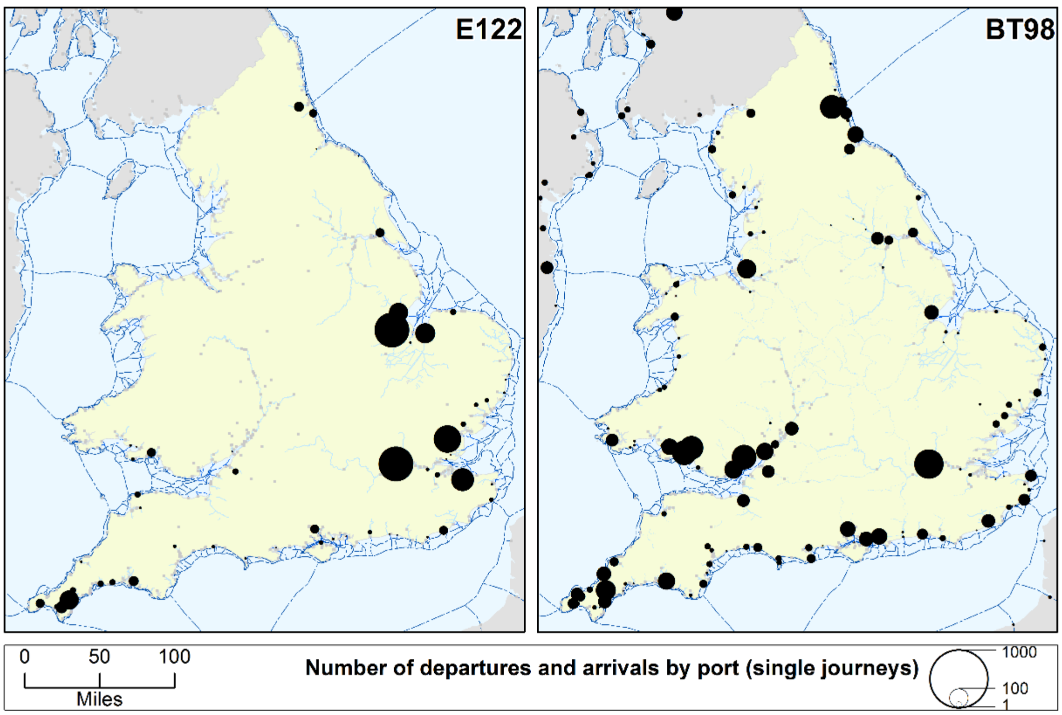
Figure 2: Seasonality in coastal shipping: number of journey departures by month.



Sources: see text.

Maps of the ports involved in our sample journeys are shown figure 3. The circle sizes indicate the number of times a port was an origin or destination for a journey. The Port Book sample (E122) contained more journeys to or from east coast ports. Essex and Lincolnshire are very common, while most southern and western ports are far less common. By contrast, the Board of Trade sample (BT98) shows active coastal shipping across England and Wales. The geographic difference in the samples are due to the survival of Exchequer records. It presents an issue for comparisons of journey times and speed. Below we address this issue by matching journeys across sources on geographic characteristics. The following section explains the methods.

Figure 3: Number of journeys to or from a port in Port books and Board of Trade records



Note: E122 refers to the Port Book sample and BT98 refers to the Board of Trade sample.

2.1 Methods for comparing journey times and speeds

We use departure dates and the latitude and longitude of origin and destination ports to match journeys with similar characteristics.[21] There are several matching techniques in literature. The Mahalanobis scoring measure is arguably most appropriate in our setting because there are few

[21] We observe some ship masters, but they were not the same in the 17th and 19th century so it would be impossible to match on masters.

observables.[22] Let v be a set of journey observables. For each pair of observations in the Port Book and Board of Trade samples, we calculate the matrix product $d' \cdot X \cdot d$, where d is a k by 1 vector of differences in the set of journey observables v and X is the inverse of the k by k covariance matrix of observables v. The resulting product is a scalar or number.[23] The Port Book journey which yields the lowest value for $d' \cdot X \cdot d$ is matched to the Board of Trade journey and its value is called the Mahalanobis score. We allow replacement so that Port Book journeys can be matched to an arbitrary number of Board of Trade journeys.

Journey observables include five variables: $season_i$, $originlat_i$, $originlon_i$, $destlat_i$, and $destlon_i$ The first measures the distance between winter and summer months. The season index equals 0 if a ship departed in the months of June or July; it equals 1 if a ship departed in the months of May or August; 2 if a ship departed in April or September; 3 if a ship departed in March or October; 4 if departure was in February or November; 5 if departure was in January or December. The second and third variables are the latitude and longitude of the origin port. The fourth and fifth are the latitude and longitude of the destination port.

An 'imbalance' could occur if there are not enough good matches for Board of Trade observations, say because the port locations are so different. We use differences-in-means tests for the variables v to identify whether the samples are sufficiently similar. Balance is achieved when the sample is restricted to smaller Mahalanobis scores and the means of the observables are not significantly different in the two samples.

2.2 Sample comparison

[22] See Leuven and Sianesi (2018), Stuart (2010) for more details.

[23] For example, suppose v_{1i} and v_{2i} are the only two observables for Board of Trade journey i and v_{1j} and v_{2j} are two observables for port book journey j. The first element is the 1 by 2 vector is $d' = (v_{1i} - v_{1j}, v_{2i} - v_{2j})$. The two elements are small if the observables for i and j are similar. Such cases will produce a small matrix product $d' \cdot X \cdot d$.

We first summarize journey times and speeds in the baseline samples without applying matching (see table 1). The first column in panel A reports summary statistics for the baseline Port Book sample. The second column reports the same for the Board of Trade sample. Journey times are higher on average in the Port Books (13.6 versus 9.4). Summary statistics for journey miles per hour are shown in columns (3) and (4) in panel B of table 1. Journey speeds are lower on average in the Port Book sample (12.5 versus 52.7). There are some fast speeds in the Board of Trade: 44 voyages (2.2% of the sample) have a speed greater than 200 miles per day. We think some of these journeys are by steam ship. If we drop any journey with a speed greater than 200 miles in a day, the mean speed drops marginally (48.6 miles a day).

How comparable are journeys in the baseline samples? The simple answer is they are not. Columns (5) and (6) in panel C reveal that latitudes and longitudes for origin and destination ports are significantly different. The imbalance suggests matching techniques may improve sample comparability. We now turn to such an analysis.

Table 1: Summary of journey times and speeds

	Baseline sample		Matched	
	Port book, 1650-1680	Board of Trade, 1830-1845	Port book, 1650-1680	Board of Trade, 1830-1845
Panel A: journey times	(1)	(2)	(7)	(8)
Average journey times in days	13.6	9.4	12.5	8.6
Median Journey times in days	9.0	6.0	10.0	6.0
Standard dev. Journey times	17.4	9.7	9.9	9.2
Min Journey times	0.0	0.0	1.00	0.0
Max Journey times	248	78	46	66
(p-value diff. in mean with BOT)	(0.000)***		(0.004)***	
Number of Journey times obs.	953	2050	53	425
Panel B: Journey speeds	(3)	(4)	(9)	(10)
Average miles per journey day	12.5	52.7	17.9	48.0
Median miles per journey day	8.9	38.0	13.6	35.3
Standard dev. miles per journey day	12.8	51.3	12.6	42.1
Min miles per journey day	0.2	0.2	1.4	1.1
Max miles per journey day	205.3	441.8	52.9	225.1
(p-value diff. in mean with BT)	(0.000)***		(0.000)***	
Number of miles per journey day obs.	937	1994	53	415
Panel C: Balance tests	(5)	(6)	(11)	(12)
Mean season index	2.155	2.145	2.11	1.87
(p-value diff. in mean with BT)	(0.878)		(0.284)	
Mean origin port latitude	488,170	331,626	388,306	364,518
(p-value diff. in mean with BT)	(0.000)***		(0.128)	
Mean origin port longitude	234,037	274555	254,414	289,719
(p-value diff. in mean with BT)	(0.000)***		(0.174)	
Mean destination port latitude	469,790	333508	358,367	344,049
(p-value diff. in mean with BT)	(0.000)***		(0.600)	
Mean destination port longitude	201,716	266134	127,538	111,877
(p-value diff. in mean with BT)	(0.000)***		(0.224)	

Notes. ***, **, and * indicate statistical significance at the 1, 5, and 10% level respectively. The matched sample is restricted to Mahalanobis scores less than 0.21. BT refers to Board of Trade.

A summary of the matched Board of Trade and Port Book Samples is shown in the right panels of table 1. We restricted the matched sample to lower Mahalanobis scores to obtain balance (see panel C). We are left with 53 observations from the Port Books and 425 from the

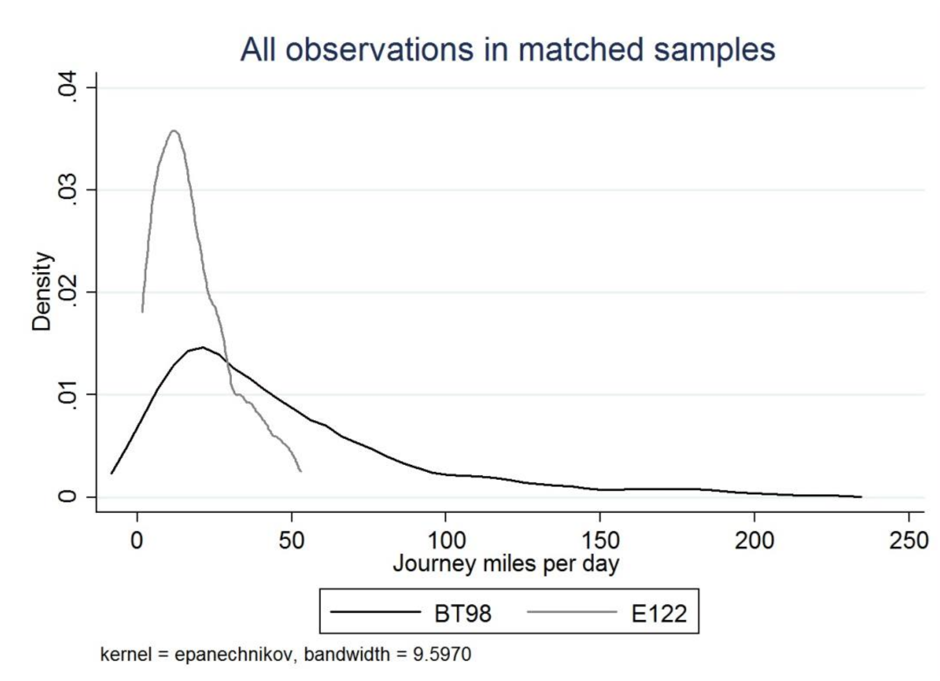
Board of Trade sample. There are two main findings. First, average journey times are approximately 38% lower in the Board of Trade sample compared to the matched Port Books sample (8.57 versus 12.5). Second, average journey speeds are just over 166% higher in the Board of Trade sample (48.01 versus 17.95). We conducted a difference in means test for journey times and speeds. The results show that mean journey time and mean journey speed in the Port Books are significantly different than the same in the Board of Trade records (the p-value is 0.004 and 0.000) respectively.

We also examined the variance in each sample. The standard deviations are very similar for journey times in the two sources. But they are very different for journey miles per day. In the Board of Trade records the variation is much higher. This can be seen in Figure 4 which plots the kernel densities of the matched samples. There is a long right tail to the Board of Trade (BT98), while there is almost no right tail in the Port Books (E122). Why was this so? Many of the high speed voyages in the Board of Trade are associated with ships on long-distance routes. This is illustrated in Figure 5 which shows the distribution of journey miles per day for journeys less than 100 miles. The long right tail is greatly diminished in this distribution. We think long distance voyages increasingly got better ships and crews and were able to sail faster.

It is worth pointing out that comparisons between the matched samples are robust. For example, if we do not restrict our matched sample to be balanced, then we have 148 observations from the Port Books and 1994 for the Board of Trade. The mean journey miles per day are 21.65 and 50.09 respectively. Thus, in the unbalanced matched sample the conclusions are similar. One may want to drop voyages in the Board of Trade matched sample which have a speed greater than 150 or 200 miles per day to exclude steamers. If so, the mean journey miles per day in the matched Board of Trade sample changes to 47.2 and 42.4 respectively. Thus, the concern that the

Board of Trade sample contains steam ships does not overturn the main conclusion. If we use certification dates as the arrival dates for ships in the Port Books, then our balanced matched sample is larger (n=188 for Port Books and n=776 for Board of Trade).[24] In this case, we find the average journey times are 29 versus 9 days (the lower being the Board of Trade). We know that this comparison is biased in favor of the Board of Trade because certification took some time. If 5 days are subtracted from Port Book observations as typical certification times, then average Board of Trade journey times are just over one-third of Port Books (9 versus 24 days).

Figure 4: Kernel densities for journey miles per day in the matched samples



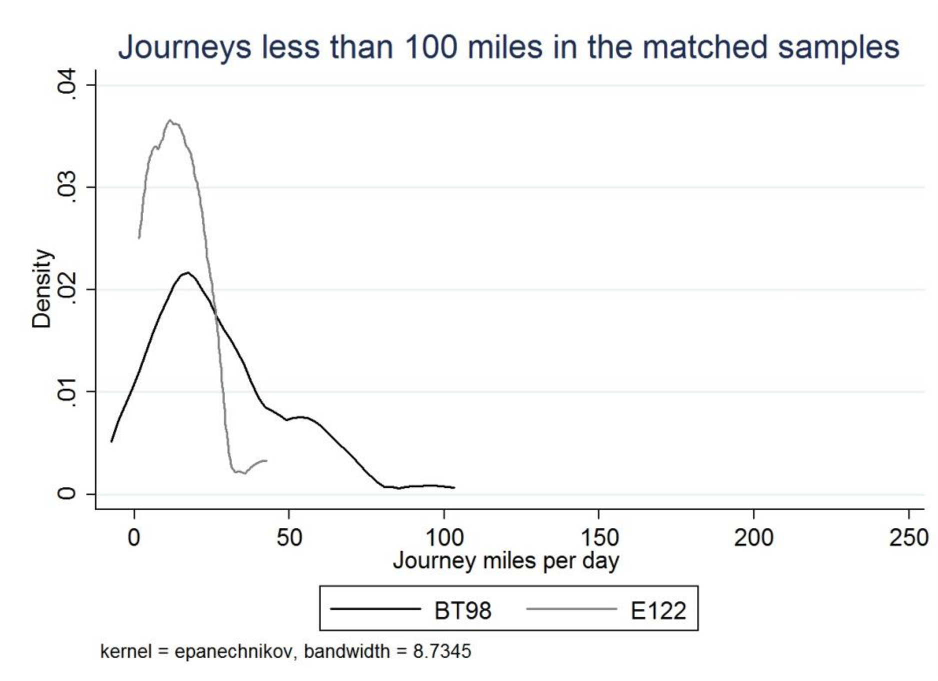
Note: BT98 refers to the Board of Trade sample and E122 to the Port Book sample.

The increase in voyage speeds was caused by many factors. At the moment, we have limited evidence on which were the most important. Armstrong (1991, p. 84) argues for a transition from the square to the fore-and-aft rig, which allowed coastal vessels to make more efficient use of

[24] We restricted the matched sample using certification to Mahalanobis scores less than 0.21 to obtain balance

winds. The transition to metaled hulls was another factor. Metaled hulls increased the lifetime of the ships and were an important innovation in Asian shipping (Solar and Lens 2015). Currently, we don't know how many coastal ships had metaled hulls or the fore-and-aft rig.

Figure 5: Kernel densities for journey miles per day including only voyages less than 100 mi.



Note: BT98 refers to the Board of Trade sample and E122 to the Port Book sample.

Changes in hull length and shape were another potential driver of greater speeds. While we don't observe such ship characteristics they are likely to be correlated with ship size measured in tons. Hausman (1987) provides evidence that average coastal ship size increased in the north-east coal trade from 210 tons in the early 1700s to 280 tons in the early 1800s. In other trades, ships were smaller. Our Board of Trade data show that the average size was 74 tons in the 1830s. For comparison, Willan (1967) claims most coastal vessels were 30 to 40 tons in the 17th century.

The empirical problem is that ship-size effects are hard to separate from other factors. Our full Board of Trade sample contains 205 observations on ship tonnage and journey speed. A univariate regression confirms that ships with larger tonnage are correlated with higher speed. Note there is a similar difference in speeds between coastal and East India Company ships, which were much larger on average. However, once origin and destination port pair dummy variables are included in the regression, the size effect becomes statistically insignificant.[25] It is likely that port dummy variables are capturing unobserved cargo effects. Our Board of Trade data contain 320 observations on cargo carried. They always list a single commodity. The most common are ballast, coal, culm, copper, iron, wood, limestone, and slates. Regressions show that speeds differ depending on these types. Ships with copper had the highest speeds, while wood and iron had the lowest. A more detailed analysis of the speed-cargo-size relationship is needed.

There is one more useful fact to report regarding speeds in our matched samples. We find that speeds *increased* more for journeys departing from the south and west coasts compared to the east coast (see table 2). This finding could be related to differential impacts of peace in the 19th century or greater changes in navigational knowledge along southern and western coasts.

Table 2: Summary of Journey speeds by coast

	Port book, 1650-1680	Board of Trade, 1830-1845
	Average miles per journey day (1)	Average miles per journey day (2)
If voyage departs from east coast	22.59	49.50
If voyage departs from south coast	12.18	44.81
If voyage departs from west coast	18.84	47.60

Sources: see text. Averages are based on the matched sample in table 1.

[25] Results from this regression are available upon request.

Section 3. Voyage cycle times

Voyage cycle times are a useful metric for measuring shipping productivity. A shorter voyage cycle implies that a ship spent less time at sea and/or spent less time in ports loading, unloading, and preparing for voyages. Voyage cycles are inversely proportional to the annual number of voyages, which is another measure of performance. In this section, we measure voyage cycle times. As a first step, we discuss how voyage cycles are calculated.

3.1 Calculating voyage cycles

The Board of Trade records are organized as six-month voyage schedules. We identify all voyages from port A to B, back to A, and then from A to B again without any intervening ports. We record the number of days between an A to B journey and the next A to B journey.[26] In total, 1023 voyage cycles between 237 port pairs are constructed in this source.

The Port Books (E122) require reorganization of the data to identify voyage cycles. We sort journeys by ship and by home port and then by date of departure to create a chronological panel of all journeys for each ship. Second, like the Board of Trade records, we identify sequences of journeys between the same two ports. In other words, a ship must sail from A to B and then its next journey must be from A to B to be counted as a voyage cycle. We calculate the number of days between the first journey from A to B and the start date of the next journey from A to B. The same calculation is made for subsequent A to B journeys until the ship sails to another port C or stops in our records. We observe 1540 voyage cycles from 106 port pairs. Voyage cycles

[26] The observations come in two forms. Some only record a ships movement from A to B and not from B to A. In this case, there is a list of A to B sailings. In the second case, ship movements from A to B then B to A and A to B are recorded. In this case, we calculate the days between the first A to B movement and the next A to B movement.

lasting less than 3 days are excluded since these probably reflect dating errors in our sources. None of the results are sensitive to including 0, 1, or 2-day voyage cycles.

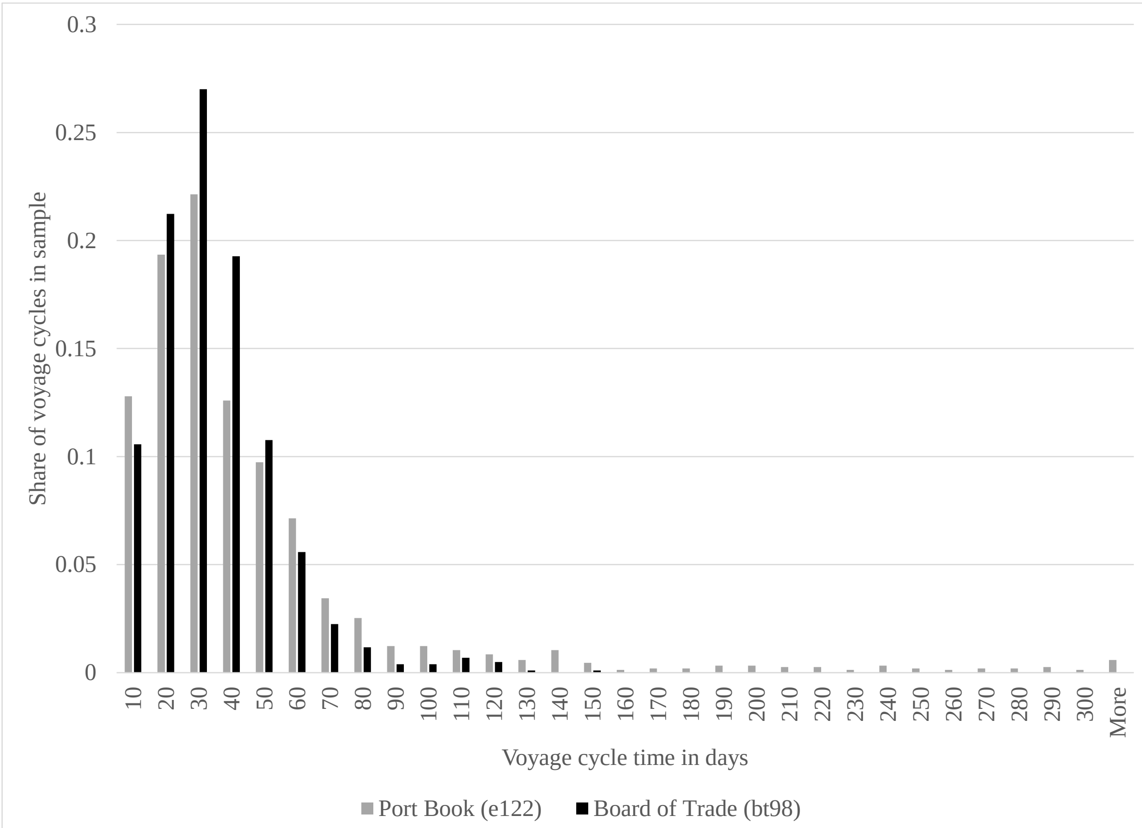
Summary statistics on voyage cycles are shown in columns 1 and 2 in table 3. The average cycle was 30.1 days in the Board of Trade sample and 42 days in the Port Book samples. Very long voyage cycles were more common in the Port Books sample. This can be seen in figure 6 which shows the distributions. There is a non-trivial share (3.5%) of voyage cycles lasting more than 180 days in the Port Books. As these were long spells, it is likely that ships went idle in a port for some time. Idleness could be due to a lack of recording when sailing abroad or when fishing, or because ships were under-utilized, or experienced peril. Unfortunately, we do not know why a ship went idle.

Table 3: Summary of Voyage cycles in Port Book and Board of Trade samples

	All voyage cycles		voyage cycles < 6 months
	(1)	(2)	(3)
Voyage cycle	Port book, 1650-1680	Board of trade, 1830-1845	Port book, 1650-1680
Average voyage cycle in days	42.6	30.1	35.7
Median voyage cycle	28.0	27.0	28.0
Standard dev. voyage cycle	48.3	18.7	28.8
Min voyage cycle	3.0	3.0	3.0
Max voyage cycle	346	143	181
Average distance between port pairs in miles	118.5	262.0	117.2
Number of voyage cycles	1540	1023	1490
Number of port pairs	106	237	102

Sources: see text.

Figure 6: Distribution of voyage cycles in Port books and Board of Trade records



Sources: see text.

Direct comparisons of voyage cycles in the Board of Trade and Port books have two problems. First, idleness greater than 6 months is observed in Port Books and not necessarily in the Board of Trade records. Suppose a ship sailed from A to B and then returned to A and went idle for more than 6 months before sailing to B. There may be no entry for the ship during idleness in the Board of Trade because ships are observed in 6-month schedules. But in the Port Book records if a ship went idle for more than 6 months this idleness time would be counted in a voyage cycle. We address this issue by creating a sub-sample where voyage cycles greater than 6 months are excluded. Summary statistics for the restricted Port Book sample are shown in column (3) of table 3. The mean and standard deviation of the voyage cycle are much lower.

Below we explore more how the conclusions change depending on whether the restricted or unrestricted Port Book sample is being analyzed.

There is a second problem that voyages observed in the Board of Trade and Port books are not comparable because of their different geographic characteristics. We address this imbalance using a similar technique as above. Voyage cycles are matched based on observable characteristics including an index for season of departure, the mid-point of the longitude for the two ports, and the midpoint for the latitude of the two ports. We use the midpoint because voyage cycles do not have a well-defined origin and destination port. The sailing could start in A, then B, and then end in A or the opposite, starting in B, then A, and ending in B. The midpoint for latitude and longitude provides an approximation for port location. The next section gives the details.

3.2 Comparing voyage cycles in Board of Trade and Port Books

Summary statistics for the matched samples from the Exchequer Port Books and the Board of Trade are shown in table 4. Match 1 is for voyage cycles lasting less than 6 months. Match 2 is for all voyage cycles. As above, we restrict the matched samples to lower Mahalanobis scores to achieve balance on all observables (see panel B). We find that the Port Book average voyage cycle was higher in both matched samples. The differences are statistically significant at the 1% level. The degree of the difference depends on whether voyage cycles greater than 6 months are excluded. Port Book voyage cycle times are 34% higher in match 1 (39 versus 25.2) and 104% higher in match 2 (59.9 versus 29.3). The extent of change depends on whether long periods of ship idleness occurred in the 1830s and are not observed.

Table 4: Summary of Voyage cycles in the matched sample

	Match 1		Match 2	
	Port book, 1650-1680 VCs<6 months	Board of Trade, 1830-1845	Port book, 1650-1680 All VCs	Board of Trade, 1830-1845
Panel A: Journey speeds	(1)	(2)	(3)	(4)
Average voyage cycle in days	39.0	25.2	59.9	29.3
Median voyage cycle	28.0	27.0	34.0	24.0
Standard dev. voyage cycle	38.1	18.0	73.4	18.0
Min voyage cycle	3.0	3.0	3.0	3.0
Max voyage cycle	164	143	333	143
(p-value diff. in mean with BT)	(0.000)*		(0.000)***	
Number of miles per journey day obs.	135	877	143	883
Panel B: Balance tests	(1)	(2)	(3)	(4)
Mean season index	2.096	2.044	2.097	2.055
(p-value diff. in mean with BT)	(0.723)		(0.767)	
Mean mid-point ports latitude	438,699	425,766	436,098	425,265
(p-value diff. in mean with BT)	(0.228)		(0.300)	
Mean mid-point ports latitude	229,623	248,218	231,155	249,260
(p-value diff. in mean with BT)	(0.110)		(0.112)	

Notes. ***, **, and * indicate statistical significance at the 1, 5, and 10% level respectively. We restrict the first and second matched sample to Mahalanobis scores less than 1.2 and 1.3 respectively. BT refers to Board of Trade.

The lower variance of Board of Trade voyage cycles is another important difference between the matched samples. Focusing on the match 1 sample, the standard deviation is 50% lower (18.0 versus 38.1). The coefficient of variation is 27% lower (0.71 versus 0.98). Note the contrast with journey times where the variances of the Board of Trade and Port Book samples were similar. The difference is related to port times as we show below. But first we examine more evidence on voyage cycles in other sources.

3.3 Comparing voyage cycles in Board of Trade and Severn Port Books

The Severn Port Books are similar in organization to Exchequer port books studied above. The voyage-level observations are sorted into a “ship panel” using ship name and home port and then by date of departure. From there, we extract 17,365 voyage cycles for 76 port pairs. Much of the data is between Gloucester and a few other ports. We observe 14,167 voyage cycles between Gloucester and Bristol, 960 between Gloucester and Bridgewater, and 1033 between Gloucester and Chepstow. These three port-pairs comprise 93% of the observations.

Summary statistics for the Severn sample are shown in table 5 along with a comparison to the Board of Trade sample. In the full sample, including all voyage cycles, Severn times are longer (45.5 versus 30.2). Restricting the Severn sample to voyage cycles less than 6 months reduces the time gap with Board of Trade considerably (34.6 versus 30.2). The standard deviation is also much lower in the restricted Severn sample.

Table 5: Summary of Voyage cycles in Severn port book sample

	All voyage cycles	voyage cycles < 6 months	
	(1)	(2)	(3)
	Port book Severn, 1575-1765	Port book Severn, 1575-1765	Board of trade, 1830-1845
Average voyage cycle in days	45.5	34.6	30.2
Median voyage cycle	28.0	28.0	27.0
Standard dev. voyage cycle	57.1	29.8	18.7
Min voyage cycle	1.0	1.0	3.0
Max voyage cycle	365	182	143
Average distance between port pairs in miles	55.8	55.2	262.0
Number of voyage cycles	18,363	17,365	1023
Number of port pairs	84	76	237

Sources: see text.

The geographic differences between the Severn Port Book and Board of Trade voyages are a potential problem. Therefore, we again match voyages on observables, including an index for season of departure, the mid-point of the longitude for the two ports, and the midpoint for the latitude of the two ports. We matched only Severn Port Book voyage cycles less than 6 months to any Board of Trade voyage cycle. We also restrict the matched sample to lower Mahalanobis scores until we have a sample size of 31 Board of Trade voyage cycles. We stopped at 31 because it is generally thought to be the minimum necessary for classical statistics. Balance is absent unfortunately because there are not many good quality matches between the Severn Port Book and the Board of Trade samples. Despite these limitations, the results provide insights (see table 6). Voyage cycle times are 100 % higher on average in the Severn Port Books compared to the matched Board of Trade. The coefficient of variation is similar.

Table 6: Summary of Voyage cycles in the Severn matched sample

	Port book Severn, 1650-1680 VCs<6 months	Board of Trade, 1830-1845
Panel A: Journey speeds	(1)	(2)
Average voyage cycle	34.3	17.0
Median voyage cycle	28.0	12.0
Standard dev. voyage cycle	29.50	13.96
Min voyage cycle	1.0	3.0
Max voyage cycle	182	55
(p-value diff. in mean with BOT)	(0.001)*	
Number of miles per journey day obs.	17,149	31

Notes. ***, **, and * indicate statistical significance at the 1, 5, and 10% level respectively. We restrict the first matched sample to Mahalanobis scores less than 5

3.4 Voyage cycles in the Church tax records

St. Paul's Church records are another source for voyage cycles in the 17th century. They list arrival dates in London for ships involved in the north-east coal trade. The time coverage is between 1688 and 1695 and 282 ships are observed. Voyage cycles are calculated as the number of days between ship arrivals in London. In total, we have 1482 voyage cycle observations. As with the Port Books, we consider two samples, one that excludes voyage cycles greater than 6 months and one that includes all observations. Voyage cycles less than 20 days are also excluded in the Church sample because they are likely to be errors. In the Board of Trade sample, the lowest voyage cycle between the north-east and London is 27 days.

Table 7 summarizes the Church records. The average voyage cycle is 96.7 days in the full sample and 75 days in the sample with voyage cycles less than 6 months.

Table 7: Summary of Voyage cycles in St. Paul's Church records, 1688-1695

	All Voyage cycles	Voyage cycles < 6 months
Average voyage cycle	96.7	75.0
Median voyage cycle	70.0	63.0
Standard dev. voyage cycle	70.7	39.0
Min voyage cycle	20.0	20.0
Max voyage cycle	364.0	182.0
Average distance between port pairs in miles	385	385
Number of voyage cycles	1482	1305
Number of port pairs	2	2

Sources: see tex.

There is a remaining concern about measurement error in the Church records because we do not know whether ships went to other ports in between their arrivals in London. To explore this further, we examine the number of times a ship is observed in the Church records in the period from 1688 to 1695. The most common outcomes were for a ship to be observed once or twice during the 7-year period. A minority of ships are observed more than 10 times. We think the latter ships were more likely to be specialized in the trade and could have lower voyage cycle times. However, the data show that ships observed more than 10 times have a similar average voyage cycle time of 89 days.

How do north-east voyage cycles in the Board of Trade sample compare? We have 21 observations between London and Newcastle, London and Sunderland, and London and North Shields in the Board of Trade. The average voyage cycle is 39.1 days. This estimate looks reasonable if we convert into annual number of voyages and compare with other sources. According to one coal trader who testified before a Select Committee, the average number of voyages per year in the north-east coal trade was 11 between 1819 and 1824.[27] Another trader stated the average number was 10 to 12. These estimates may be high if traders did not take ship idleness into account. Nevertheless, between 10 and 11 voyages per year is reasonable. They imply an average voyage cycle between 36.5 (365/10) and 33.9 days (365/11). This is close to our estimate of 39.1 days. We think there is consistent evidence that voyage cycles between the north-east and London were approximately 100% longer in the 1690s compared to 1830-1845.

Section 4. Decomposing voyage cycle times

Voyage cycle times reflect both sailing times and turnaround times in ports. What was the balance between these two? We can answer this question for 184 voyage cycles in the Board of Trade Records. Specifically, we calculate (1) time to sail between ports A and B, (2) time spent in port B before sailing, (3) time to sail between ports B and A, and (4) time spent in port A before sailing again. A summary of the calculations is given in table 8. Strikingly, about twice as much as time was spent in ports as time sailing (23.2 versus 13.6 days).

[27] Report from the Select Committee on Manufactures, Commerce and Shipping: With the Minutes of Evidence and Appendix and Index, p. 449 (BPP 1833 VI).

Table 8: Decomposing Voyage cycles in Board of Trade records

Voyage cycle component	Time in days
(1) Average time to sail between ports A and B	6.6
(2) Average time in port B	11.1
(3) Average time to sail between ports B and A	6.9
(4) Average time in port A	12.1
Average total time sailing (1) + (3)	13.6
Average total time in ports (2) + (4)	23.2
Average time in voyage cycle	36.8
Number of voyage cycles.	184

Sources: see text.

If port times were so important to voyage cycle times, and if voyage cycle times were declining as we show above, then it is likely that time in ports decreased between the mid-17th century and the early 19th century. We can provide some evidence for such a trend. In some Board of Trade records, it is reported when a ship arrives in a port and when it departs following its arrival (i.e. turnaround times). In total, 2,229 turnaround times are observed in 178 ports in the Board of Trade records. In the Port Books (E122) organizing voyages by ship name and date yields instances when outward departure followed arrival dates from the same port and same ship.[28] Unfortunately, only 164 port turnaround times are observed in 3 ports. London has 8 observations, Hastings has 2, and Spalding accounts for 154 observations (Dunn 2018).

The summary statistics are shown in table 9. Port turnaround times averaged 10.6 days in the Board of Trade sample. The average is 24.4 days for the Port Books sample. We can also

[28] This method relies on the accuracy of customs recording of arrival and departure dates, a process of recording that may have taken a day or two if news of ship movements was slow to arrive at the customs house. This should not affect the results dramatically, but varying recording practices must be borne in mind when comparing with 19th century Board of Trade records.

make some direct comparisons between ports over time. In the Board of Trade records, the average time in London ports was 14.91 days (n=96). The average turnaround time for London in the Port Books was 140 days. The London sample in the Port Books is small and perhaps quite specific. The eight ships that stopped in London were all from Maldon, stopping over the winter of 1663-1664. But, even if we take the four smallest observations, then average time in London c.1660 is 70 days. Unfortunately, we do not observe Spalding port times in the Board of Trade records, but we do observe times for Boston, Maldon, and King's Lynn, which are nearby. Spalding's average turnaround time c.1660 was 18.6 days. Boston's average turnaround time c.1840 was 13 days (n=30), King's Lynn was 15.3 (n=47), and Maldon was 7.75 (n=4). Together, these observations suggest port turnaround times fell by one-sixth to one-half.

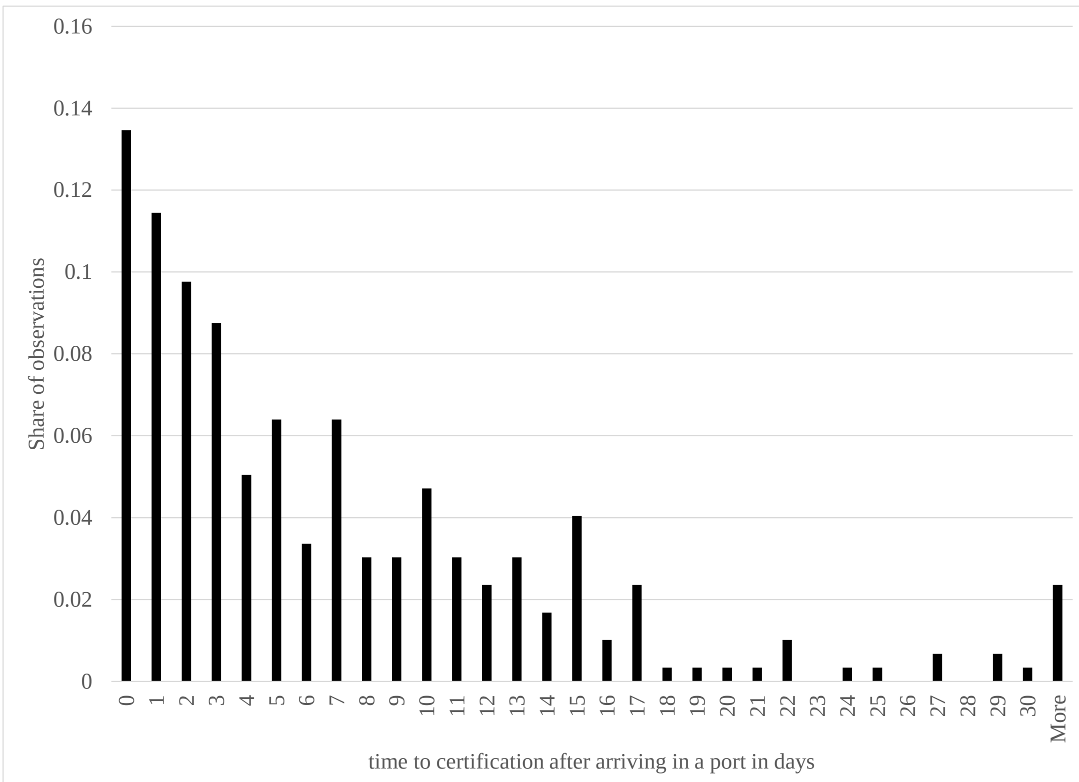
Table 9: Summary of port turnaround times

Port turnaround times in days	(2) Port book Exchequer, 1650-1680	(1) Board of trade, 1830-1845
Average port times in days	24.4	10.6
Median port times in days	14	8
Standard dev. port times	38.5	10.9
Min port times	0	0
Max port times	331	112
Number of port times obs.	165	2229
Number of ports	3	178

Sources: see text.

The coastal bond system was one key factor in the mid-17th century port times. Recall the certification of coastal ships was to ensure they conformed with customs. Certification practices seem to have varied but there is little evidence on how long it took. Dunn (2018) has analyzed 279 certification times in the Port Books and finds they average 8.5 days. However, in some cases, they could last longer - up to 20 or 30 days.[29] The distribution of certification times is shown in figure 9. This strongly suggests that certification meant significantly greater variation in port times. The abolition of coast books after 1800 must have had a beneficial effect on voyage times.

Figure 9: Distribution of certification times in Port Books



Sources: see text.

Lower port times can also be explained by infrastructure improvements in ports. London famously upgraded its port infrastructure in the early 19th century by building several wet docks. London was not alone. In 1830 there were 391 acres of wet dock space and 50 harbours were

[29] In some cases, it was found that ships departed port without their certificates, which were dated later. It seems there could be arrangements whereby certificates would be collected later on a return voyage, indicating that certification practices could vary.

being maintained. By contrast, England had no wet docks and a handful of harbours in 1660 (Pope and Swann 1960). Evaluating the effects of port improvements on time costs is an important task for future work.

Section 5. When did voyage cycles decrease?

We have provided evidence that voyage cycle times decreased between the 17th century and the early 19th century. It is possible that voyage cycle times changed gradually over this long time interval. Gradual change would be consistent with a diverse set of innovations in coastal shipping, each occurring independently. Alternatively, change may have occurred in a shorter time period, because one innovation was crucial or several were complementary. Our data can inform this issue, albeit incompletely.

We begin with evidence on change over time in the coal trade. Hausman (1977, 1984) reports that average number of voyages between London and the north-east was 4.5 for a sample of 13 ships around 1760. However, as Ville (1984) points out, some of these figures are drawn from ships deployed to other trades. Ville calculates 9 voyages per year for 2 ships specializing in the London and north-east trade in the late 1770s. We don’t have strong evidence to identify whether 4.5 or 9 voyages c.1765 is correct, so we assume the average number of voyages in the north-east coast trade was 7 at this date. This implies the average voyage cycle was around 52 days. 52 days is higher than our estimate of 39.1 days for the Board of Trade, and also lower than our estimate of 75 days from the Church records. On this evidence, the major time improvements in the London to north-east coal trade occurred gradually.

There are other sources that speak to the timing of change. As part of a report on the Port of London, Colquhoun (1800, p. 11) gives the annual number of voyages between London and several ports in 1797. The overall average was 7.6 voyages per year for 82 ports. Some of these ports can be matched to voyage cycles in the Exchequer Port Books and the Board of Trade. Dividing 365 by the average voyage cycle in each port gives an estimate of the number of voyages per year. The matches are reported in table 10. They suggest the number of voyages per year was 39% higher in 1797 compared to the mid-17th century (11 versus 7.9). Also the number of voyages was 43% higher in the 1830s compared to 1797. These figures suggest the early 19th century experienced significant improvement in voyage cycle times. But there was still some evolution from the late 17th century to the late 18th century.

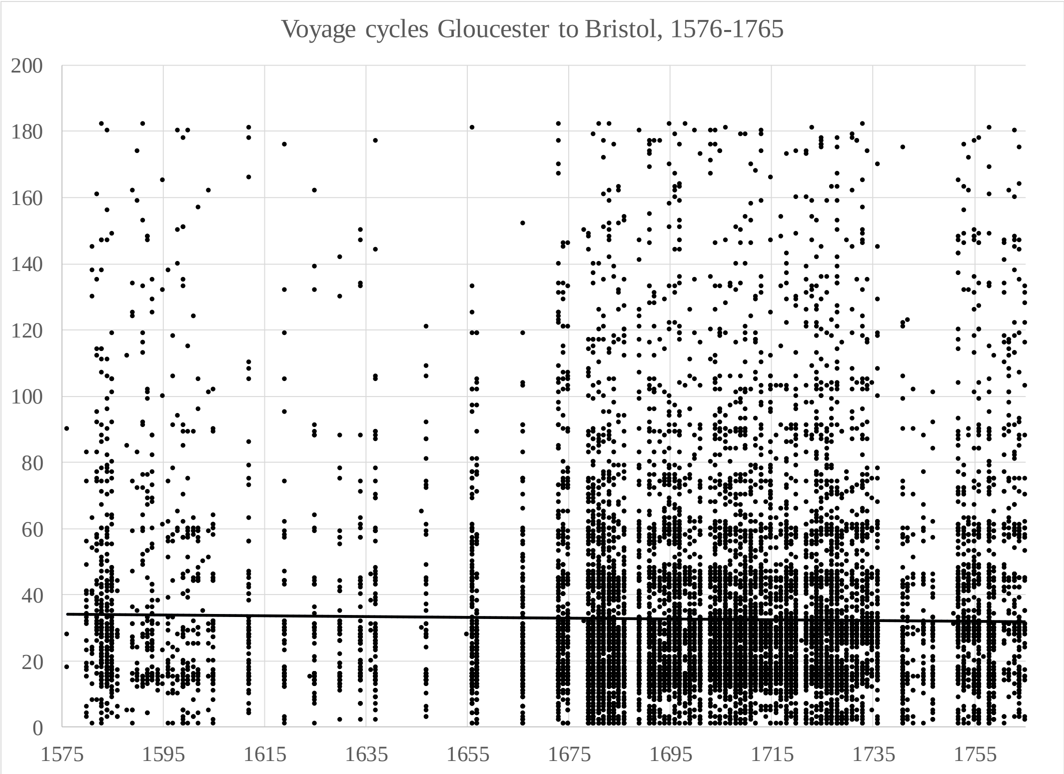
Table 10: Annual number of voyages to London, selected ports

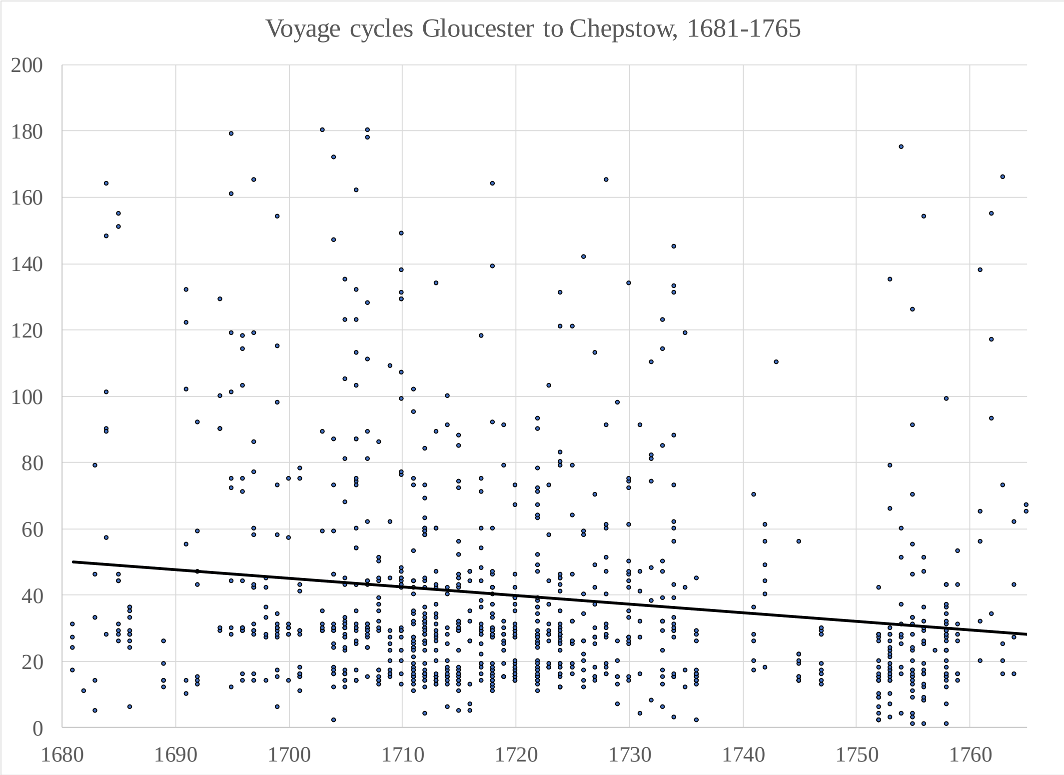
Port	Average from Exchequer port book, 1650-1680	Colquhoun 1797	Colquhoun 1797	Average from Board of Trade, 1830-1845
Bridgewater			4	6.9
Exeter	5.53	6	6	7.5
Hartlepool			4	8.2
Newcastle			9	9.3
Sunderland			9	9.3
Lyme Regis			6	9.9
Stockton			9	10.3
Hull			9	11.5
Ipswich			14	16.3
Yarmouth			9	19.2
Folkstone			15	20.2
Colchester	10.27	16	16	28.7
Faversham	11.09	24		
Maldon	9.66	24		
Average	7.9	11	9.2	13.1

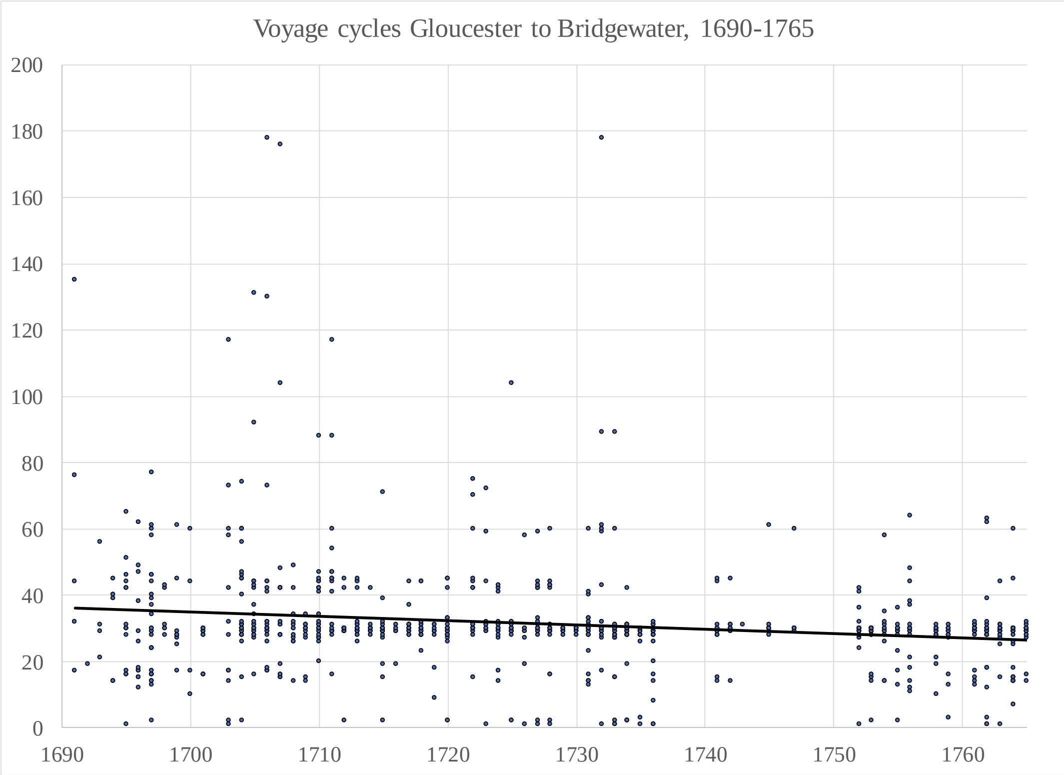
Notes. The annual number of voyages from each port to London is reported. See Colquhoun (1800, p. 11) for 1797. For Exchequer and Board of trade see sources above.

The Severn Port Books are also useful because they document many voyage cycles over a long-time span, 1585-1765. We present scatter plots of voyage cycle times against year of departure for the three main port pairs in the data (see figure 10). The dots represent a voyage cycle time observed in a year. The solid line is a linear trend fitted to the data. The first port pair is Gloucester to Bristol. There is no clear downward time trend, although the 17th century has many years with no observations. Voyage cycles for Gloucester to Chesptow are shown in the next panel. Here there is evidence for a downward time trend. Finally, voyage cycles for Gloucester to Bridgewater are shown in the third panel. Again, there is evidence for a downward time trend. Overall the data point to a gradual change in voyage cycle times. This is consistent with a diverse set of innovations in coastal shipping.

Figure 10: Long-run trends in voyage cycles for Gloucester







Sources: see text

Section 6. Conclusion

We provide the first quantitative analysis on long-term changes in coastal shipping times and speeds during the age of sail from c.1650-c.1840. We introduce an important new data source, the Board of Trade Crew lists. This is combined with coastal Port Books and Church tax records, which provide sources for the 17th century. We calculate journey times, journey speeds, port turnaround times, and times between starting one voyage and starting the next voyage to the same origin and destination, which is labelled the voyage cycle.

Our main question is whether coastal shipping times and speeds changed significantly between the mid-17th century and the second quarter of the 19th century. We show: (i) journey speeds between ports were approximately 160% greater c.1835, (ii) journey times were approximately 50% lower, (iii) voyage cycle times were 50% lower, and ports times were probably 50% lower. Overall, there is consistent evidence that coastal shipping provided speedier delivery by the second quarter of the 19th century.

The implications go beyond coastal shipping and extend to the sources of productivity growth during the industrial revolution. Crafts (1985) and McCloskey (1981) argue that shipping was second only to cotton textiles in its contribution to national productivity growth between 1780 and 1860. Harley (1988) argued that it was fourth in importance behind cotton textiles, worsteds, and inland transport. Our figures are more consistent with the Crafts and McCloskey view. Across several coastal routes, we find the average annual voyages completed per year increased by 42.3% between 1797 and 1837 (the average year in our Board of trade sample). Since annual output per ship equals average cargo capacity C times the number of voyages completed per annum V, the ratio of coastal output per ship in 1837 and 1797 is (C_{1837}/

C_{1797})*(V_{1837}/V_{1797}). Therefore holding the ratio of capacity (C_{1837}/C_{1797}) constant, our figures imply that output per ship rose by 42% or an average increase of 0.9% per annum. If capacity also increased between 1797 and 1837, say by 10%, then productivity increased by 53% or an average increase of 1.0% per annum. These rates of shipping productivity apply only to coastal shipping, but note that coastal represents about 45% of total British shipping in 1845 (Harley 1988, p. 855).

Our results also point to external effects of coastal shipping. Coal, grain, metal wares, timber and a range of other goods were shipped around the coast. Such trade probably fostered the growth of coastal cities and the development of industry.[30] These effects will be quantified in future research.

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