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Speed under Sail, 1750–1850

Morgan Kelly and Cormac Ó Gráda, University College Dublin

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Speed under Sail, 1750–1850.

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Abstract

We measure technological progress in oceanic shipping by using a large database of daily log entries from ships of the British and Dutch navies and East India Companies to estimate daily sailing speed in different wind conditions from 1750 to 1850. Against the consensus that the technology of sailing ships was static during this period, we find that average sailing speed before a moderate breeze (the usual summer conditions in the North Atlantic) rose by one third between 1780 and 1830; with greater increases at lower wind speeds. About one third of this improvement occurs when hulls are first copper plated in the 1780s, but the rest appears to be the result of incremental improvements in sails, rigging, and hull profiles.

1 Introduction

The square rigged sailing ship was a fundamental transportation and military technology of the pre-industrial world, giving the inhabitants of the Atlantic periphery of Europe a decisive advantage over their Mediterranean and Baltic neighbours in maritime trade and warfare; and allowing them to trade with and, increasingly, to subjugate, the inhabitants of other continents. It is therefore surprising that the consensus among economic historians, going back to North (1958, 1968), is that there was little improvement in maritime technology between the introduction of the Dutch fluyt (fly-boat) in the early sixteenth century and the iron steamship in the mid-nineteenth century.

Previous efforts to measure technical progress in ocean shipping have been indirect, focussing either on freight rates or, more rarely, on length of voyage. This paper measures daily sailing speed in different wind conditions directly by making use of a large database, CLIWOC, that compiles over 280,000 daily log book entries from ships of the British, Dutch, Spanish and French navies and British and Dutch East India Companies between 1750 and 1850. These give information about position, wind speed and direction, along with detailed information on the type of ship. While intended for climatic reconstruction, these data allow us to estimate how the sailing speed in open water of precise categories of ship in different wind and sea conditions evolved between the mid-eighteenth and mid-nineteenth centuries. We focus on three categories of ship for which CLIWOC provides the most extensive data: British East Indiamen, frigates of the Dutch Navy, and warships of different rates of the Royal Navy.

Our results are striking. For ships sailing before a moderate breeze (Beaufort Force 4, the normal summer wind conditions in the North Atlantic) daily speed increased by around one third between 1750 and 1830: from an average of 4.5 to 6 knots. This increase is not steady but occurs in two bursts: the first during the 1780s when sailing speed improves by half a knot to 5 knots, and the second after 1815. In stronger winds the increase is lower; while in light breezes increase it is greater, with sailing speed almost doubling from 2.5 to nearly 5 knots. Ships were sailing faster in light breezes in 1830 than they had been in moderate winds in 1750.

By the standards of the early Industrial Revolution the rates of improvement in our data are more than respectable. To what are they due? The improvement in the 1780s coincides with the introduction of copper plating of hulls, which protected against boring worms and slowed fouling of the hull by weed and barnacles. The improvement in the post-Napoleonic period does not appear to be associated with any individual major innovation and is likely to be due to incremental innovations in hull profiles, the design of sails and rigging, and the setting of sails.

A potential shortcoming of our analysis is that it ignores economic motivations: could market incentives have caused ship to be sailed faster with constant technology because crews increased in size or were worked harder to maintain optimal sail settings as wind conditions changed. That this is not the case can be seen from the fact that the focus of our analysis is for ships sailing ahead of light to moderate breezes when all sails would have been set and minimal adjustments to settings needed. When tacking into a breeze, a situation where frequent changes of sail setting are needed so the impact of increased incentives to sail faster will be most apparent, we find that the only improvement in sailing speed occurs when coppering is introduced in the 1780s.

The rest of the paper is as follows. After a literature review, we review some of the major improvements in maritime technology in Section 3 In Sections 4 and 5 we outline the data we use and engage in exploratory analysis to highlight the strong non-linearities and interactions present. Section 6 presents our findings for the sailing speed of the three classes of ships analysed, while Section 7 presents shorter series for the Dutch East India Company and Spanish packet boats.

2 Literature Review.

The cliometric literature on early modern economic growth began with North (1958, 1968) and Walton (1966, 1967; see too Shepherd and Walton 1972). Using ocean going sailing ships as a case study, North inferred positive productivity growth from a comparison of freight rates and input prices on the North Atlantic c. 1660-1860. This productivity growth, it was claimed, stemmed mainly from increasing specialization rather than from technological change, as the expansion of markets generated efficiency gains in terms of turnaround times, manpower, and load factors.

For North ocean freight shipping is the paradigmatic example of productivity growth in a world of limited technological progress. Between the introduction of the Dutch fluyt (or fly-boat) in the early sixteenth century and the steamship in the nineteenth, North argued, technological progress in shipbuilding was minimal. Productivity change, reflected in declining freight rates, was mainly due instead to 'Smithian' growth, i.e. extending the market in order to make efficiency gains and to avail of technologies previously available but not commercially viable. North (1958) already drew attention to the role of trade growth and particularly the development of backhaul freight (whether in the form of colonial produce or immigrants) in increasing productivity; later he and Walton would highlight the roles of quicker turnaround times and the public provision of protection against pirates (compare Söderberg, 2011). The modest secular growth in productivity he found was, he claimed, the product of institutional changes and the growth of long-distance trade. However, average ship speeds on the ocean registered no sustained increase 'throughout the whole Colonial period, up to the Revolutionary War'. North concedes that there was some increase thereafter, but this was inferred by comparing two very different ship types: freighters before 1775 and packet boats in 1818-17 (Walton, 1967: 73-74; North (1968): 962-3).

North assumed that the long-distance transport of goods was a homogeneous output whose price was measured by his freight rate index. These findings were heavily qualified in Harley (1988), using a broader range of freight data from British sources: he attributes North's results to the dominant role of cotton, an atypical product, in his estimates of American export freight rates; other rates fell little before the mid-nineteenth century.

North explicitly excluded any product differentiation linked to speed, by omitting data associated with the clipper, which was 'designed for speed' and charged a considerable premium for traffics with high inventory costs (North, 1968: 967). Yet contemporary accounts suggest that speed mattered to both traders and travellers before the advent of the clipper (Cotton 1949: 119-23), and that efforts to increase it preceded the clipper by a century or two (Chapelle 1967). And there is some evidence of improvements in ship speeds on the high seas (e.g. Morgan 1993; Ville 1986: 386). Rönnbäck (2012), using the Transatlantic Slave Trade Database (TSTD2 2008), finds that the speed of slave ships plying the Middle Passage rose significantly in the early modern era, corroborating earlier work by Klein (1978);. He estimates that speeds increased at an annual average of 0.3 per cent during the eighteenth century, so that a voyage taking ninety days c. 1700 would have been achieved in sixty days a century later. The outcome was not due to improved ships, but to mariners becoming more adept at using or avoiding seasonal winds. Solar (2013) has found evidence of increasing speed for the ships of the East India Company between the 1780s and the 1820s, while Solar and Hens (2013) and Solar and Rönnbäck (2015) extend these findings.

3 Technology.

The Northian paradigm assumes that, insofar as the design of both warships and cargo ships was concerned, 'all the major breakthroughs' had already been made by the mid-seventeenth century. McGowan (1980, 5) concurs: 'from the middle of the 15th century, when the development of the three-masted ship of the northern tradition had made trans-oceanic voyages a commercial possibility, until the first quarter of the 19th century, ships had changed remarkably little'. Unger (1998, 32) sees the same pattern for naval vessels: from the mid-seventeenth century until the advent of 'cheaper iron, steam engines and reliable breech-loading guns warship design was almost fixed'. Technological advances in shipbuilding in this era, such as they were, involved incremental refinements rather than revolutionary leaps forward (Gilfillan 1935; compare Harley 1971).

However, in analyses of the European economy between the early sixteenth and nineteenth centuries, shipping is usually numbered among the most dynamic sectors (Barbour 1930; Davis 1972; Menard 1991; Shepherd and Walton 1972; Unger 1998, Unger (2011)). Europe's merchant fleet expaned from about one million tons around 1600 to 3.5 million tons by 1800, an average growth of about one per cent per annum (Unger, 1998: 258).

Trade grew in tandem: de Vries (2010) calculates that Europe-Asia trade grew by an average of over one per cent per annum from around 1500 to 1800, while the much more important Atlantic trade grew at least twice as fast. For comparison, Maddison reckons that GDP in Western Europe grew by around 0.4 per cent per year between 1600 and 1820.[1]

Given such dynamism, the incentives to economize on inputs were considerable. And, indeed, there were several well-documented local improvements. One such improvement was the replacement of the whipstaff and the tiller by the ship's steering wheel beginning in the 1690s (McGowan (1980, 15–16); Rodger 2004, 221–222). By the end of the eighteenth century the ship's wheel was standard. Its use permitted finer adjustments to direction and increased the scope for taking advantage changes of wind directions. McGowan (1980, 16–18) links the practice of adding triangular headsails onto the standard three square rigging to the adoption of the steering wheel, because the wheel allowed greater precision and the headsails allowed greater manoeuvrability when tacking into the wind. Rodger (2004, 222 compare Harland 1985: 21, 36-7, 55, 81) notes that these changes made ships easier to handle 'with smaller crews in proportion to their size'.

One the most famous improvements, dating from the 1770s, was the discovery that the sheathing of ships' hulls below the waterline with copper plates offered protection against shipworm (Teredo navalis), a particular threat in warmer waters, and also reduced biological fouling by weed and barnacles. Greater speeds at sea through lower hull friction and less time spent being scraped clean in dry dock resulted (Harris, 1966; Rodger, 2004). The decision to copper the entire Royal Navy was taken in 1779. For naval ships an extra

[1] Rising from 65.5 billion to 158.9 billion 1990 international Geary-Khamis dollars. Maddison's data are available at www.ggdc.net/maddison/

half knot was a huge gain at a time when the maximum speed in battle was five or six knots; indeed, Admiral Rodney attributed his famous victory at Cape St Vincent in January 1780 to his fleet's copper bottoms. However, attaching copper plates to the hull with iron nails proved problematic, with electrostatic corrosion of the bolts causing two big ships to founder off Newfoundland in 1782; and by 1786 the Navy was converting to copper nails. Rodger (2004, 344–345) estimates that coppering increased the operational strength of the navy by one-third.

Nearly all ships trading to Asia and Africa (including the EIC fleet) were coppered by about 1790, and most ships trading to the West Indies, South America and the Gulf coast of the U.S. were coppered by the early 1800s; but cost precluded its adoption in colder waters: even by 1830 most ships on the North Atlantic route were not coppered. As a result, while most ships in the relevant trades were coppered by 1800, overall rates were low, with 7 per cent of ships registered in Britain sheathed in 1796 and 18 per cent in 1816 (Rees, 1971; Staniforth, 1985: 24-6; Solar (2013)).

Navigation improved too. The backstaff or 'Davis quadrant', which allowed a ship's latitude to be reckoned with accuracy, appeared in the 1590s, followed by the more precise octant and sextant in the early and mid-eighteenth centuries. 'Dead reckoning' and taking lunar position with a sextant offered means of determining longitudinal position. These methods were rather crude, however, and sailors were inclined to 'over-estimate rather than underestimate the number of leagues so as to be warned of their approach to land, rather than running upon it suddenly' (cited in Randles, 1995:402).

The marine chronometer offered a more reliable solution. In 1714 a series of high-profile disasters or near-disasters prompted the British House of Commons to offer a prize of £20,000 for a reliable way to estimate longitude, and this led eventually to Harrison's 'sea watch' (H4) in 1759 (Landes, 1983: 146-62; compare Randles, 1995). However, as with copper cladding, the relative expense of these first chronometers limited their adoption: production remained craft-based and it took some decades for a stable design to emerge. Chronometers did not become a standard feature on ships of the Royal Navy until the mid-1820s, and their use did not become universal until the 1840s (Britten, 1934, 230; Rodger 2004, 382–383).

Other improvements during the age of sail included the increased availability of reliable nautical aids and treatises on shipping navigation, (notably Seller's Atlas Maritimus, 1670 and the Nautical Almanac, 1767); the increased seaworthiness of bigger ships of a thousand tons or more; better hull design; and, eventually, the development of faster ships such as the clipper. Indeed, while North (1968) based his argument that the reduced risk of piracy allowed a marked reduction in crew sizes between the 1720s and 1760s on data from Davis (1972, 74–76), Davis himself attributed the reduction to 'a technical advance of some magnitude', which he tentatively attributed to improved hull design and rigging.

The evolution of sails, rigging, and ship handling are described in detail in the standard reference of Harland (1985). For instance, between the mid-seventeenth and mid-eighteenth centuries, ships acquire jibs and staysails, while the topsails take over from the courses as the main driving sails (pp 36–37).

4 Data Sources.

This paper derives ship speeds in different wind conditions from a new source. In the early 2000s the Climatological Database for the World's Oceans (CLIWOC) assembled data from British, Dutch, Spanish, and a very few French ships' logbooks to chart oceanic weather conditions from 1750 to 1850.[2] Logbooks were an essential part of navigation: for each day, they recorded position, time, bearings, weather conditions, wind direction and speed, distance covered over the previous twenty-four hours, and other relevant details. Some logbooks could be quite discursive, while others stuck mainly to quantitative data (Herrera et al. 2006; Können and Hoek 2006; Wheeler et al., 2006; Wilkinson, 2005).

CLIWOC data run from 1750 to 1850. Daily observations on longitude and latitude allow computation with elementary spherical trigonometry of daily distance sailed (course made good) and bearing. CLIWOC also gives wind direction and estimated wind speed, translated by the database compilers from verbal descriptions of wind conditions into the standard Beaufort scale: not all of these translations are correct, as we shall see below. We omit observations that CLIWOC identifies as coastal (where speed would have been constrained), days with no wind, and days where position remained unchanged (in port or at anchor).

We end up with 14,374 observations from 1750 to 1829 for the EIC, and 24,066 from 1750 to 1827 for the Royal Navy. We omit observations with wind speeds below 1 knot or above 30, and sailing speeds above 12 knots. Note that the standard North Atlantic wind speed at 50 degrees north during the summer is Force 4, rising to Force 6–7 in winter (Sandwell and Agreen 1984).

Figure 1 plots the daily position for all observations for EIC ships and Dutch frigates (with blue denoting observations before 1780 and red observations after 1820) and Royal Navy ships, showing the circular courses taken by ships following oceanic winds and currents. The straight lines on these Mercator projections show that the ships are typically following a fixed compass heading rather than navigating great circles. In the case of the EIC, it can be seen that ships are following the same course in both periods: Europeans had already been sailing to the India Ocean for 250 years by 1750, so the best course had evidently been learned before our period. Dutch ships change from mostly sailing to West Africa (where the Dutch maintained a slaving outpost) before 1780 to Java after 1820. The bunching of daily sailing speeds around the equator, and as ships made the difficult eastward run around southern Africa, are evident.

Figure 2 shows the raw data of daily distance covered, expressed as nautical miles per hour (knots, where a nautical mile is a minute of longitude at the equator, or 1.8 kilometers), by year for the East India Company (EIC),

[2]The data and accompanying documentation are available online at http://www.ucm.es/info/cliwoc/cliwoc15.htmI; Wheeler et al. (2006).

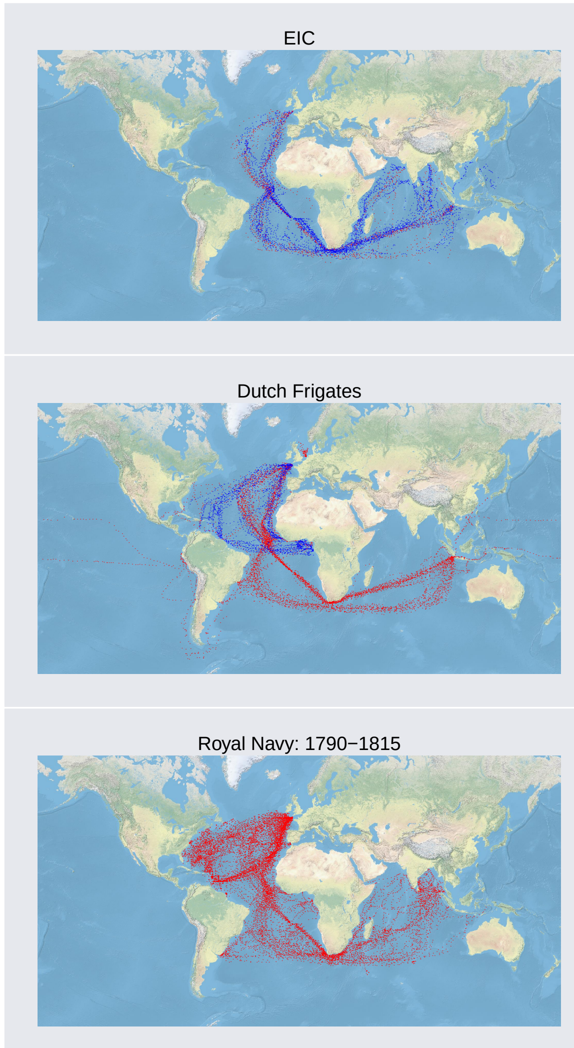

Figure 1: Daily positions for the East India Company, Dutch Frigates, and Royal Navy. In the first two panels, observations before 1780 are blue, while those after 1820 are red.

Dutch Frigates, and Royal Navy, with a locally weighted sum of squares line added to show trends in the data. It is clear the there is some improvement in sailing speed, at least for the EIC and Dutch Frigates, but that variability of observations is very large. The three wars in this period (The Seven Years War, 1756–1763; the American War of Independence, 1779–1784; and the Revolutionary and Napoleonic Wars, 1792–1814 excluding temporary cessations) are shaded and stand out as episodes of lower sailing speed. It can also be seen that

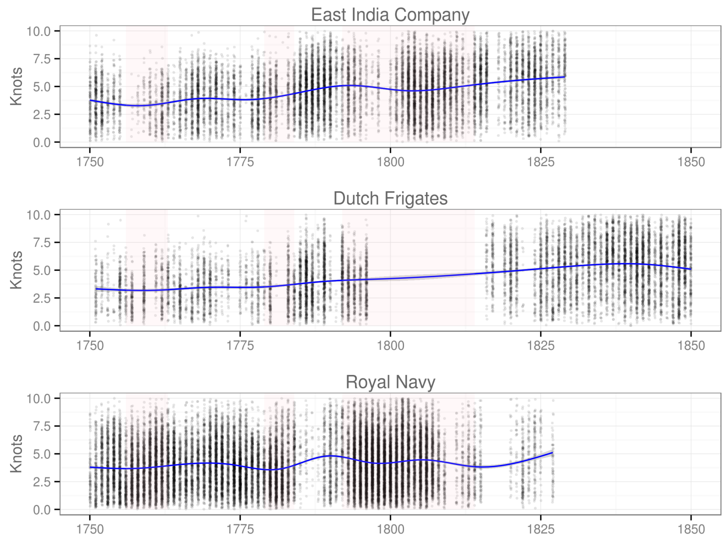

Figure 2: Raw observations of sailing speed for EIC, Dutch frigates, and Royal Navy.

data for the Royal Navy are sparse after 1815, which means that out conclusions about sailing speed during this time must be tentative.

The wind conditions encountered in our sample are summarized in Figure 3. The wind speed, in knots, is the midpoint of the Beaufort category that the compilers of CLIWOC thought most closely fitted the original log observation. Observations above 34 knots, corresponding to gale force, are not included. For the Royal Navy, it can be seen that the commonest condition is a Moderate Breeze of 11–16 knots, Force 4, with Fresh Breezes of Force 5 and Light Breezes of Force 2 also common. For the East India Company, whose route took its ships through the South Atlantic and to the edge of the Roaring Forties, higher winds of Force 6 and sometimes Force 7 occur. For both the EIC and Royal Navy, observations of Force 3 are largely absent and, we will see, appear to be conflated with Force 2. For the Dutch observations, by contrast, Force 3 is the commonest wind speed even though they are sailing in similar waters to the East India Company. It is evident from estimated sailing speed below, that the Dutch Force 3 observations are, in most cases, Force 4.

The wind angle is the angle of the wind recorded on the day, relative to the direction that the ship headed on that day. An angle of zero degrees corresponds to heading straight into the wind. It can be seen that the commonest point of sail was before the wind, as the ship followed prevailing winds and currents, or at right angles to the wind. As well as the course made good, we have the distance that the ship recorded that it sailed. When sailing before the wind, the distance sailed is about twenty-five per cent higher than the distance covered, reflecting the fact that the ship typically sailed a few degrees off the wind to

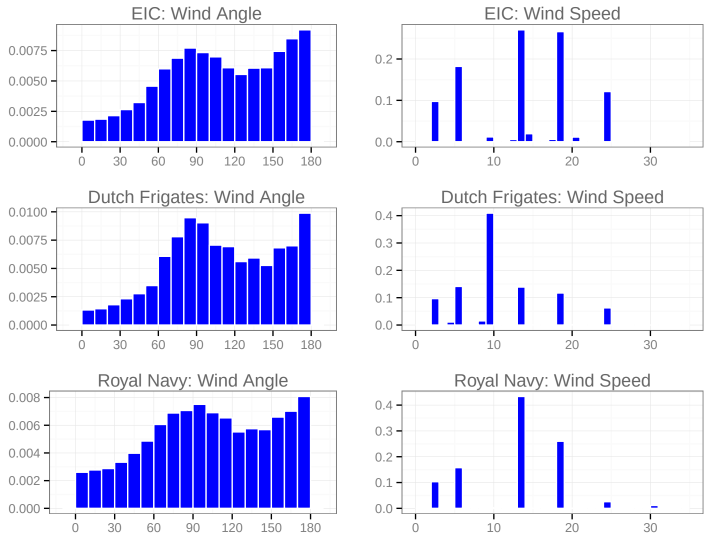

Figure 3: Data on points of sail and wind speed.

prevent sails from interfering with each other, and to allow headsails to function. The ratio of distance sailed to course made good of course rises with the wind angle, but remains constant through time: ships in our sample did not tack into the wind more efficiently as time passed.

5 Exploratory Analysis.

As the raw data on sailing speed through time in Figure 2 make apparent, the increase in sailing speed through time is non-linear, making OLS estimates misleading. By way of a preliminary data analysis we apply a semi-parametric analysis, where each explanatory variable is fitted using a penalized spline (Wood, 2006, 217–265). To explain average speed we include the year of the observation, wind speed, and the angle of the wind relative to the ship's course. As well as wind, ocean currents strongly affected a ship's progress. To allow for the fact that ships moved at different speeds in identical wind conditions in different parts of the ocean, we include latitude and longitude as explanatory variables.

A final factor in speed is the size, shape and direction of waves—these as a group are called "sea state". Even with favourable winds, short steep waves can bring you to a standstill. These most commonly happen when the wind and tide are working in opposite directions but are not an issue here where coastal data are excluded. But it doesn't entirely deal with the problem. (Also the rolling of the ship can reduce sail effectiveness even with long, low waves.) However, storms, even distant ones, can bring up heavy seas that last long after the winds

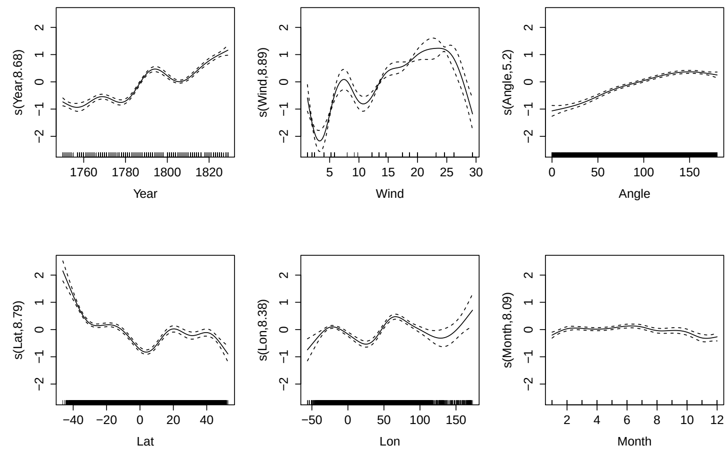

Figure 4: Penalized spline estimates of determinants of EIC sailing speed.

have returned to normal. We therefore include month of the year to allow for variations in sea state.

We include the six variables of year, wind speed, wind angle, longitude, latitude, and month in the semi-parametric regression for the EIC summarized in Figure 4. (To keep the focus non-linearities in the data we ignore, for now, the strong interactions between variables.) The shape of these functions represent spline transformations of the each variable to produce an optimal fit. The numbers of knots chosen by the algorithm are listed on the y-axis of each figure, with higher values denoting less smoothing. It can be seen that sailing speed increases with wind speed (although the low number of observations at low wind speeds cause some misbehaviour), reaching a peak around 25 knots. This is the exact wind speed (Force 7) at which ships would reef topsails (Harland, 1985, 53); lowering other sails as wind increased. Sailing speed rises gradually with angle to the wind, peaking at around 150 degrees. Sailing speed rises as the ship heads south from England, dropping around the equator and picking up as it heads into the south Atlantic, with markedly high speeds below 30 degrees reflecting the effect of the strong Agulhas and Benguela currents on ships returning around Africa. Time of year has a negligible impact.

The time pattern is revealing. Sailing speed appears more or less constant until the 1780s, and then rises sharply until the start of the Napoleonic wars. It then falls slightly but recovers and grows strongly until the end of our sample period.

We also ran regressions with the speed of the ship and wind measured in logs rather than in levels. These produced heavy lower tails of very large negative residuals, indicating misspecification.

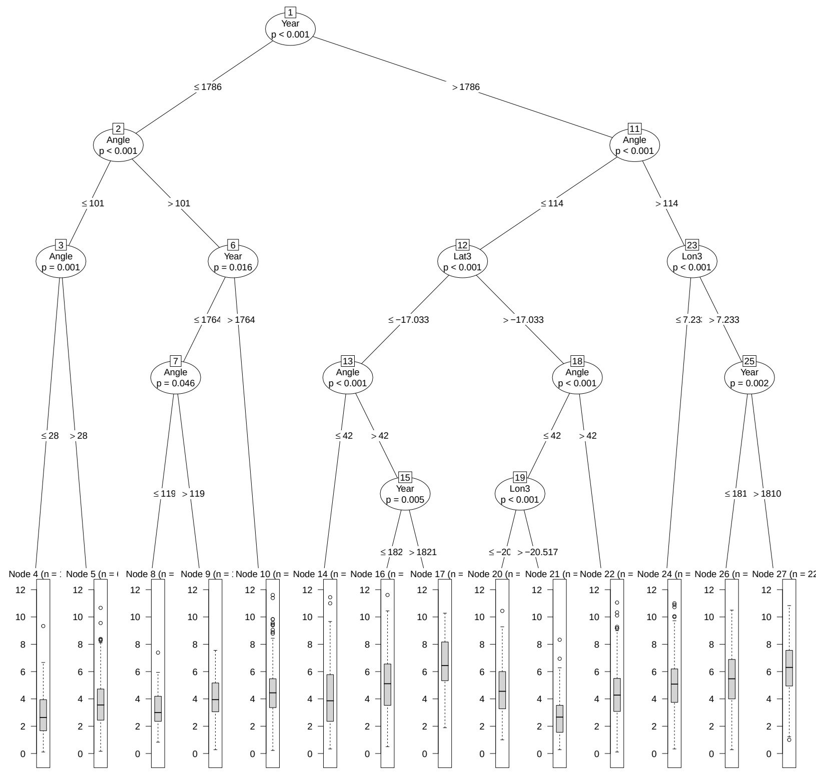

Figure 5: Classification tree of EIC sailing speed in Moderate Breeze.

5.1 Classification Trees

There are strong interactions in the data: as well as wind speed and direction, the speed of a ship will depend on currents which are determined by its location (longitude and latitude) in the ocean. A useful way to start exploring interactions in the data is with a classification tree: here we use the unbiased recursive partitioning framework of Hothorn, Hornik and Zeileis (2006). This is a two-step procedure where the covariate with the highest association with the dependent variable (based on a Strasser-Weber permutation test) is chosen, and this covariate is then split to maximize the difference between the dependent variable in the two subsets. The procedure continues until the p-value of the test for independence between the dependent variable and the covariates, reported at each node, falls below 5 per cent.

Figure 5 gives the first three levels of a tree for EIC ship speed in Moderate Breeze. It shows that the most important split occurs in 1786, with coppering,

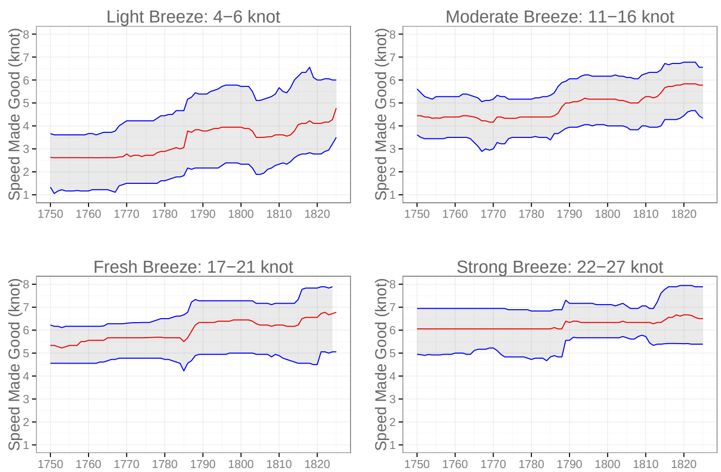

Figure 6: Median and quartiles of speeds of EIC ships sailing before winds of different strength.

and that in both sub-periods the most important split is the angle to the wind being greater or less than around 110 degrees.

6 Evolution of Sailing Speed.

A notably successful evolution of classification trees in terms of obtaining high explanatory power without overfitting is the random forest methodology of Breiman (2001). Here, in a data set of size N with p potential explanatory variables, we bootstrap (sample with replacement) a large number of samples of size N, and for each of these we grow a tree. To minimize potential problems with explanatory variables, at each split in the tree we choose randomly a subset of m variables (where typically $m \approx \sqrt{p}$). In bootstrapping the sample, each time around one third of observations are not chosen, which means that we can average the prediction error for each observation over all trees. To assess the importance of each explanatory variable we can assess how this prediction error changes when the values of the variable in question are randomly permuted. In this paper we use present results computed using the Quantile Regression Forest variant of Meinshausen (2006), implemented in the R package 'quantregForest'.

As noted above, the estimates of wind speed are tentative. We therefore partition the data into different wind speeds, analyzing each separately. This gave notably tighter confidence intervals for sailing speed.

6.1 East India Company.

The EIC logbooks cover 311 voyages by 79 ships giving 15,840 usable observations. Looking at variable importance, for a moderate importance we get Year= 0.79, Angle to wind = 0.50, Latitude= 0.47, Longitude= 0.32, Month= 0.08. The correlation between predicted and recorded speed is 0.68. In a light breeze the respective values of the 4 variables are 0.58, 0.28, 0.57, 0.20, 0.06 and the correlation is 0.67.

Figure 6 gives the estimated median and quartiles of sailing speed, assuming a wind angle of 180 degrees. (The diagrams are calculated assuming that the ship is 50 degrees north, 10 degrees west.) It can be seen that the largest increases in sailing speed occur in lower winds. In a light breeze, sailing speed rises by over 80 per cent from 2.6 knots in 1750 to 4.75 knots in 1825 (as noted above, it suggests that the estimated wind speed of Force 2 is too low, and the wind is more likely to have been a Gentle Breeze of 7–10 knots). In particular, speed rises by 15 per cent, to 3 knots by the early 1780s. With the introduction of coppering it jumps by 25 per cent to 3.75, and rises by another 25 per cent after the Napoleonic period. The rise in speed associated with copper is of the same order of magnitude as that estimated by Solar and Hens (2013) on the basis of on the length of time taken by EIC ships, which would have sailed a good deal of their voyages in the lower wind speeds of the tropics, to complete voyages.

In a moderate breeze of 11-16 knots, the average wind found in the North Atlantic at the latitude of Britain in the summer months, the rise in sailing speed is lower, increasing by a third from 4.5 knots until the 1750s to 6 knots in the 1820s. Speed rises by around 10 per cent to 5 knots with the introduction of coppering, and by a further 20 per cent after the Napoleonic period. Moving to a Fresh Breeze, speed rises from 5.5 to 6 knots with the introduction of coppering, and by a further half knot after 1815 giving a total rise of slightly under 20 per cent. Finally in Strong Breezes, average speed only rises by about one half knot from 6 knots around the introduction of coppering. In both Fresh and Strong Breezes, the fastest quartile of ships experiences about double the rise in speed of average ships, with notable increases after 1815. Effectively, a ship can sail as fast in a Light Breeze in the 1820s as it could in a Moderate Breeze in the early 1780s, with the same comparison holding for fresh and moderate breezes.

When not sailing before the wind, Figure 7 shows that gains in sailing speed appear to occur only after 1815 with no detectable impact when coppering is introduced. At 45 degrees, speed improves from 3 to just over 4 knots; while at 90 degrees, speed rises from 4 to 5.5 knots.

6.2 Dutch Frigates

We have 12,933 observations for frigates (lightly armed, long-hulled, relatively narrow vessels) of the Dutch navy. These extend our coverage to 1850, but with a gap from 1795 to 1814. Figure 8 gives the speed of Dutch frigates in different wind speeds, supposedly corresponding to Beaufort force 3 to 6, again sailing at

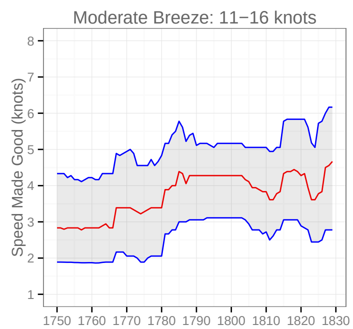

Figure 7: EIC sailing speed at 45 and 90 degrees to a moderate breeze.

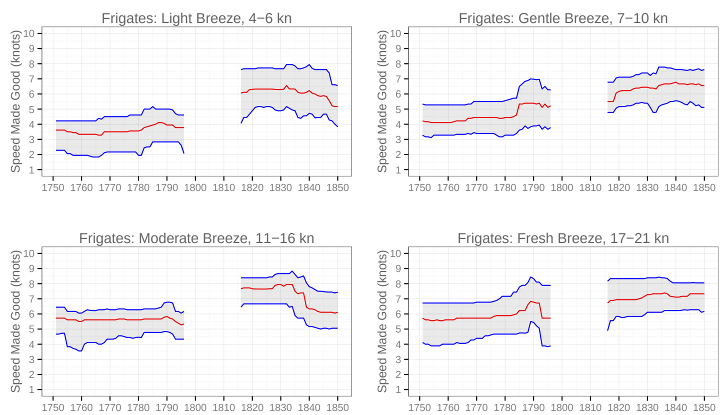

Figure 8: Speed of Dutch frigates in different wind speeds.

180 degrees, at 50 degrees north, 10 degrees west. As noted above, the estimated wind speeds are questionable, with ships routinely sailing faster than the wind in Light Breezes. However, the story is also one of increasing speeds. The pattern of increase is similar to that recorded by the EIC with speed in Light Breeze increasing from 4 to 6 knots. In Gentle Breeze, we observe a rise from 4 to nearly 5 knots, with a jump in speed from 4.5 to 5.5 knots in the 1780s (presumably due to coppering), and a steady rise after the Napoleonic gap until 1830. None of the series shows a perceptible rise between 1830 and 1850. In moderate breezes, speed is steady at 6 knots until after 1815, increasing to 7.5 knots, but falling after 1840. In Fresh Breeze, sailing speed is no faster than in Moderate Breeze, suggesting that the wind speed here is, again, under-estimated: for EIC ships we saw that sailing speed peaks in Strong Breeze.

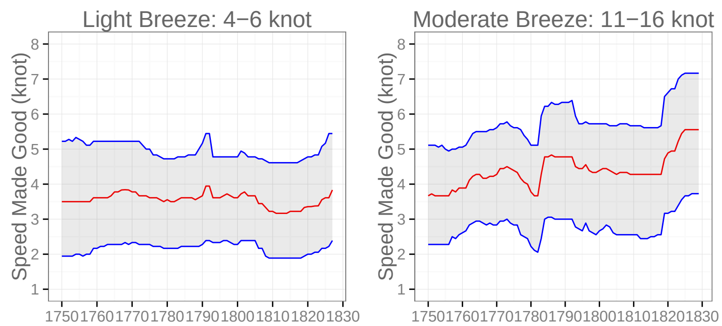

Figure 9: Speed of Royal Navy ships in different wind speeds.

6.3 Royal Navy

In contrast to the EIC, ships of the Royal Navy did not have an incentive always to sail as fast as possible. In wartime, escorting convoys and patrolling for enemy shipping would usually lead to a fall in sailing speed. While EIC ships were fairly homogeneous (Chatterton, 1933; Sutton, 1981, although size tended to fall through time: Solar 2013.), the size of naval ships in our sample varies from third rate ships of the line, carrying 64 to 80 guns of 2,000 tons displacement (plus a handful of even larger second rates) down to 4-gun sloops of 60 tons. The data are based on 362 voyages by 4th rates, 386 by 3rd rates, 386 by sloops, 444 by 5th rates, 729 by 6th rate, and 7 by 2nd rates, producing 24,165 observations in all.

Looking at variable importance, in a moderate breeze the values of each variable are Year= 0.29, Angle to wind= 0.78, Latitude= 0.42, Longitude= 0.28, Month = 0.09 and Guns= 0.13, while the correlation between recorded and predicted speed is 0.70.

Figure 9 gives sailing speed for naval ships in light and moderate breezes, estimated for a 50-gun ship. Two things are apparent. There are large drops in speed during the three war episodes; and speed in light wind remains roughly constant. For moderate winds, speed rises by 1.5 knots as it did for the EIC, with the same pattern of equal increases occurring before the early 1770s, in the mid-1780s, and after 1815, although we stress again that the extreme paucity of observations after the last date makes inference problematic. Because the starting speed is half a knot slower than the EIC at 4 knots, the percentage rises are slightly larger.

7 Other Ships.

We also have 7,270 observations for Spanish paquetbotes (packet boats: lightly armed ships for transporting mail) for the period to 1797, and 5,390 observations

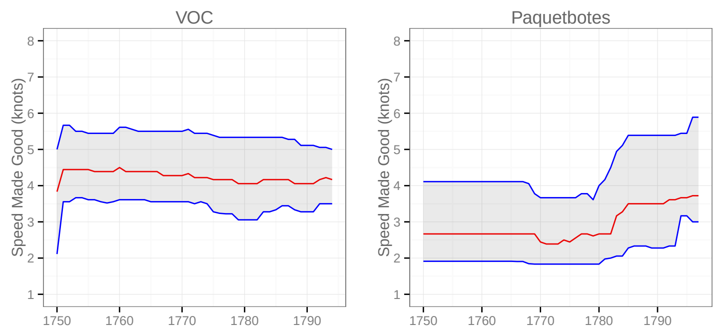

Figure 10: Speed of Dutch East Indiamen and Spanish packet boats in moderate breeze.

for ships of the Dutch East India Company (VOC) ending in 1794 (On the VOC and its ships see Bruijn and Gaastra 1993). Figure 10 gives estimated speed sailing before the wind in a Moderate Breeze (we move the Dutch wind speed one Beaufort force higher).

It can be seen that the Dutch sailing speed starts about the same as the British EIC speed at 4.5 knots but declines through time to 4 knots. The Spanish series starts at a very low level of 2.5 knots but rises to 3.5 in the mid-1780s. Unlike most other series, the Dutch VOC series shows no rise in the 1780s.

8 Conclusions.

North's classic study of trans-Atlantic freight rates is in keeping with the traditional image of pre-Industrial Revolution Europe as an area of slow economic growth with little worthwhile technological change. In this view such growth as did occur was the product of institutional change. North's claim is all the more striking since it concerns the most dynamic element of the early modern economy, its foreign trade. We have presented evidence here of increasing speed of both military and mercantile ocean-going vessels between the mid-eighteenth and mid-nineteenth centuries. This evidence, which refers to oceans in both hemispheres, is consistent with modest and gradual technological change between the mid-eighteenth and nineteenth-centuries. The significant increase in speed shown by ships' logbooks suggests that the measure of productivity change employed in North's classic paper may underestimate its true extent, since it ignores this improvement in the quality of the service provided.

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