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Speed under sail, 1750-1830

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Speed Under Sail, 1750-1830

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Speed Under Sail, 1750-1830

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Note: this is a revised version of the paper that appeared under a slightly different paper as UCD Centre for Economic Research Working Paper 2014-5.

Speed under Sail, 1750–1830.

Morgan Kelly and Cormac Ó Gráda.

Abstract

We measure technological progress in oceanic shipping directly by using a large database of daily log entries from ships of the British and Dutch East India Companies and Navies to estimate daily sailing speed in different wind conditions from 1750 to 1850. Against the consensus among economic (but not maritime) historians that the technology of sailing ships was static during this time, we find that average sailing speeds of British ships in moderate to strong winds rose by nearly a third. Driving this steady progress seems to be continuous evolution of sails and rigging, and improved hulls that allowed a greater area of sail to be set safely in a given wind. By contrast, looking at every voyage between the Netherlands and East Indies undertaken by the Dutch East India Company from 1595 to 1795, we find that journey time fell only by 10 per cent, with no improvement in the heavy mortality, averaging six per cent per voyage, of those aboard.

JEL: N0

Keywords: Technological progress, shipping.

1 Introduction.

With its hundreds of squares yards of canvas sails making it the most effective means of harnessing inorganic energy in the pre-industrial world, the sailing ship represented a fundamental transportation technology of the western world until the mid-nineteenth century. Given the strong incentives, both military and commercial, to improve the performance of such vessels, it may seem surprising that the consensus among economic historians going back to North (1968) and Harley (1988) is that, between the Dutch fluyt in the sixteenth century and the iron steamship in the nineteenth, maritime technology was effectively stagnant.

Previous efforts to measure technical progress in ocean shipping have been indirect, typically measuring changes in the cost of shipping freight

or, less commonly, in the length of voyage. This paper instead takes a direct approach, measuring how daily sailing speeds in different wind conditions evolved through time. To do this we use the large CLIWOC database that, in an effort to reconstruct oceanic climate conditions, compiled 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 details on the type of ship. We analyse the two types of ship for which CLIWOC provides the most extensive data: British and Dutch East Indiamen and naval vessels.[1]

Against the orthodoxy of technical stasis, both East India Company (EIC) and Royal Navy ships show broadly similar patterns of steady improvement throughout the period. In gentle breezes (up to Beaufort Force 3 or 10 knots) sailing speeds hardly improve between 1750 and 1829 but in higher winds speed increases notably. At Forces 4 (the usual summer condition in the North Atlantic) and 5 ship speed rose by nearly one third.

Dutch naval vessels show similar progress, reaching British levels by 1816 and improving by 20 per cent or more by 1850. For a longer perspective, we also analyse the duration of every voyage undertaken by the Dutch East India Company (VOC) between the Netherlands and the East Indies between 1595 and 1795 and find, in contrast to the substantial improvement in the EIC, that sailing times fell by only 10 per cent over two centuries, while mortality of those on board actually rose slightly through time, with 6 per cent dying on an average voyage east, and over 12 per cent on a quarter of voyages.

The final set of records that we examine is the passage time of British post office sailing packets sailing to and from New York, and these reveal an improvement of 15 per cent between 1750 and 1829. This slow progress changes however when American packets appeared in the 1820s, and by the 1840s the fastest packets were sailing fifty per cent faster than they had done in the 1750s.

What explains these improvements in sailing speed? A widespread view is that speed rose suddenly in the 1780s after hulls were coated with copper

[1]CLIWOC also provides extensive data on Spanish frigates and mail packets sailing to South America between the 1760s and 1790s. No improvement occurs , and we do not report the results here.

that reduced fouling by weeds and barnacles. This explanation is problematic. First, reduced hull friction should have led to the greatest improvement in slack winds, where no improvement in fact occurred. Secondly, speed rises steadily through the period, rather than showing a sudden jump in the 1780s with little improvement before or after. Our findings suggest that incremental improvements in sails and rigging, along with major advances in the strength of ships that made them less likely to flex in heavy seas, account for most of the improvement.

The obvious way for a ship to sail faster is to set more sails but this is limited by the tendency for the ship to pitch and roll, taking on water as it does so, and risk being blown over by a squall, when over-canvassed. Stronger, more water-tight, and better designed hulls allowed a greater area of sail to be set in a given wind, particularly stronger winds.

Our findings of notable improvements in ship speed during the Industrial Revolution are in keeping with a growing reaction against the orthodoxy in economic history that the technological progress of the late eighteenth century was largely confined to cotton spinning, iron making, and steam engines, with other sectors mired in stasis. The steady improvements in shipping technology outlined here support the view of a more broadly based advance across many manufacturing sectors proposed by Berg and Hudson (1992) among others, with sectors such as brewing, pottery, glass, hydraulics and mechanical engineering showing signs of technological dynamism in this period: for a survey see Mokyr (2009, 131–144).

Although we conclude that North and Harley were incautious in extrapolating from Atlantic freight to shipping in general, our results do not otherwise contradict theirs. North and Harley analysed the highly competitive North Atlantic route. This cost minimising market made it optimal for merchant ships to operate well within a technological frontier being pushed outwards by the Royal Navy and East India Company, to whom expense was little object.

The rest of the paper is as follows. After a literature review, we outline the major improvements in maritime technology affecting sailing speed during the seventeenth and eighteenth centuries in Section 3 In Sections 4 and 5 study the rise in the sailing speed of EIC and Royal Navy ships. Section 6 analyses the sailing speed of Dutch vessels, and Section 7 examines British post office packets.

2 Literature Review.

On the North Atlantic route, North (1968) found that freight rates fell from 1600 to 1850. Simply asserting that technological progress in shipping was negligible, North instead attributed these falling prices to increased specialization permitted by larger markets, the development of backhaul freight (either colonial produce or immigrants), lower turnaround times, and smaller crews allowed by the suppression of piracy. Harley (1988) however showed that North's price falls were largely due to denser packing of cotton bales and that, when a more reliable price index was estimated, freight rates were constant before steamships in the 1850s.

Rönnbäck (2012), corroborating earlier work by Klein (1978), subsequently found that the average length of voyage of slave ships on the middle passage fell from about ninety days around 1700 to sixty a century later, an improvement he attributed to better knowledge of seasonal winds (see also Rönnbäck and Solar 2014). Solar (2013) finds that the voyage length of EIC ships to Bombay fell by 28 per cent between the early 1770s and the 1820s while VOC times to Batavia between the 1770s and 1790 were largely unchanged, consistent with our findings here.

3 Technology.

The dismissal of productivity growth in shipping by North and Harley runs against the extensive lists of innovation in histories of maritime technology such as Naish (1957) and Harland (1985). Davis (1972, 71) found that average tonnage per crewman on ships entering London rose by 50 per cent between 1686 and 1766, and conjectured that this improvement reflected an important but unknown innovation in ship design. Improvements in the seventeenth century include chain pumps and thicker planking of hulls; but the most important are to sails and rigging: shrouds set up with deadeyes and chains; ratlines for access to the sails; the replacement of four masts by three leading to a more divided and easily handled sail plan; the replacement of spritsails by fore-and-aft jibs; and the appearance of triangular staysails between masts. Replacing the clumsy whipstaff with the steering wheel from the 1690s made ships more manageable in heavy seas and gave the helmsman a clear view of the sails allowing precise course adjustments

to maximise sailing performance (McGowan 1980, 15–16; Rodger 2004, 221–222). The major advances in the theory and practice of navigation that took place in the late eighteenth century are outlined by Kelly and Ó Gráda (2017) and there is the possibility that improved charts and dead reckoning enabled ships to sail faster by reducing the need to move cautiously in unfamiliar waters.

Although Naish (1958) claims that by the early eighteenth century the square rigged sailing ship was a mature technology (albeit one that was able to compete successfully with steam ships on long distance routes until the second half of the nineteenth century: Harley 1971), ship design altered fundamentally in the late eighteenth century with the gradual appearance of ships with a single flush deck, an innovation that is probably of greater importance than the well known appearance of copper sheathing.

3.1 Coppering.

From the time of Columbus, shipworms that eat rapidly through wooden hulls had become a threat to vessels in warmer waters, and a common solution, used continually by Spain and intermittently by Britain, was to coat hulls with lead sheets. While guarding against shipworms, lead suffered numerous disadvantages: weight, variable quality, failure to reduce fouling by weeds and barnacles, and galvanic action with iron that caused the bolts and pintles holding the keel and rudder onto the ship to corrode rapidly.

From the 1750s, the Admiralty experimented with copper plating that not only was lighter but eliminated biological fouling, leading to its widespread adoption on Royal Navy ships in the 1770s.[2] However, while coppering is often represented as a decisive technological leap (see for example Solar and Hens 2015; Harris 1966), the reality is more complex. In a world before metallurgy, the effective use of copper sheathing progressed by slow and often costly empirical trial and error: what Meisenzahl and Mokyr (2012) call "tweaking".

Besides galvanic action attacking iron fixings (a mechanism not understood until Humphrey Davy's work in the 1820s), copper plates dissolved rapidly, leading the Admiralty to replace the iron nails fixing the plates to the hull with difficult to install, short-lived, and extremely expensive copper

[2] Rodger (2004, 344–345) estimates that the reduced time needed to careen hulls and replace worm-eaten timbers increased the operational strength of the navy by one-third.

ones; and to experiment with more durable types of copper (Fincham 1851, 94–100; Staniforth 1985). Because coppering works by poisoning marine organisms trying to colonise the hull as it dissolves, its effectiveness against fouling now fell. The futility of simultaneous efforts to improve the durability of copper plates and to reduce biological fouling was not recognised even by well informed observers like Fincham in the 1850s, leading to continual frustration: McCarthy (2005, 101–115).

3.2 Hull Strength.

One typically overlooked improvement—but a vital one, as we will see below—was the gradual rise in the rigidity of hulls. Joining many wooden planks together to form a large hull results in poor structural integrity, so that large ships sagged (hogged) under their own weight, and flexed badly (worked) in heavy seas, letting in water and losing speed.

Leading late eighteenth century efforts to improve the shear strength of hulls was EIC Surveyor (chief architect) Gabriel Snodgrass who began doubling plank thickness; introducing iron knees to attach decks to hulls, and diagonal bracing between ships' ribs; and making the sides of ships vertical rather than sloping inwards. Most importantly, and probably inspired by his knowledge of Indian ship designs, Snodgrass introduced ships with a single flush deck that were stronger and more watertight in heavy seas than traditional stepped ones (Snodgrass 1797; Parkinson 1937, 135–138). Forced by wartime timber shortages to use shorter planks, and consequently facing even greater problems of rigidity, these innovations were finally introduced into the Royal Navy after 1803 by Robert Seppings when Master Shipwright of the Chatham dockyard and subsequently Chief Surveyor of the Admiralty.

Kelly and Ó Gráda (2017) show that the increasing strength and watertightness of ships coincided with a dramatic fall in the risk of ships foundering in the Atlantic. They also allowed sailing speed to rise. The obvious way to go faster is to increase sail area, but being over-canvassed causes a vessel to pitch and roll, shipping water as it does so, and also increases the risk of being blown over by a sudden squall. Improved stability and rigidity of hulls lowers these risks and allows a greater area of sail to be set in a given wind.

3.3 Scientific Contributions.

Regarding scientific efforts to improve ship speed and handling, hydrodynamics and ship design became a major area of empirical and theoretical research from the early eighteenth century, attracting leading mathematicians such as d'Alembert, Bouguer and, most notably, Euler who made repeated studies of hydrodynamics through his career culminating in his 1749 *Scientia Navalis* (Nowacki 2006; 2008). Hydrodynamical theory, however, simply proved too complex for eighteenth century mathematics—with the first successful results only coming with Froude over a century later—and the resulting ships performed poorly (Naish, 1957).

More fruitful were systematic efforts to use scale models to test ship design. Against Newton's mechanical theory of fluid resistance in Book II of the *Principia,* which implied that resistance of a vessel depended solely on the shape of its bow, the numerous experiments carried out by William Beaufoy for the Society for the Improvement of Naval Architecture from 1790–1793 highlighted the key role of stern and side friction; while continued experiments by his associates showed how ships could be made much longer relative to their width without compromising their handling. However, although Beaufoy's findings had considerable influence on later steamship design, they were ignored by the Royal Navy (Schaffer, 2004).

4 Data Sources.

This paper derives ship speeds in different wind conditions from a new source: ships' daily logbooks compiled by the CLIWOC (Climatological Database for the World's Oceans) project) to chart oceanic weather conditions from 1750 to 1850 (Können and Hoek, 2006).[3] As well as wind direction and speed, CLIWOC gives daily observations of each ship's direction, distance covered, longitude, and latitude. We use the daily change in longitude to compute how far the ship had sailed, referred to as course made good (this excludes any extra distance caused by tacking into the wind). Although latitude could be computed accurately, most longitude estimates in this period were made by dead reckoning (Kelly and Ó Gráda, 2017), so our dependent variable of ship speed will be measured with some error.

[3]The data and accompanying documentation are available at http://www.ucm.es/info/cliwoc/cliwoc15.html.

CLIWOC also gives wind direction and estimated wind speed, translated by the database compilers from verbal descriptions in the logbook (for example "gentle trade wind") into the standard Beaufort scale. We exclude observations that CLIWOC identifies as coastal (where speed would have been constrained by fears of running aground), days with no wind, and days where position remained unchanged indicating that the ship was in port or at anchor. At the other end, we omit observations with winds above 34 knots (gale force), where recorded ship speed is implausibly high (above 10 knots), or where reported ship speed is more than half wind speed. We end up with 11,988 observations from 1750 to 1829 for the EIC, and 19,717 from 1750 to 1827 for the Royal Navy.

We also include the tonnage of the vessel. Although the theoretical maximum hull speed of a ship is proportional to the length of its waterline, meaning that longer ships can sail faster than shorter ones, ships of our period sailed so slowly that this maximum speed is not an issue. CLIWOC provided the tonnage of all Royal Navy ships, and the tonnage of East Indiamen was taken from the "East India Company Ships" website.[4]

Figure 1 plots the daily position for all observations for EIC and Royal Navy ships from 1751 to 1770, showing the circular courses taken by ships following oceanic winds and currents. The bunching of daily positions around the equator and as ships made the difficult eastward run around southern Africa, are evident.

The wind conditions encountered in our sample are summarized in Figure 2. 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 uncommon: given that Force 4 is the modal observation, it seems likely that these were conflated with Force 2 when CLIWOC coded the verbal wind descriptions.

The wind angle is the angle of the wind recorded, relative to the direction that the ship followed through that day so an angle of zero degrees means heading straight into the wind. It can be seen that the commonest

[4] http://eicships.info

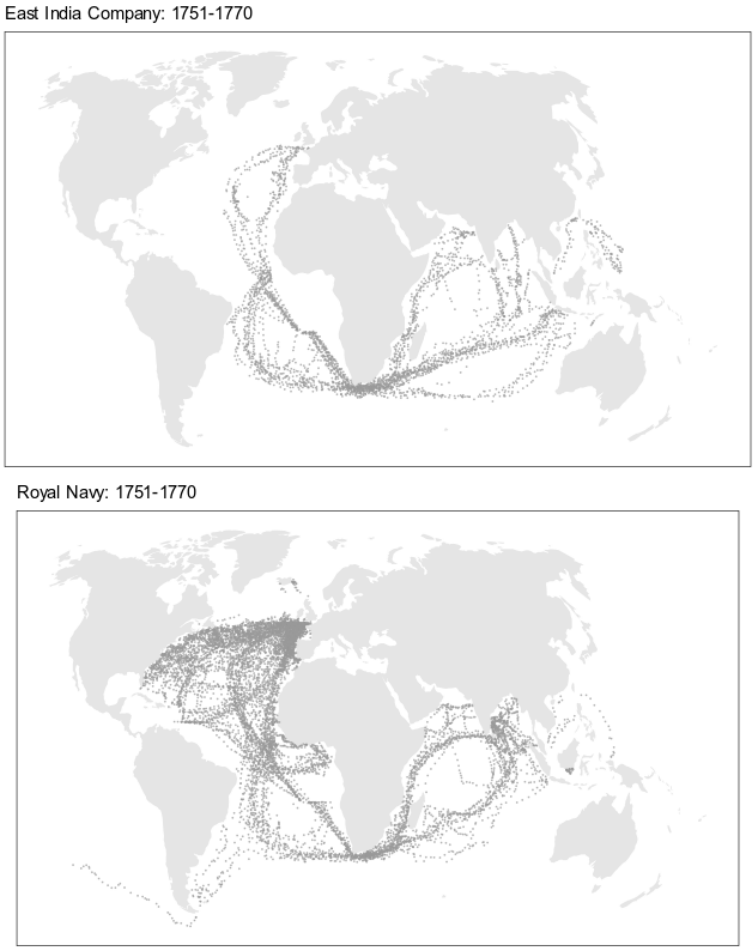

Figure 1: Daily positions of East India Company and Royal Navy ships, 1751–1770.

point of sail was before the wind, as the ship followed prevailing winds and currents, or at right angles to the wind.

5 Sailing Speed: EIC and Royal Navy.

Plots of the relationship between each of four explanatory variables and average speed for the EIC, using a 5 per cent sample of observations, are given in Figure 3, with a locally weighted sum of squares line added to indicate trends. It can be seen that sailing speed increases with wind speed reaching a peak around 25 knots. This is the wind speed (Force 7) at which ships would reef topsails Harland 1985, 53; with other sails being successively

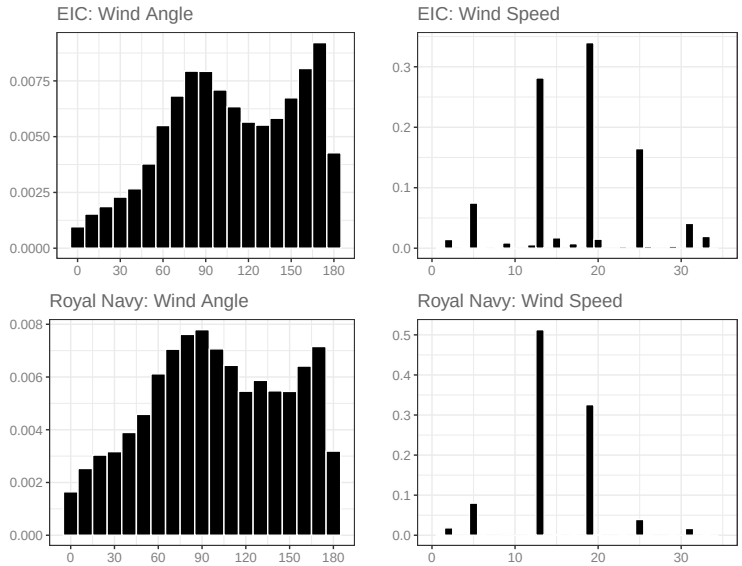

Figure 2: Distribution of points of sail and wind speed for the East India Company and Royal Navy.

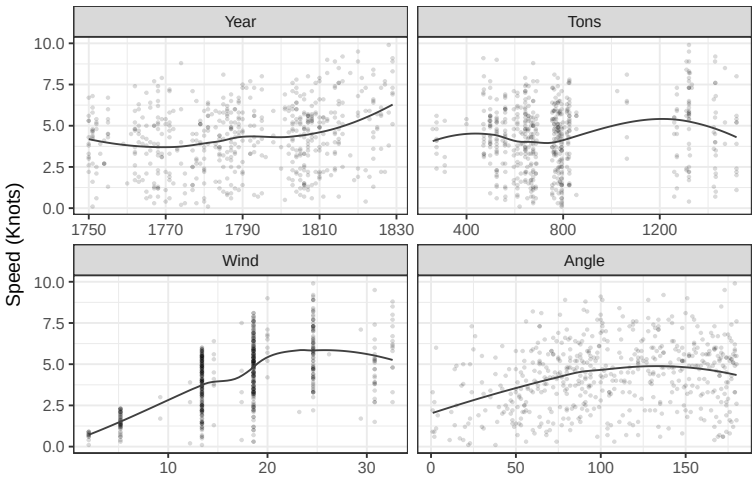

Figure 3: Relationships between explanatory variables and ship speed for the British East India Company, 1750–1829.

reefed as wind rose. Sailing speed rises gradually with angle to the wind, peaking as expected around 90 degrees. Speed rises with tonnage but this variable is conflated with time: most Indiamen were in the range 700–800 tons before 1800, but this rises to 1,300 tons after.

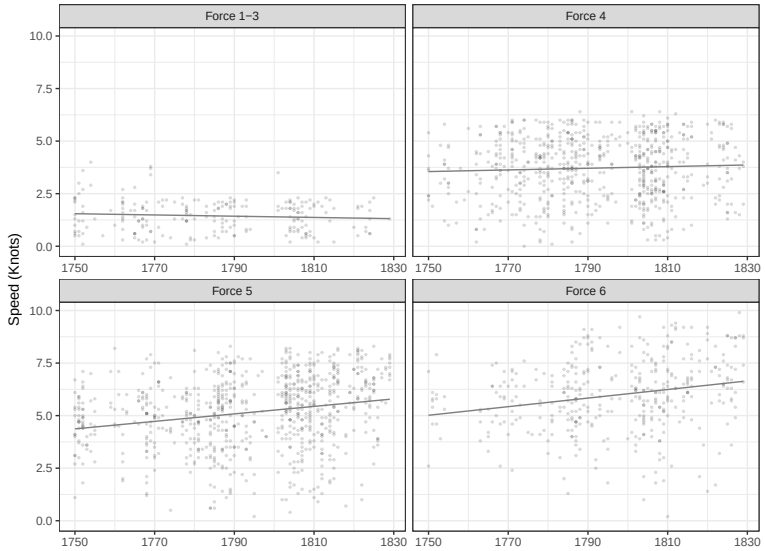

Figure 4: Sailing speed of EIC at different wind forces, 1750–1829.

	EIC				Royal Navy			
	Force 1-3	Force 4	Force 5	Force 6	Force 1-3	Force 4	Force 5	Force 6
(Intercept)	1.886	3.369	4.482	5.292	1.147	3.204	4.391	5.655
	(0.136)	(0.184)	(0.240)	(0.257)	(0.105)	(0.184)	(0.242)	(0.695)
Year	−0.006	0.012	0.017	0.018	0.008	0.013	0.018	0.016
	(0.002)	(0.003)	(0.003)	(0.003)	(0.004)	(0.005)	(0.008)	(0.021)
Tons	0.000	0.000	0.001	0.000	−0.000	−0.000	−0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Seven Years War	0.091	−0.302	−0.382	−0.056	0.001	−0.015	0.078	1.251
	(0.079)	(0.152)	(0.318)	(0.200)	(0.088)	(0.147)	(0.181)	(0.528)
American War	−0.050	−0.187	−0.584	−0.605	−0.025	−0.239	−0.609	−1.823
	(0.054)	(0.111)	(0.176)	(0.134)	(0.107)	(0.115)	(0.201)	(1.096)
Napoleonic War	0.017	−0.160	−0.244	−0.334	−0.182	−0.238	−0.445	−0.368
	(0.066)	(0.081)	(0.096)	(0.134)	(0.140)	(0.108)	(0.234)	(0.603)
R^2	0.086	0.141	0.199	0.262	0.040	0.135	0.114	0.149
N	1405	3564	3943	1759	1473	7376	4665	564
RMSE	0.730	1.225	1.401	1.395	0.685	1.453	1.838	2.262

Standard errors clustered by vessel in parentheses. Year is number of years since 1750. All other explanatory variables are de-meaned. Displacement of ship measured in hundreds of tons. Royal Navy observations end in 1827. Coefficients for angle to the wind, longitude, latitude, and month not reported.

Table 1: Sailing speed of EIC and Royal Navy ships at different wind forces, 1750–1829.

Figure 4 shows how the speed of Indiamen changed in different wind conditions between 1750 and 1829: the patterns for warships are almost identical. It can be seen that in gentle breezes (Force 1–3) speed hardly improves but in stronger winds (Force 4–6) it rises by around one third.

Table 1 gives the results of OLS regression of speed in different winds on these explanatory variables, for the Indiamen and warships from 1750 to 1829 and 1827 respectively. We add two dummies. Month of year is considered because the sea state can be driven by distant storms and can slow, or sometimes halt, progress even with a favourable wind. A dummy for each of the wars during the period is added to allow for slower convoy sailing.[5] A dummy for EIC ships sailing east—where captains had an incentive to arrive early to sell their personal cargoes before competing captains appeared—had no explanatory power.

The EIC lost its monopoly on the India trade in 1813 (see Bogart 2015), creating the possibility that its ships then faced commercial pressures to sail faster, but all of our observations after this time are for ships on the China route where it still had a monopoly.[6] All explanatory variables are demeaned except year, which is the number of years since 1750 so the intercept gives average sailing speed in 1750.

Table 1 shows that larger ships did not sail faster, and that wartime convoying reduced sailing speed markedly, usually by 0.2–0.6 knots. Month of year had a small impact, but latitude and longitude have a negligible effect. The explanatory power of the Navy regressions are about half those of the EIC reflecting the fact that warships changed their speed with circumstances (for example, between escorting a convoy or pursuing enemy ships) whereas East Indiamen sailed at a steadier pace.

The most notable aspect of Table 1 however, is the steady rise in sailing speed, outside slack winds, from 3.4 to 4.4 knots in Force 4 and from 4.5 to 5.9 in Force 5 for the EIC, with slightly smaller improvements for the Navy.

6 Sailing Speed: VOC and Dutch Navy.

While it would be desirable to look at the changing performance of Dutch ships in varying wind speed, the CLIWOC estimates of wind speed for these ships appear to be severely inaccurate: in 29 per cent of Dutch observations the ship is sailing at more than half calculated wind speed, and in 9 per

[5]The three wars in this period are the Seven Years War, 1756–1763; the American War of Independence, 1779–1784; and the Revolutionary and Napoleonic Wars, 1792–1814 excluding temporary cessations.

[6]We are grateful to Peter Solar for this observation.

	1750–1796		1816–1850		
	Frigates	VOC	Frigates	Brigs	Corvettes
(Intercept)	2.951	3.708	5.208	4.334	4.202
	(0.120)	(0.103)	(0.185)	(0.210)	(0.501)
Year	0.021	−0.005	0.011	0.032	0.020
	(0.005)	(0.004)	(0.008)	(0.009)	(0.021)
R^2	0.019	0.005	0.002	0.013	0.006
N	5949	6089	7844	4744	3914
RMSE	1.957	1.785	2.432	2.338	2.381

Standard errors clustered by ship in parentheses.

Table 2: Sailing speed of Dutch Ships, 1751–1850.

cent it is sailing faster than the wind. We therefore look only at how sailing speed evolved through time.

We examine the performance of naval frigates and VOC ships from 1751–1796 and frigates, brigs, and corvettes from 1816–1850: the gap is when the Netherlands was occupied by France. Table 2 gives regressions of speed on year for all classes of ships, with the intercept again giving average speed in the starting year. The fit of the regressions is considerably poorer than the British ones and does not improve noticeably if angle to the wind and position are included. However it can be seen that although the speed of VOC ships is unchanged, that of naval vessels rises substantially. The average sailing speed of frigates rises by markedly before 1796 but this is from an extremely low starting point and by 1816 they have roughly reached British speeds. However, their sailing speed continues to rise steadily, improving by 20 per cent by 1850, with somewhat larger rises for brigs and corvettes.

6.1 Duration of Dutch East India Company Voyages, 1595–1795.

Details of all 8,194 voyages undertaken by ships of the VOC during the seventeenth and eighteenth centuries have been compiled by Bruijn, Gaastra and Schöffer (1987).[7] We focus on the 3,754 voyages eastward between Dutch ports and Batavia (present day Jakarta) between 1595 and 1795, and 1,945 return voyages (many ships remained in the east to engage in local trade, unlike the EIC which had most ships for the country trade built locally).

Figure 5 shows the duration of these voyages (subtracting time spent at the Cape of Good Hope) and it is immediately evident that speed only improves marginally over these two centuries. Table 3 gives a regression

[7] These are available at http://resources.huygens.knaw.nl/das/index_html_en.

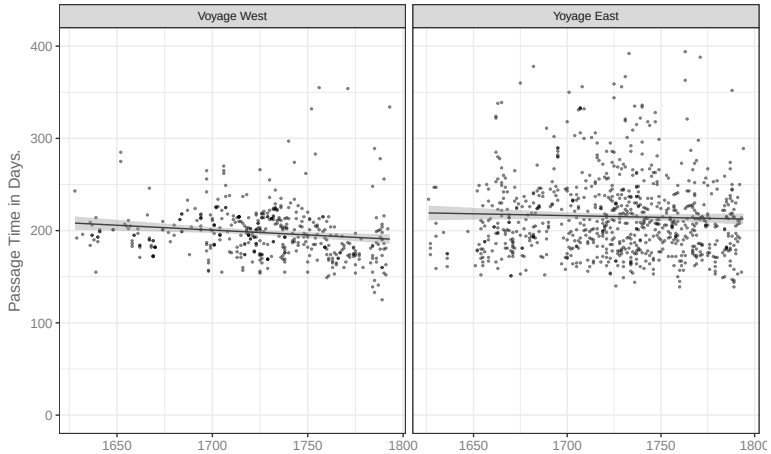

Figure 5: Voyage duration of VOC ships, 1595–1795.

	Days East	Days West	Mortality
(Intercept)	202.647***	211.187***	1.795
	(21.036)	(5.008)	(15.612)
Year	−0.103	−0.122***	0.051***
	(0.065)	(0.033)	(0.008)
Tonnage	−0.085	−0.011*	
	(0.069)	(0.005)	
Age	3.020	0.592**	0.120**
	(2.972)	(0.202)	(0.038)
Loading			0.141***
			(0.041)
Duration			0.000
			(0.069)
R^2	0.002	0.025	0.049
Num. obs.	2982	1544	2495
RMSE	670.318	35.174	8.187

Heteroskedastic consistent standard errors in parentheses. Age is number of years since the ship was built, Mortality is the percentage who died on the voyage east relative to the number on board at departure, Loading is the number at departure per 100 tons. All covariates except year are demeaned. Duration is the voyage length in days.

Table 3: VOC voyage duration and mortality rates, 1595–1795.

of voyage length in days on number of years after 1600, tonnage of vessel, and age of vessel with the last two covariates demeaned so that the intercept corresponds to the mean voyage duration of an average ship in 1600. Dummies for the port in the Netherlands that the ship left or returned to did not affect voyage duration. It can be seen that improvement in sailing time over the period does occur but at a slow rate of roughly ten per cent

over 200 years. This virtual stagnation is consistent with the findings of van Zanden and van Tielhof (2009) and van Lottum and van Zanden (2014) that the productivity growth of Dutch shipping ceased after 1650 and suggests that Dutch complaints through the eighteenth century about the technological conservatism of the VOC (Unger, 2013) were well founded.

The data also give the number on board at the start of the voyage east, and the number who died en route. Sailing for months in tropical heat took a heavy toll: the median mortality rate on a voyage east was 6 per cent, and on a quarter it exceeded 12. Again, there is no improvement in this rate: in fact, as Table 3 shows, it deteriorates slowly through time. The duration of the voyage has little impact on mortality but the age and loading of a vessel (persons per 100 tons, where the average per voyage is 20) did raise it slightly.

These heavy mortality figures are for ships that survived the voyage, and quite a few did not: we measure these as ships whose destination port and date of arrival are left blank. Of ships leaving the Netherlands, 3.8 per cent did not reach their destination, and this rate remains constant through the period, and the risk of loss is unaffected by the tonnage of the ship or its age. Losses on ships leaving Batavia are an implausibly high 10.8 per cent suggesting possible inaccuracies in these records.

7 Duration of Post Office Packet Voyages.

As well as daily observations for the EIC and Royal Navy, we have voyage lengths for ships of the British Post Office From 1755 to 1825, the British Post Office operated fast sailing packets between Falmouth, in the southwest of England, and New York. Even in the era of Old Corruption, the packet service was notable for its "abuses": the ships were privately owned and seen primarily as vehicles for smuggling and, occasionally, piracy, with captains frequently absent and collecting pay for non-existent crewmen (Norway, 1895, 13–55).

Usually the voyage westward was direct, with the return voyage stopping for several days in Halifax, Nova Scotia. Details of each voyage have been assembled by Olenkiewicz (2013). Figure 6 shows the sailing time in days, excluding stopovers in Halifax, for each eastward and westward voyage for which precise arrival and departure times at each port are recorded:

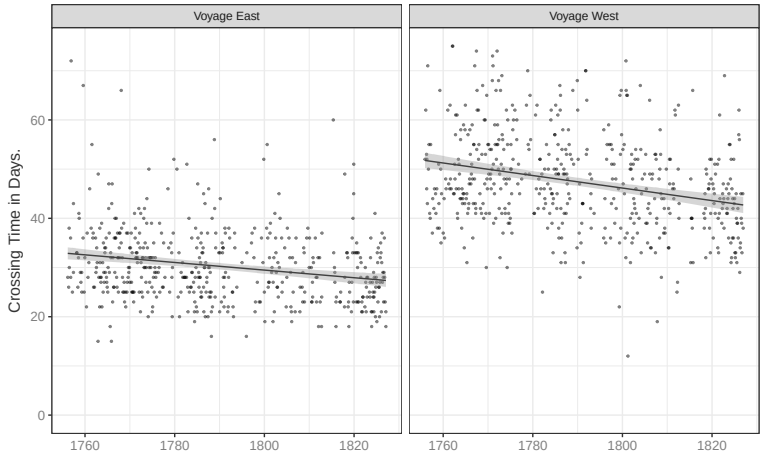

Figure 6: Crossing time for Post Office Packets, 1755–1825.

arrival and/or departure dates from Halifax are often missing in early decades. For clarity, 16 westward voyages that lasted between 75 and 98 days are excluded from the diagram.

It can be seen that westward voyages—along the great circle route up the Canadian coast, and following winds and currents—are a good deal faster than eastward ones, but that there is a steady downward trend in both of around 0.2 per cent per year. Although all packets were coppered in the 1780s (Harris, 1966) the absence of a fall in crossing times during this decade is notable.

Table 4 gives a regression of voyage length east and west against year, including monthly dummies that are not reported. The intercept is the average sailing time in 1755, and crossings fall by about a day per decade over the 70 years of records. Passages east are largely unaffected by season, but the slower westward passage times rise markedly in winter, with January voyages taking an average of two weeks longer than April ones. Packets sailed alone so speed did not fall in wartime but services were sometimes suspended or went only as far as Halifax.

From 1819, commercial American packets, effectively prototypes of clipper ships, began carrying passengers and freight between New York and Liverpool with average sailing times in the 1820s of 24 days west and 38 days east.

	Days East	Days West
(Intercept)	30.432	59.379
	(1.190)	(2.348)
Year	−0.071	−0.107
	(0.017)	(0.021)
R^2	0.084	0.190
Num. obs.	506	534
RMSE	7.437	10.703

Heteroskedastic consistent standard errors in parentheses. Monthly dummies are not reported.

Table 4: Regression of crossing time for British North Atlantic Packets, 1755–1825.

Part of this jump in sailing speed probably lies in the superior seamanship of their crews and the strong incentives of captains (who typically owned a substantial share in their vessel, and relied on personal reputations for fast sailing to attract passengers) to sail as hard as possible (Albion, 1938). However, technical progress among these packets can be determined by looking at how their sailing speed subsequently evolved. By the late 1830s the ships of the Collins Line—whose flat bottomed hulls intended to clear sandbars at harbour mouths unexpectedly made them considerably faster than traditional packets with deep V-shaped hulls—were doing the crossings in 20.5 and 30.5 days respectively (Fox, 2004, 6). In other words, sailing speed had risen by half, reducing crossing times under sail by one third since the 1750s.

8 Conclusions.

Analyses of the European economy between the early sixteenth and nineteenth centuries typically number shipping among its most dynamic sectors (see, for example, Barbour, 1930; Davis, 1972; Menard, 1991; Shepherd and Walton, 1972; Unger, 1998, 2013). Europe's merchant fleet expanded 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). Driving this growth was expanding trade: de Vries (2010) calculates that the 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, from Maddison's estimates, GDP in Western Europe grew by around 0.4 per cent per year between 1600 and 1820.[8]

The North-Harley dismissal of technological progress in shipping—itself part of a wider orthodoxy that innovation during the Industrial Revolution extended little past cotton spinning, iron making, and steam engines—is symptomatic of the divorce of economic history from technological history. In this paper we outlined the many improvements in ship design during this period. To analyse whether they affected ship performance we looked at a large database of sailing speeds of British and Dutch East Indiamen and naval vessels. For British ships we found substantial and continuous progress—EIC ships sailed one third faster in 1830 than in 1750—with most improvement occurring in stronger winds. For Dutch ships, by contrast, we found that warships showed large speed improvements but that VOC ships displayed none. Looking at every voyage undertaken by the VOC between the Netherlands and the East Indies between 1595 and 1795 confirmed this stagnation, with voyage length falling by only ten per cent over two centuries and the heavy onboard mortality rate actually increasing somewhat through time.

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