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ABSTRACT

Sailing Ship Technology, Navigation and the Duration of Voyages to Australia, 1848-85*

Sailing ships persisted on emigrant voyages to Australia until the late nineteenth century and passage durations decreased by three weeks from the late 1840s to the mid-1880s. The shortening of voyages by sail has been linked to improvements in navigation and in sailing ship technology but without quantitative estimates. Analysis of 311 voyages of emigrant ships that sailed directly from a UK port to Adelaide from 1848 to 1885 shows that the decline in voyage duration was associated with increases in tonnage, iron construction and, above all, clipper-style ship design. Advances in ship technology also enabled captains to take fuller advantage of sailing the so-called great circle route to Australia. Examining a unique dataset of the tracks of 290 voyages from Europe to Melbourne in 1854-62, I find that larger and clipper-style ships reduced voyage durations, both directly, because they were faster on a given track, and indirectly, because they could better exploit the great circle route.

JEL Classification: F22, N77, O33

Keywords: colonial Australia, sailing ships, voyage durations

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Introduction

In a path-breaking article Graham (1956) demonstrated that the years from 1850 to 1875 were the greatest days of the sailing ship, which was not finally eclipsed by steam until the 1880s. In his words, "The incredible defiance of the Industrial Revolution by sail during the second half of the nineteenth century was partly the consequence of new developments in sailing ship construction, and chiefly the result of the long and costly delays that occurred in the development and adaptation to the iron ship of an effective high-pressure steam engine with adequate boilers, condensers and screw propellers" (Graham 1856, p. 75). Not surprisingly, most of the attention has focused on the development of steam, which tends to be seen as an advancing technology, overtaking the relatively static technology of sail (Harley 1988; Kaukiainen 1992; Pascali 2017). Nevertheless, there were important improvements in sailing ship technology both before and after the mid-nineteenth century (Kelly and Ó Gráda 2019; Mendoça 2013).

As is well known, sailing ships persisted on the longer routes to India, China and Australasia, even after the opening of the Suez Canal (Harley 1971). Nowhere was this more evident than on the route from the UK to Australia where sail continued in the emigrant trade well into the 1880s and in the wool trade to the turn of the century (Hatton 2024b; Jackson 1980). Here I focus on the duration of voyages of ships sailing directly from the UK to Adelaide and to Melbourne as a measure of progress under sail. While a large literature celebrates the record voyages achieved by the most advanced ships and astute (or adventurous) captains (Clark 1911; La Grange and La Grange 1936, Lubbock 1948; MacGregor 1973; Stammers 2013; Mundle 2017), a few studies have provided more comprehensive estimates of average durations of voyages by sail from the UK to Australia. McDonald and Shlomowitz (1991) report that emigrant voyages from the UK to Australia fell from 106 days in 1847-51 to 91 days in 1881-5. More recently Hatton (2024b) finds that emigrant voyages from the UK to Sydney fell from 125 days in 1837-41 to 101 days in 1857-61 and 87 days in 1877-81.

In this paper I explore two key factors that influenced the voyage durations of sailing ships on voyages from the UK to Australia: sailing ship technology and improvements in navigation. Accounts that focus on improvements in the performance of sailing ships from mid-century list a variety of advances in ship technology that include increases in size, improved designs of hulls and rigging, and above all, the advent of the clipper ship (Lubbock 1848; MacGregor

1973; Mendoça 2013). They also note improvements in aids to navigation including better charts, better methods of fixing ships' position, and deeper knowledge of sailing conditions on different routes (Kelly et al. 2021). However, little attempt has been made at quantifying their links with voyage durations after mid-century. In what follows I assess the influence of the changing characteristics of ships and the routes that they sailed, and explore the complementarity between advances in ship construction and design and developments in navigation, in particular, sailing the so-called great circle route.

To do so I exploit two datasets: one for emigrant voyages to Adelaide from 1848 to 1885 and one for a range of voyages to Melbourne in 1854-62. These voyages went directly from the UK to Australia without stopping at intermediate ports and hence are not affected by layovers. In both cases the characteristics of the individual ships have been linked to the voyages and these are then associated with voyage times. From 1848 to 1885 the duration of voyages to Adelaide fell by 25 days, or 5.65 days per decade. I find that larger ships (by tonnage) and iron ships were faster, while older ships and those rigged as barques were slower. But the most important feature is 'clipper' design, which reduced voyage times by about eight days. However, it is unclear whether these associations simply reflect the speed of ships on a given course or whether improvements in design also enabled captains to better exploit great circle navigation.

For voyages to Melbourne in 1854 to 1862, when clippers had become more common, I use a unique dataset which provides the tracks of voyages extracted from ships' logs. These indicate that on the first leg, southing from the English Channel to the prime meridian, the voyage was shorter if the ship navigated east of the Cape Verde Islands. On the second leg, easting from the prime meridian to approaching Cape Otway at 140°E, the voyage was shorter the further south the ship navigated, better exploiting the great circle and the winds of the roaring forties. I find that on the both legs of the voyage larger ships were faster and those rigged as barques were slower, but clipper-designed ships were especially fast. I use mediation analysis to explore the extent to which the link between ship characteristics and voyage length is mediated by the route taken. I find that higher tonnage is mainly a direct association with voyage duration while barque-rigging is linked more indirectly via the track chosen. But clipper design is partially mediated—clipper ships were faster anyway but their shorter voyages were also partly due to exploiting better nautical tracks, especially in the southern oceans.

This paper contributes to three literatures. First, there is a large literature on how improvements in ship design and technology increased speeds and reduced costs. While much of this concerns the transition from sail to steam and advances in steam technology (Harley 1971, 1988; Pascali 2017), several contributions have focused on improvement in the speed of sailing ships (Rönnbäck 2012; Solar 2013; Solar and Rönnbäck 2015; Solar and Hens 2016; Kelly and Ó Gráda 2019). But the latter relate to the era before the introduction of clippers and iron hulls in the mid-nineteenth century and so they concentrate on earlier developments in ships' architecture and innovations such as the coppering of hulls.[1] The second literature relates to the improvements in navigation which include better nautical charts (Kelly et al. 2021) and fuller knowledge of winds and currents, as well as improved means of navigation (Miotto and Pascali 2022). Although the advent of steam had dramatic implications for the routes taken (Williams and Armstrong 2010; Pascali 2017), possible complementarity between ship technology and the tracks navigated has not been investigated for the era of the sailing ship.

The third literature relates to the persistence of sail under the challenge of steam on the voyages to the Far East and Australia (Graham 1856; Broeze 1989). For Australia in particular, voyages were long and emigrants from Europe endured hardships as well as considerable foregone earnings (Hatton 2024b). Because of the higher costs of passage, Australian colonies offered a variety of subsidised passages, although that imperative weakened as voyage times decreased (Hatton 2024a). As Blainey (1966, p. 173) noted, from 1850 "the long era in which distance was tyrant seemed to be fading away," with profound implications for the Australian economy. While the fading of tyranny of distance is often associated with the transition from sail to steam and the opening of the Suez Canal, up to the 1880s, the gains were largely achieved under sail. Yet the underlying factors have not been quantitatively explored.

The rest of the paper proceeds as follows. The next section discusses progress in sailing ship technology and navigation. Details of the sample of emigrant voyages to Adelaide are

[1] These also include the use jointing with iron brackets (knees), diagonal bracing of hulls and flush decks (Kelly and Ó Gráda (2019).

introduced and this is followed by an analysis of the association between voyage times and the key characteristics of ships. I then introduce a unique dataset that provides the coordinates of the tracks of sailing ships from Europe to Melbourne in the early clipper era. These data are first used to examine the links between the tracks of ships and the duration of voyages. I then turn to examining the links between ship characteristics, the track followed, and their associations with voyage durations. The key findings are summed up in the conclusion.

Advances in sailing ship technology and navigation

One element that spurred advances in sailing ship design around mid-century was the 1836 revision of the UK tonnage law (measuring volume, not weight). Under the old regulation, the registered tonnage of a ship, on which port dues were based, was a function only of the length and breadth of the ship. This led to the construction of deep, narrow, flat-bottomed ships, which without cargo or ballast, could be unstable (Clark 1911, p. 20; Graham 1856, p. 78). The 'new measurement' better reflected the true carrying capacity the ship and eased the corset on ship design, but it did not come into legal force until 1855. According to Graham (1856, p. 78): "Had the Tonnage Law of 1836 been compulsory, and its terms enforced, the 'flying clipper', as a breed, might well have made its start in Britain rather than the United States." It should be added that until 1849 British shipbuilders had also enjoyed some protection from competition under the Navigation Acts.

Clipper ship design, which came into vogue in the 1850s, comprised several elements. These include sharper deadrise (more V-shaped hulls in mid-section), more tapered bows, sometimes with concave sides (sharper entrance), and a greater area of sail for a given tonnage (La Grange and La Grange 1936; Lubbock 1948; Chapelle 1967; MacGregor 1973). These features were incorporated to varying degrees in the design of ships, many of which would not have been viewed as clippers but, in general, it led to increased length relative to breadth. Added to these developments were advances in methods of construction and the materials used. Most important among these were strengthening of wooden hulls with wrought iron frames (composite ships) and subsequently the transition to all-iron hulls. Iron ships were more rigid, which reduced hogging and sagging of the hull, and could therefore be larger, but suffered more from bottom-fouling than wooden hulls sheathed with copper or 'yellow metal' (an alloy of copper and zinc).

The links between these improvements and voyage times to Australia were widely acknowledged. They were hastened by the gold rush of the early 1850s, which saw some of the faster ships switched from other routes and further stimulated the building of new clippers for the Australian run. The most iconic of these was the *Marco Polo* of the Black Ball Line, which in 1852 sailed from Liverpool to Melbourne with 930 passengers in a record 74 days.[2] While a range of clippers made fast passages, a variety of more modest and less famous ships, typically square rigged and increasing in tonnage over time, also made the voyage in respectable times**.** For example, the *Essex* (843 tons), described as a favourite Blackwall ship, made good passages to Melbourne of around 95 days in the 1850s unless the winds were especially unfavourable *(South Australian Register* 3/8/1857; *Melbourne Argus* 7/11/1859;). These wooden ships were soon joined by iron-hulled ships. For example, the *Lincoln*, described as "a handsome vessel of iron, with every late improvement introduced in construction" (*South Australian Register* 4/12/1865) took 81 days in 1865. Even more striking, the *Storm Cloud*, "a first-class clipper, built of iron, and . . as fine a specimen of naval architecture as any previous arrival in our waters" (*South Australian Register* 29/4/1858) took just 74 days in 1858.

Also important in reducing voyage times were changes in the route. Voyages in the first half of the nineteenth century sailed south towards Brazil, then steered southeast, often stopping at intermediate ports, notably Cape Town, before crossing the Indian Ocean keeping north of 40°S, as recommended by the UK Admiralty.[3] But by mid-century (as detailed below), the voyages did not stop at the Cape and so they could steer further west in the Atlantic and then south in the Indian Ocean to follow the great circle route (Charlwood 1981, p. 16; Loney and Stone 2000, Ch. 4). However, for emigrant ships, this meant carrying food, water and other provisions for the whole duration, something that became more feasible as the voyage lengths declined. While in the late 1830s the UK Emigration Commissioner recommended (but

[2] The frequently quoted figure of 68 days (Hollenberg 2006, p. 100; Mundle 2017, p. 148), is land-to-land; port-to port was 74 days and the total voyage (from the passenger list) was 78 days. The *Marco Polo* completed the round trip in five months and 22 days, returning to Liverpool via Cape Horn after spending 24 days at Melbourne—the first time that the round trip had taken less than six months. Under the hard-driving captain 'Bully' Forbes, the 1852 voyage was exceptional and it beat the steamer *Australia* by a week each way. Under other captains it continued on the Liverpool-Melbourne run until 1867 but gradually became slower, averaging 80-90 days outward (Lubbock 1848, pp. 32-41; Hollenberg 2006, p. 105).

[3] Clark 1911, p. 261; Loney and Stone 2000, pp. 25-32. The Admiralty route was essentially a variant of the Brouwer route to Batavia, pioneered by Dutch explorer Hendrik Brouwer in 1611.

did not enforce) stopping at the Cape (or other intermediate port) by the 1850s this was infrequent.[4] This was underscored by the Passenger Acts, which, by stipulating more space and an enhanced dietary scale of provisions to be provided for a specified number of days, improved the comfort of passengers (MacDonagh 1961).[5]

Developments in navigation included improved charts and navigational instruments as well as accumulated knowledge of winds, currents and potential hazards.[6] Matthew Maury of the US Naval Observatory collected and published data for sailing routes and weather conditions on thousands of voyages, providing captains with evidence of the best track for each season (Hearn 2002). Most influential for the Australian run was Liverpool-based John Towson who encouraged captains to follow the great circle route and, from 1848, published tables to help them navigate it. [7] This involved sailing further west in the south Atlantic and then steering south of the Cape of Good Hope into the roaring forties and as high as 50°S. It was under Towson's influence that the captain of the *Marco Polo* chose the track on its record-breaking 1852 voyage (Hollenberg 2000, pp. 53-4, 107-8). Maury also promoted the great circle route but he warned that the wisdom of sailing into such high latitudes depended also on the state of the ship and the well-being of passengers (Maury 1855, p. 740). The hazards included strong winds, turbulent seas, the risks of collisions with icebergs and shipwreck on rocky outcrops (Loney and Stone 2000, Ch. 4; Mundle 2017, Ch. 6).[8]

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[4] Before 1840 passengers and crew often suffered from scurvy on ships that did not re-provision *en route*. This was more common on convict ships, which less often stopped at the Cape, possibly to avoid escapes (Staniforth 1991, p. 124).

[5] For voyages to Eastern Australia, the 1842 Passenger Act required ships to supply breadstuffs for steerage passengers for22 weeks. Prior to this sea stock was brought on board by passengers as well as purchased from the ship's store. Under the 1851 Act, ships were required to depart with provisions for 140 days and passengers were to be issued daily with cooked food. (McDonagh 1961 p. 238).

[6] One important development was the diffusion of the marine chronometer, which replaced dead reckoning and lunar distancing as methods of fixing longitude (Miotto and Pascali 2022).

[7] Great circle navigation had been known since the sixteenth century but was revived as practical guidance to seafarers in the nineteenth century (Cotter 1976). In his position as Scientific Examiner of Masters and Mates at Liverpool from 1850, Towson was particularly influential in popularising great circle sailing to Australia (Blainey 1966, p. 178-80; Cotter 1977). It is worth noting however that 'great circle sailing' is something of an exaggeration as strictly following the great circle from 40°S and 0°E to 40°S and 140°E would take the route as far south as the mid-60s, touching the coast of Antarctica. Towson referred to the recommended track as the composite great circle route, others referred to it as the compromise route; 'great circle sailing' was also taken to mean the entire voyage, returning via Cape Horn.

[8] Particular hazards in latitudes of the 40°S and above include the Crozet and Kerguelen archipelagos and the Prince Edward, McDonald and Heard Islands. There were also uncharted shoals such as those encountered in 1856 by the ship *Australia* at 38°S and 127°E (*South Australia Register*, 23/1/1856). Some were close to Australia such as the uncharted coastal reef just 60km west of Cape Otway on which the clipper *Schomberg* was lost on its maiden voyage in 1855 (Loney and Stone 2000, p. 111); the *Loch Ard* was lost in the same vicinity in 1878.

By 1850 some captains were already experimenting with using the great circle route. But the small ships sometimes ran into difficulty, as extracts from the logs of arriving ships reported in the Adelaide papers indicate. In 1849 the *Constance* (578 tons) made the passage in 79 days which was "later said to be by great circle sailing" (Sexton 1990, p. 155). But a year later the same ship took 101 days "since the [Emigration] Commissioners would not allow her to travel on the great circle route for fear of 'health risk' beyond 40°S" (Sexton 1990, p. 179). The captain of the *Sultana* (588 tons) which arrived in July 1850, "tried "circular sailing" to a limited extent, but found great difficulty in getting to the northward again, owing to the prevalence of N.E. and N.N.E. winds" (*South Australian Register* 27/7/1850). Nevertheless, captains persisted in taking more southerly passages. It was reported that the *Reliance* (805 tons) which arrived in 1851 "tried the great circle sailing, and found it advantageous", sailing as far south as 54°S (*South Australian Register* 15/9/1851).

Thus while some (including the Emigration Commissioners) were circumspect about great circle sailing, many captains chose a compromise route that just edged the roaring forties (consistent with Maury's advice).[9] Others, as noted above, plunged deep into the forties and beyond, which involved greater risk. It could also mean a slower passage if the ship lost masts or rigging in the gale force winds. Examples of such mishaps abound. One example is the *Hooghley* (540 tons) which at 49°S lost its maintopgallant mast and later in a sudden squall lost its foretop mast, the voyage taking 104 days (*South Australian Register* 20/4/1855). Another is the 1863 voyage of the iron ship *Sir John Lawrence* (698 tons) which at latitude 44°S "fell in with a hurricane of unusual violence, which swept away the quarter-boats, and volumes of water poured on deck, causing havoc and destruction to the deck gear, while aloft the maintopsail was blown away, foretopsail split in ribbons," (*South Australian Register* 15/12/1863). Nevertheless, it reached Adelaide in 100 days. And when, in 1864 at 47°S and 100°E, the iron barque *Adamant* (815 tons) "which could sail very fairly" ran into a snowsquall, its "foretopsail was split, the mizentopmast came down with a crash, the mainyard was sprung, and some of the head stays parted" (*South Australian Register* 14/10/1864). But it

[9] For example, the captain of the *Kent* (a wooden ship of 998 tons), which sailed the easting to Melbourne between 41° S and 44° S, remarked that "many ships bound to these colonies have tried to make better passages by going into 50° to 55° south latitude, where a vast amount of discomfort must be entailed on the passengers crowded in these ships, and, from recent accounts, shows much danger to the ships and all on board, from collision with ice; and there is reasonable presumption that the missing ship, *Guiding Star*, may have met her fate from collision with ice in those latitudes (*Melbourne Argus*, 25/7/1855).

was quickly repaired and made the voyage in 73 days. This suggests an element of complementarity between larger and more robust ships and navigating the turbulent seas of the more direct route.

While these developments helped to maintain the competitiveness of sail in the emigrant trade, steam was slowly advancing. Steamers were becoming competitive with voyage times that, by the 1860s, were similar to those of sail. But because of higher costs they were mainly confined to transporting cabin passengers, high value goods, and mail (Broeze 1989). An outstanding exception was Brunel's *SS Great Britain,* which having bankrupted the Great Western Steamship Company, was sold at a knockdown price (Farr, 1965, p. 15). It carried emigrants on 32 voyages to Melbourne from 1852 to 1875, averaging 65 days. But while a number of other steamship lines commenced passenger services to Australia they were often abandoned as unprofitable (Clarke 1911, pp. 286-7; Lubbock 1848, p. 286-7)[10]. Indeed, it was not until the 1880s that steamships came to dominate the transport of steerage emigrants to Australasia.[11]

Emigrant ships to Adelaide

I turn first to voyages of emigrant ships from the UK to South Australia. I use the data for 323 voyages that arrived in Adelaide in 1848 to 1885 from the database created by Haines et al. (2004). This set of voyages is restricted to those carrying government assisted emigrants on ships chartered specifically for the purpose, and the duration of each voyage is simply the difference between the dates of arrival and departure. These durations represent continuous sailing from final departure to first arrival and so they do not include days from the origin of the voyage to the last UK port of departure. For example, ships that originated in London often loaded goods before moving on to Plymouth for final departure, which could add weeks to the voyage if measured from the origin.[12] And unlike many of the voyages of earlier sailing

[10] The travails of individual steamship lines that commenced (often short-lived) services to Australia are documented by Maber (1967). It is worth noting that the early steamships were auxiliary steamers that were fully rigged and made part of the voyage under sail. Some, such as the *Argo* (1815 tons), used steam power only when the winds were unfavourable (Lubbock 1948, p. 287; Maber 1867, p. 52-3).

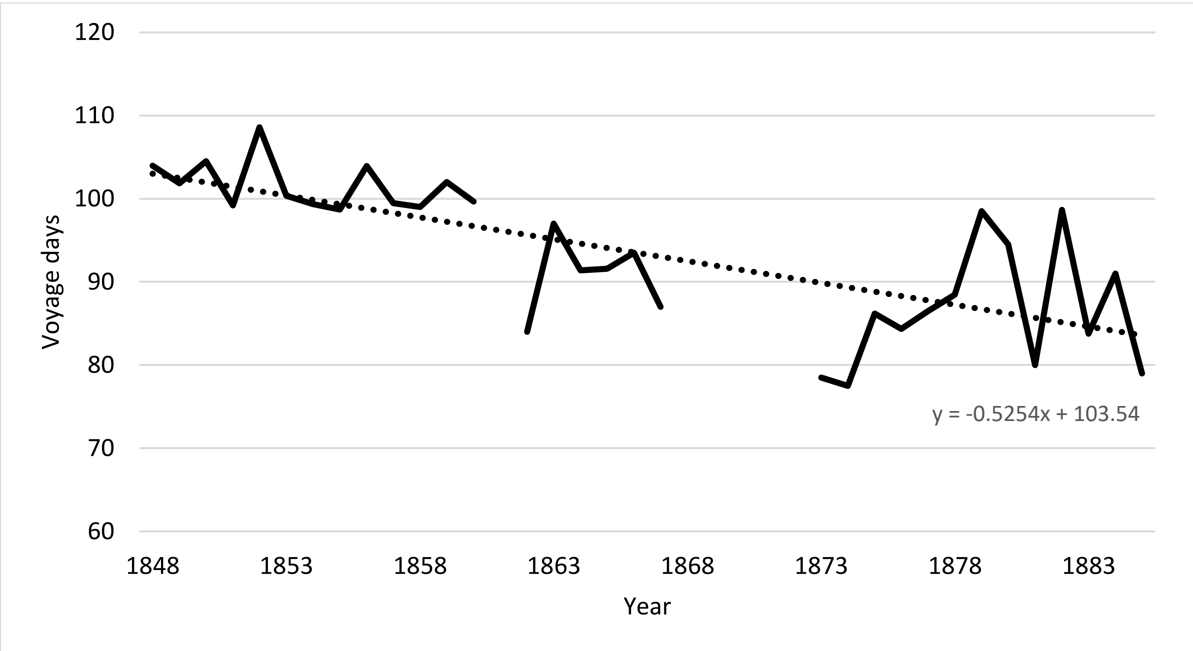
[11] Hatton (2024b) describes some of the factors that account for the delayed transition from sail to steam on the route to Australia in addition to the ongoing improvements in the efficiency of steam relative to sailing ships. The breakthrough came in the early 1880s when the P&O and Orient Lines were awarded mail contracts, which helped to cover the tolls on the Suez Canal making the Suez route more viable; also the advent of refrigeration expanded the scope for perishable (and lucrative) return cargoes outside of the wool season.

[12] From 1852 Plymouth was the Australian mail port and it was also established as a major emigration depot.

ships and some later steamships, these did not call at Cape Town, which would add time at port and preclude great circle sailing.[13] Similarly, unlike voyages to Sydney or Brisbane, which sometimes called at intermediate Australian destinations, these ships went directly to Adelaide.

The profile of voyage times is plotted in Figure 2. The downward trend in voyage durations follows a similar trend to that observed in other series. But the voyage durations are a little shorter, as they do not include any stops at intermediate ports. There are also gaps in the series, notably for the years 1868 to 1872 when the South Australian government suspended assisted immigration. The series is more volatile in the years from 1873 to 1885 when there are 5.4 voyages per year as compared with 16.5 per year from 1848 to 1860.

Figure 1: Average durations of migrant voyages from the UK to Adelaide, 1848-1885



Source: See text and Appendix 1.

In order to assess the contribution of changes in shipping technology to voyage durations I collect some key characteristics of the ships involved. These are obtained by using information from Parsons (1999) and from the South Australian Government website, *Passengers in History*, which link ships with voyages and include details of the type of ship, its

[13] Steamships often called at Cape Town to load coal at Table Bay where the facilities were expanded in the early 1850s. While there were also major coaling stations at Madiera, Las Palmas, St. Vincent (Kirkaldy 1914 Part IV Ch. X) there was nothing between the Cape and Australia. The foregone cargo or passenger space in carrying sufficient coal for the 5,000 nautical mile leg from the Cape to Australia was one reason why sailing ships survived competition from steam for so long.

tonnage and the year it was built. These pieces of information are important for linking each voyage to the correct ship as there are often several ships with the same name.[14] The missing details could then be added from *Lloyds Register* and a variety of other sources (see Appendix 1). Twelve voyages were excluded, either because the ship could not be found or because the exact specifications were unclear, leaving 311 voyages. These were sailed by 232 different ships and so there is a wide range of variation.

Tonnage is an important variable as larger ships could travel faster and carry more sail. For this I use the 'new measurement,' which followed the reform of 1836, and which more accurately reflected the capacity of the ship. Older ships are likely to be slower and age is calculated as the difference between the year of departure and the year that the ship was built. Also recorded is whether the vessel was rigged as a ship, where all three masts were square-rigged, or a barque, where the rearmost mast (the mizzenmast) was rigged fore and aft. Barques carried less sail, required less crew and were more manoeuvrable but were slower in a following wind. Another important variable is whether the ship was constructed of iron, which as noted above, imparted greater strength and structural stability than a wooden hull. Finally, while clipper-style ships were streamlined in shape and designed for speed, there is no precise definition. In the absence of a better definition, I designate a 'clipper' as where the length of the ship is at least five times the breadth (beam).[15] Unfortunately, this can be calculated only for ships on 265 of the 311 voyages. Appendix 1 provides further details.

Table 1: Descriptive statistics for ships to Adelaide

	(1) Obser-vations	(2) Mean	(3) Standard deviation	(4) Trend coefficient	(5) Trend t-statistic
Tonnage (100s)	311	8.88	3.33	0.22	17.16
Age of ship (years)	311	7.78	9.65	0.03	0.63
Rigged as barque (=1)	311	0.26	0.44	0.00	0.01
Iron construction (=1)	311	0.19	0.40	0.03	18.18
'Clipper' dimensions (length/beam >=5)	265	0.46	0.50	0.03	15.13

[14] For instance, one ship named *Caroline* sailed in 1855; in *Lloyds Register* for that year there are 28 ships named *Caroline*.

[15] Definitions that might be better, based on ships' block coefficients or prismatic coefficients, are simply not possible with available information.

Source: See text and Appendix 1.

As Table 1 shows, the average tonnage of ships across voyages is 888 tons and their average age was 7.8 years. A quarter of voyages were by ships rigged as barques, one fifth were by iron ships, and 45 percent by 'clipper' ships. It is worth also noting the trends over time, as represented by the coefficients (and t-statistics) from regressions of each of these characteristics on departure year (columns 4 and 5). These show that while tonnage was strongly increasing over time, there was no trend in the age of ships or whether rigged as a barque. Not surprisingly, iron construction and 'clipper' dimensions are both strongly increasing.

Regression results for voyages to Adelaide

Regression results are presented in Table 2, where the dependent variable is the number of days on the voyage and all the regressions include three seasonal dummies. In the first column, the only other explanatory variable is year of departure. The coefficient implies that, as in Figure 1, voyage durations decreased on average by 5.5 days per decade. The second column includes a dummy for departure from a northern UK port (e.g. Liverpool, Glasgow) which adds four days. A dummy for departure from London was never significant. The coefficient on tonnage is strongly significant and implies that shifting from 500 to 1000 tons is associated with a reduction of 4.5 days.[16] The coefficient on ship's age implies that adding six years to the age of the ship lengthens the voyage by about one day. The dummy for barques (relative to full-rigged ships) is positive indicating that the latter took a little over three days longer while for iron ships the voyage was 4.5 days shorter. In the presence of these variables the coefficient on the time trend is reduced, suggesting that more than half of the decrease in voyage times over the sample can be accounted for by changes in ship characteristics.

The result in column (2) may simply reflect the fact that ship characteristics capture non-linear trends in voyage length. In the third column, the linear time trend is replaced by a set of 5-year dummies. This means that the coefficients are estimated from variation within each five-year period. Column (3) shows that the coefficients on tonnage, age of ship and iron

[16] A negative association between tonnage and duration is consistent with the findings by Rönnbäck (2012) and Solar and Rönnbäck (2015) for slave ships on the middle passage, and by Solar and Hens (2016) and Solar and de Zwart (2017) for merchant shipping before 1830.

construction hold up remarkably well. It is worth noting also that, even when 5-year dummies are added, only 35 percent of the variation is explained. This serves as a reminder that there is considerable unexplained variation due both to unmeasured heterogeneity among ships and captains and, most importantly, in the sailing conditions.

Table 2: Days on the voyage and the characteristics of ships

	(1)	(2)	(3)	(4)	(5)
Year of departure	-0.538***	-0.225**		-0.075	
	(0.06)	(0.10)		(0.10)	
Departed northern port		4.360**	4.228**	4.176**	3.356
		(1.96)	(2.10)	(1.95)	(2.07)
Ship tonnage (100s)		-0.882***	-0.813***	-0.644**	-0.567**
		(0.28)	(0.28)	(0.27)	(0.27)
Age of ship (years)		0.178**	0.172**	0.089	0.087
		(0.08)	(0.08)	(0.09)	(0.08)
Rigged as barque (=1)		3.074**	2.460*	1.901	1.321
		(1.43)	(1.43)	(1.52)	(1.51)
Iron ship (=1)		-4.555**	-4.991**	-3.061	-3.079
		(2.19)	(2.23)	(2.14)	(2.16)
'Clipper' (=1) (length/beam >=5)				-7.430***	-7.611***
				(1.79)	(1.82)
Period dummies	No	No	Yes	No	Yes
Observations	311	311	311	265	265
R-squared	0.238	0.325	0.352	0.371	0.406

Notes: OLS regressions of voyage durations in days. All regressions include three seasonal dummies: March-May, June-August and September-November; cols (3) and (5) include dummies for five year periods beginning 1848-52. Standard errors in parentheses; significance levels: *** 1%, ** 5%, * 10%.

In the final two columns a dummy variable for 'clipper' is added to the regressions, which as noted above, reduces the number of observations. As shown in column (4), this further weakens some of the other coefficients, notably age, rigging and iron ship construction. This should not be surprising as the changing shape of ships is correlated with other improvements in ship design, some of which are captured by the other variables in the model. The coefficient on 'clipper' is negative, large and highly significant. It implies that ships having a length to beam ratio of five or above cut the voyage time by more than a week. It is also notable that the coefficient on the time trend becomes insignificant and close to zero. When 5-year dummies are included in column (5) tonnage and 'clipper' remain highly significant but all other variables are insignificant. At first sight, the coefficient on departure year in column (4) seems to suggest that only ship design matters and that improvements in navigation, specifically adopting the great circle route, were unimportant. But further below I investigate whether improvements in ship design and construction were the *means* of taking the more direct route and therefore that they indirectly capture the improvements in navigation.

As shown in Appendix 2 Table A2, when the dataset is restricted only to wooden ships, the coefficients on tonnage, age and barque-rigged are similar in size to those in Table 2 but less significant. But the variable ‘clipper’ remains highly significant, underlining the fact that this variable is important for the speed of wooden ships (the original clippers), and the result is not simply because more rigid iron hulls made for greater length to breadth among iron ships. As noted above, several important studies have found that the speeds of sailing ships were significantly increased by sheathing the wooden hulls with a thin sheet of copper on ‘yellow metal’, which reduced the fouling of the hulls by barnacles and weeds (Solar and Rönnbäck 2015; Solar and Hens 2016; Kelly and Ó Gráda 2019). The ships in the sample were all metalled but, as shown in Appendix 2, Table A2, when a variable is added for years since last metalled, this proved to be insignificant. This suggests that whether or not wooden hulls were sheathed was more important than how recently the sheathing was renewed.

The tracks of ships to Melbourne

In order to distinguish between the effects of improved ship technology and differences in navigation it is necessary to plot the course taken by ships sailing from the UK to Australia. Here I utilise a unique dataset data for 296 voyages departing in 1854 to 1862 from a range of European ports, not only the UK. These data were collected by George Neumayer, the director of the Melbourne Flagstaff observatory. Neumayer was an explorer and meteorologist who, having previously visited Australia, returned in 1857 with a set of scientific instruments to establish the Melbourne Flagstaff Observatory in 1858. Having studied the work of Maury, Neumayer instigated the collection of meteorological and oceanographic information from captains of ships arriving in Melbourne, and in particular, the coordinates recorded in the ships’ logs.[17] He was particularly interested in exploring safer and more efficient navigation and so information from the logs was transcribed and analysed. The main results were presented in Neumayer (1964) which contained a section on nautical observations that provided a series of tables reporting key data points for the tracks of

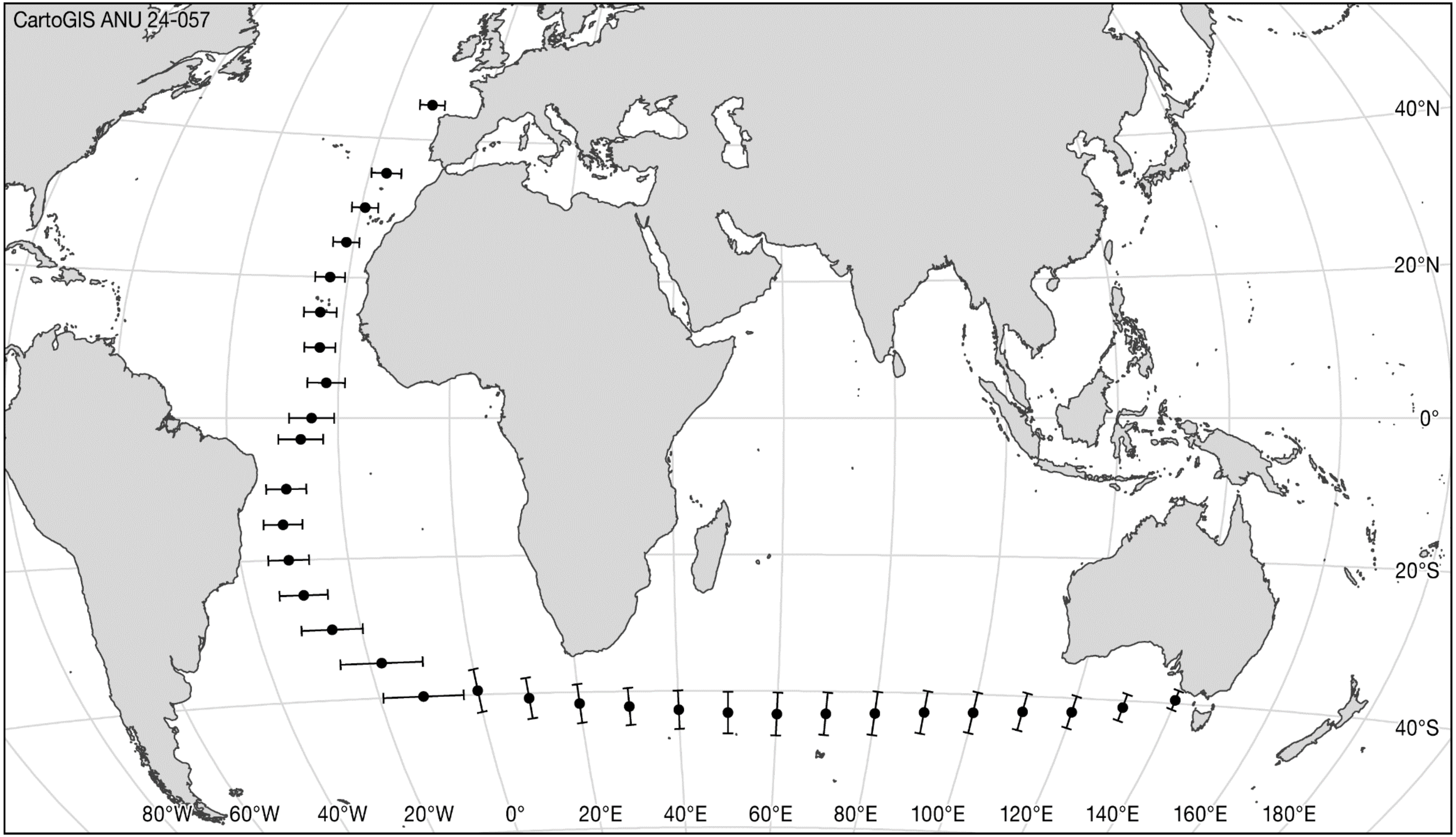
[17] Neumayer invited captains to share their logs in exchange for re-calibrating their instruments.

voyages and sailing times. From these data, he concluded that there remained considerable scope for improvements in navigation to reduce voyage times (Neumayer 1864, p. 330).

Neumayer's tables report the tracks of a total of 296 voyages in three segments. The first was from the Lizard (the western end of the English Channel) to the parallel of St. Roque, Brazil (3°S). These are readings of longitude for given benchmarks of latitude from 45°N to 3°S. The second segment was from the latitude of St. Roque to the prime (Greenwich) meridian, again reporting readings of longitude for given benchmarks of latitude from 10°S to 40°S. The third section covered easting from the prime meridian to 140°E, which is the approach to Cape Otway in Australia, this time as readings of latitude for benchmarks of longitude. It is worth noting that a few voyages are omitted from the first and third segments as they either did not sail from the Lizard (probably originating in New York) or did not go directly to Melbourne.

These three segments are combined in Figure 2, which shows the mean position of all voyages at each benchmark with whiskers representing one standard deviation of longitude or latitude either side of the mean. The figure shows that, from the English Channel, the average ships' track followed the trade winds across the Bay of Biscay and down the eastern side of the North Atlantic. On reaching the equatorial doldrums at about 5°N, the average track then turns away from Africa towards South America continuing in a SSW direction, reaching about 31°W at a latitude of 20°S before turning east. From there the average track descends south, and increasingly east, in an arc towards 40°S in order to catch the winds of the roaring forties. On the route south there is increasing variation in longitude among the voyages, as illustrated by the standard deviation bands. However, the last two observations (35°S and 40°S) are somewhat misleading as they are based on a restricted number of observations since not all voyages sailed that far south before reaching the prime meridian. Indeed, as shown by the first reading in the third segment, the average track crossed the prime meridian at a shade under 40°S. From there ships sailed east with the average track descending to a little over 43°S at 60°E before heading towards Cape Otway. It is worth noting that the variation in latitude is relatively small, indicating that most voyages followed latitudes between 38°S and 45°S.

Figure 2: Tracks of voyages from Europe to Australia



Note: Winkel tripel projection map with round markers for the mean coordinates for each benchmark of latitude or longitude and whiskers of one standard deviation.

Neumayer's tables record the point-to-point sailing times for the three segments of the route. Table 3 reports the means and standard deviations in days for each segment and overall. As shown in the table, the shortest segment of the average track was 22.8 days from the latitude of St. Roque to the prime meridian while the first and third segments took an average of 32 and 37 days respectively. The average for complete voyages is 90.4 days, which is about ten days shorter than was observed for the emigrant voyages to Adelaide over the same years. The difference reflects the additional days for the latter between the origin of the voyage and reaching the Lizard and between reaching 140°E and disembarkation at Melbourne.

Table 3: Sailing times between different points on the route

	Lizard to St Roque	St. Roque to Prime Meridian	Lizard to Prime Meridian	Prime Meridian to 140°E	St. Roque to 140°E	Lizard to 140°E
Mean (days)	32.04	21.76	53.77	36.68	58.40	90.48
Std. deviation	5.94	4.45	8.36	7.53	10.39	14.02
No. of voyages	290	296	290	292	292	287

Note: For reasons noted in the text, of the 296 voyages, six lack the first segment from the Lizard to St. Roque and four lack the last segment from the prime meridian to 140°E (one of which also lacks the first segment).

How are sailing times associated with the tracks followed on these voyages? I explore the voyages in two parts: first the passage south from the Lizard to the prime meridian (combining Neumayer's first two segments) and then the passage east from the prime meridian to 140°E. Table 4 reports the results of using selected points on the route, generally those with the highest correlations with voyage times. Results for each set of coordinates are presented in Appendix 2 Tables A3 to A5. Column (1) of Table 4, for days from the Lizard to the prime meridian, also includes a dummy (=1) for sailing east of the Cape Verde islands (16°N, 24°W), a point noted by Neumayer and reported in his tables. As he surmised, sailing east of Cape Verde, cut the southward sailing time, according to the coefficient, by about five days. Degrees west at 45°N, the most northerly reading, gives a significant negative coefficient while degrees west at 15°S, the mean point furthest west, does not. As column (2) shows, replacing 45°N with 25°N gives a slightly larger and more significant coefficient. This suggests that keeping well out from the African coast while steering towards Cape Verde enabled ships to make the most of the NE trade winds. As reported in Appendix 2, Table A3, the coefficients on degrees west at any latitude south of Cape Verde (16°N) are not significant. Sailing further west in the doldrums from the coast of Africa towards South America might slow the passage but on the other hand it afforded earlier exposure to the north westerly trade winds in the southern latitudes. While one might have anticipated that an optimum passage could be identified by using a quadratic specification, squared terms were never significant.

Table 4: Days on the voyage and key coordinates of the track

	(1)	(2)	(3)	(4)	(5)	(6)
	Lizard to Prime Meridian	Lizard to Prime Meridian	Prime Meridian to 140°E	Prime Meridian to 140°E	Lizard to 140°E	Lizard to 140°E
°W at 45°N	-0.506**					
	(0.205)					
°W at 25°N		-0.812***			-0.868**	-0.819**
		(0.274)			(0.415)	(0.410)
East of Cape Verde (=1)	-4.458***	-6.851***			-9.012***	-8.829***
	(1.070)	(1.331)			(2.028)	(2.002)
°W at 15°S	0.053					
	(0.149)					
°S at 50°E			-1.428***	-11.243***	-2.110***	-17.257***
			(0.137)	(2.704)	(0.263)	(5.168)
°S at 50°E squared				0.112***		0.172***
				(0.031)		(0.059)
R-squared	0.098	0.106	0.293	0.324	0.284	0.305
Observations	290	290	292	292	287	287

Note: All regressions include three seasonal dummies: March-May, June-August and September-November. Standard errors in parentheses; significance levels: *** 1%, ** 5%, * 10%.

For the days on the passage east from the prime meridian to 140°E, column (3) of Table 4 shows that degrees south at 50°E gives a negative coefficient with a t-value of 10, which indicates a significant advantage in sailing further to the south. 50°E is chosen as it is relatively early in the easting passage and is the most significant coefficient among those for different meridians, although all are negative and significant (Appendix 2, Table A4). As noted earlier, easting at more southerly latitudes could reduce voyage times both because of the stronger winds and because of the shorter (great circle) distance. But on the other hand, sailing further south exposed the ship to more turbulent seas, icebergs and risk of shipwreck. Column (4) adds a squared term and the result shows that there is a clear quadratic in degrees south at 50°E, with both terms significant. As demonstrated in Appendix 2, Table A5, degrees south at other meridians give very similar results. The minimum of this quadratic is at 50.2°S and, while this suggests a clear trade off, it is worth noting that only nine voyages sailed further south than 50°S at 50°E. As Neumayer (1864, p. 325) observed, sailing further to the south in the roaring forties brought diminishing gains in time saved on the voyage. The final two columns show that the linear and quadratic coefficients remain significant for days on the entire voyage from the Lizard to 140°E, while the dummy for east of Cape Verde also retains significance.

Ships and Routes to Melbourne

For emigrant voyages to Adelaide, faster voyages were associated with ships with higher tonnage, newer and square-rigged ships, and above all, clipper-style construction. But in the absence of sailing tracks it is not possible to ascertain to what degree this was simply due to the quality of the ship for a given track or whether superior ship quality also enabled captains to navigate a more efficient track. In this section I first test whether the characteristics of the ships listed by Neumayer have similar associations with voyage durations to Melbourne as with those to Adelaide. After presenting reduced form estimates I then turn to seeing how far this can be associated with the track followed.

Neumayer's tables provide only the name of the ship and the date of departure. These voyages are more heterogeneous than those in the Adelaide sample, as many either were not British ships, or did not originate from British ports, or were not emigrant ships. As a result, greater effort was required to identify the right ship, as described in more detail in Appendix 1. As there is no source comparable to South Australia's *Passengers in History* for linking ship details with arrivals in Melbourne, basic information on tonnage (and occasionally other characteristics) was gathered from newspaper reports on arrivals and, for ships carrying migrants, from passenger lists. This helped to identify the right ship, often among many with the same name, and thence to find its details in the registers. In addition to *Lloyds Register*, the other main sources used were *American Lloyd's Register of American and Foreign Shipping* and *Bureau Veritas.* While the type of rigging and iron construction could be found fairly readily, the basis of tonnage measurement is less clear. Where only one value is available (and not specified as old or new measurement) it was assumed to be old measurement if the ship was built before 1853, otherwise new measurement. As with the emigrant ships to Adelaide, the relationship between old and new measurement, where both are available, was used to impute new measurement in 41 cases. Similarly, ship dimensions, used to define 'clippers' as length to beam ratio of at least five, could not be found for all ships.

Details on tonnage, year built, rigging and iron construction was found for all ships except two, leaving a maximum of 294 voyages involving 196 different ships. The data include a wide range of ships including some of the well-known clippers such as *Marco Polo*, *Lightning*, *Red Jacket*, *Champion of the Seas*, *Lord of the Isles* and *Flying Cloud*, as well as many much more modest ships and barques, some of less than 500 tons. Descriptive statistics are reported in Table 5. The ships in the Melbourne sample are somewhat larger and newer than those heading to Adelaide, with slightly fewer barques and only a handful of iron-hulled ships. Dimensions were found for ships on 261 of the voyages and, among these, more than 60 percent are designated as 'clippers'.

Table 5: Descriptive statistics for ships on voyages to Melbourne

	(1)	(2)	(3)
	Observations	Mean	Std. deviation
Tonnage (100s)	294	10.41	4.48
Age of ship (years)	294	6.50	4.72
Rigged as barque (=1)	294	0.20	0.40
Iron construction (=1)	294	0.02	0.13
'Clipper' dimensions (length/beam >=5) (=1)	261	0.62	0.49

Notes: For details of construction see text and Appendix 1.

Table 6 reports the results of regressions of days on the voyage on ship characteristics for days from the Lizard to the prime meridian, from there to 140°E, and then for the entire voyage. These regressions also include dummies for season of departure from the Lizard. Comparison of columns (1) and (3) or (2) and (4) indicate that the same characteristics are significant for both legs of the voyage. These are the negative coefficients on tonnage and positive coefficients on being rigged as a barque. In contrast to the results for voyages to Adelaide, age of ship and iron hull are insignificant although there are very few cases of the latter. On both legs of the voyage, the 'clipper' dummy takes a strong negative coefficient, as for voyages to Adelaide, and this weakens the other coefficients especially for the first half of the voyage. The same variables are significant for the whole voyage, as indicated in columns (5) and (6). From column (6), an increase in tonnage of 500 tons is associated with a decrease 2.7 days while rigging as a barque slowed the voyage by 8.3 days and 'clipper' design is associated with a reduction in voyage length of 8.4 days. As shown in Appendix 2, Table A6, the coefficients on ship characteristics are robust to including year of departure and adding a dummy for emerging from the Irish sea rather (rather than the English Channel) which would place the ship further west at the latitude of the Lizard.

Table 6: Days on segments of the voyage and ship characteristics

	(1) Lizard to Prime Meridian	(2) Lizard to Prime Meridian	(3) Prime Meridian to 140°E	(4) Prime Meridian to 140°E	(5) Lizard to 140°E	(6) Lizard to 140°E
Ship tonnage (100s)	-0.408***	-0.217*	-0.439***	-0.329***	-0.845***	-0.541***
	(0.122)	(0.121)	(0.098)	(0.099)	(0.190)	(0.186)
Age of ship (years)	0.053	-0.071	0.092	0.014	0.170	-0.040
	(0.100)	(0.104)	(0.081)	(0.085)	(0.157)	(0.161)
Rigged as barque (=1)	3.309**	2.611*	6.232***	5.394***	9.907***	8.322***
	(1.378)	(1.452)	(1.099)	(1.184)	(2.157)	(2.250)
Iron hull (=1)	-0.815	0.091	-1.506	-0.931	-2.580	-1.098
	(3.599)	(3.394)	(2.910)	(2.768)	(5.599)	(5.213)
'Clipper' (=1) (length/beam >=5)		-4.882***		-3.299***		-8.437***
		(1.027)		(0.836)		(1.583)
R-squared	0.127	0.165	0.287	0.277	0.247	0.276
Observations	288	259	290	258	285	256

Note: All regressions include seasonal dummies: March-May, June-August and September-November. Standard errors in parentheses; significance levels: *** 1%, ** 5%, * 10%.

Mediation Analysis

To what extent does the association between ship characteristics and days on the voyage reflect different tracks followed by different types of ship? In order to examine this question, I turn to mediation analysis (see Celli, 2022). This distinguishes between the direct effect of ship characteristics on voyage duration and the indirect effects of these characteristics on voyage duration working through the route taken. The structure of the model is as follows:

$$Y_i = \gamma + cX_i + \varepsilon_i \qquad (1)$$

$$M_i = \alpha + aX_i + \epsilon_i \qquad (2)$$

$$Y_i = \beta + bM_i + c'X_i + \mu_i \qquad (3)$$

Where Y is the outcome variable, M is the mediator and X is one or more independent variables, i indexes the observation and ε, ϵ and μ are error terms. c in equation (1) is the total association between X and Y, a in equation (2) is the association between X and the mediator, M, and b in equation (3) is the association between the mediator and the outcome. Substituting (2) into (3), the indirect association between X and Y is ab and the direct association is c'. Assuming that c is non-zero, if either a or b are zero then there is no mediation and if c' is zero there is full mediation. If a, b and c' are all non-zero there is partial mediation and the proportion of the association between X and Y that runs through the mediating variable is $\frac{ab}{ab+c'}$.

In order to make this operational I use structural estimation (path analysis) so that the equations are estimated simultaneously (see Mehmetoglu, 2018). As before, the outcome of interest (Y) is number of days on the voyage. The mediator variables (M) are the key points on the route most strongly correlated with voyage time (as in Table 4). For the first leg, from the Lizard to the prime meridian, this is the dummy for sailing east of Cape Verde and for the second leg, from the prime meridian to 140°E, it is degrees south at 50°E. In light of Table 6, the independent variables (X) are tonnage, barque and 'clipper'.

The upper panel of Table 7 presents the results for the first leg, the Lizard to the prime meridian. Column (1) shows that the coefficient of the mediating variable, navigating east of Cape Verde (b, in equation (3)) is negative and significant while tonnage and 'clipper' both take significant negative coefficients indicating a direct association. In column (2) the coefficients (a in equation (2)) are significant for barque and 'clipper' but not for tonnage. Column (3) reports the mediation channel coefficients (ab) and their standard errors. The significance tests indicate that tonnage is mainly a direct association, barque works mainly through mediation, and 'clipper' is partially mediated. Evidently barques were able to take less advantage of steering east of Cape Verde while clippers were able to gain some advantage but were faster in any case. The final column shows that for 'clipper', where the coefficients are significant in both columns (1) and (2), the proportion mediated is a modest 18 percent

The lower panel of Table 7 reports the mediation analysis for the second leg from the prime meridian to 140°E. Not surprisingly the coefficient on the mediator, degrees south at 50°E, is negative and significant and the coefficients on the three ship characteristics are also significant. However, in column (2) only the coefficient on 'clipper' is significant indicating that, on the easting leg, shorter voyages for larger ships and longer voyages for barques, were direct associations only. It was evidently the 'clippers' that were best able to take advantage of great circle sailing. Column (4) suggests that 43 percent of the association with shorter voyages came though navigating further south.

Table 7: Mediation analysis, Lizard to Prime Meridian and Prime Meridian to 140°E

	(1)	(2)	(3)	(4)
	Dep var: Days, Lizard to Prime Meridian	Dep var: East of Cape Verde (=1)	Mediation channel coefficient	Proportion mediated of total
East of Cape Verde (=1)	-5.916***			
	(1.252)			
Tonnage (100s)	-0.258**	-0 014	0.084*	-0.483
	(0.114)	(0.007)	(0.047)	
Barque (=1)	1.399	-0.277***	1.643***	0.540
	(1.395)	(0.089)	(0.631)	
'Clipper' (=1) (length/beam >=5)	-4.174***	0.157***	-0.933**	0.183
	(0.950)	(0.061)	(0.412)	
	259	259		
	Dep var: Days, Prime Meridian to 140°E	Dep var: Degrees south at 50°E	Mediation channel coefficient	Proportion mediated of total
Degrees south at 50°E	-0.965***			
	(0.135)			
Tonnage (100s)	-0.307***	0.030	-0.029	0.087
	(0.089)	(0.041)	(0.039)	
Barque (=1)	4.839***	-0.654	0.631	0.115
	(1.073)	(0.492)	(0.484)	
'Clipper' (=1) (length/beam >=5)	-1.996**	-1.436***	-1.386***	0.410
	(0.759)	(0.337)	(0.379)	
	259	259		

Note: Mediation analysis based on structural estimation by maximum likelihood. All regressions include seasonal dummies: March-May, June-August and September-November. Standard errors in parentheses; significance levels: *** 1%, ** 5%, * 10%. The standard errors in column (3) are constructed using the Sobel method.

Table 8 reports the results of mediation analysis for the whole voyage from the Lizard to 140°E. In this case both mediating variables, east of Cape Verde and degrees south at 50°E, are included. These are both significant in column (1), consistent with columns (5) and (6) of Table 4, as are the three ship characteristics, consistent with column (6) of Table 6. As before, the tonnage of ships is mainly a direct association, as reflected in the low significance of the tonnage coefficients in columns (3) and (5). But barque now has both an indirect association, which evidently stems from the first leg of the voyage and a direct association, which stems from the second leg. This is reflected in the coefficients barque in columns (1) and (3) of Table 7. Column (6) of Table 8 shows that, taken together, these account for 34 percent of the overall association. As before, the association of voyage days with 'clipper' is both direct and indirect on both legs. In this case mediation accounts for 35 percent of the overall association.

Table 8: Mediation analysis, Lizard to 140°E

	(1)	(2)	(3)	(4)	(5)	(6)
	Dep var: Days, Lizard to 140°E	Dep var: East of Cape Verde (=1)	E of Cape Verde mediation channel	Dep var: Degrees south at 50°E	Degrees S at 50°E mediation channel	Proportion mediated (both mediators)
East of Cape Verde (=1)	-7.714***					
	(1.854)					
Degrees south at 50°E	-1.276***					
	(0.259)					
Tonnage (100s)	-0.561***	-0.014*	0.105*	-0.039	0.038	-0.133
	(0.168)	(0.007)	(0.063)	(0.052)	(0.053)	
Barque (=1)	5.820**	-0.277***	2.139**	-0.834	0.847	0.338
	(2.067)	(0.090)	(0.864)	(0.651)	(0.653)	
'Clipper' (=1)	-5.734***	0.156**	-1.205**	-1.832***	-1.851***	0.346
	(1.442)	(0.616)	(0.557)	(0.568)	(0.571)	
Observations	256	256		256		

Note: Mediation analysis based on structural estimation by maximum likelihood. All regressions include seasonal dummies: March-May, June-August and September-November. Standard errors in parentheses; significance levels: *** 1%, ** 5%, * 10%. The standard errors in column (3) are constructed using the Sobel method. The proportion mediated is: $(a_1b_1 + a_2b_2)/(a_1b_1 + a_2b_2 + c')$, where 1 and 2 are the two mediators.

Conclusion

The transition in ocean shipping from sail to steam took decades to complete due to the gradual progress of steam technology. But sail persisted on longer voyages to destinations such as Australia partly because the performance and productivity of sailing ships also improved. While much has been written about record voyages, notably by the clippers, little effort has been made to evaluate the impact of the continuing improvements in the construction and design on the average speed of sailing ships after mid-century. In this paper I focus on the decline in voyage durations for emigrant ships to Australia and link these directly to key attributes of the ships. Increases in tonnage, iron hulls and 'clipper' dimensions are directly associated with shorter voyages. Taken together, these advances can account for most of the reduction of 5.5 days per decade in voyages to Adelaide from 1848 to 1885.

Improvements in navigation have also been widely noted, both among contemporaries and historians. Principal among these was abandoning the old Admiralty route to Australia and adopting the great circle route. It was claimed, following the insights of Maury and the practical guidance of Towson, that improved navigation could cut more than three weeks from the voyage to Australia (Graham 1956, p. 82). In his account of the clipper ship *Marco*

Polo, Hollenberg (2006, p. 108) wrote that "by far the most important factor determining the duration of the voyage to and from Australia was the route taken and this was demonstrated many times over by the huge improvements in times that occurred once Towson's advice was widely adopted and the old Admiralty route discarded." As this route was pioneered by the clippers, perhaps it is not surprising that it became known as the clipper route.

Evidence from voyages to Melbourne suggests clear links between the tracks of ships and their voyage times, notably in the southern oceans but also in the Atlantic. However, improved ship quality and improved navigation cannot each separately account for the whole of the improvement in voyage times. I suggest instead that part of the reason that advances in the construction and design of sailing ships were important is that they enabled captains to take fuller advantage of the more-direct great circle route to Australia. The evidence from the tracks of ships to Melbourne indicates that the characteristics of ships was linked directly to voyage times due to faster sailing on a given track but also indirectly via the track taken. Tonnage was mainly a direct negative association with voyage duration while barque-rigging was indirect and positive, at least on the southing leg. But 'clipper' dimensions had both direct and indirect associations, the latter accounting for a little over a third of the lower voyage durations. So the faster speed of clippers was only partly due to the track that they sailed.

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Appendix 1: Data sources and methods

Emigrant Ships to Adelaide

As noted in the main text the set of assisted emigrant voyages to South Australia used in the analysis was compiled by Haines et al. (2004) and made available as a CD. These were taken from original ships lists, which can be accessed at: https://www.archives.sa.gov.au/finding-information/discover-our-collection/migration-and-crew/passenger-lists-1845-1940. For each voyage, they record the port and date of final departure from the UK and the date of arrival in Adelaide. The average voyage durations by year, which are plotted in Figure 1 of the main paper, are listed in Table A1 below together with standard deviations and the number of voyages for each year. It is worth noting that these voyages carried a total of 104,267 passengers. As compared with the totals for South Australia over the years 1848-85 presented by Haines (1997, pp. 264-5) these account for 98.5 of assisted migrant arrivals and for 68.7 percent of all migrant arrivals.

Table A1: Voyage durations in days, by year of departure

Year	Mean	Std Dev	Number	Year	Mean	Std Dev	Number
1848	104.0	10.2	22	1867	87.0	.	1
1849	101.9	10.9	22	1868			
1850	104.5	8.6	10	1869			
1851	99.2	12.6	17	1870			
1852	108.6	8.2	16	1871			
1853	100.3	12.7	18	1872			
1854	99.4	11.1	33	1873	78.5	2.1	2
1855	98.7	11.3	34	1874	77.5	3.1	4
1856	103.9	11.7	14	1875	86.2	13.3	5
1857	99.5	9.3	11	1876	84.3	7.9	18
1858	99.0	16.8	10	1877	86.5	8.8	8
1859	102.0	19.1	4	1878	88.4	11.4	9
1860	99.7	4.5	3	1879	98.5	5.8	6
1961				1880	94.5	12.0	2
1862	84.0	24.9	3	1881	80.0	7.1	2
1863	97.0	9.8	5	1882	98.7	3.5	3
1864	91.4	11.2	8	1883	83.8	7.5	8
1865	91.6	11.4	14	1884	91.0	1.4	2
1866	93.5	12.5	8	1885	79.0	.	1

Source: see text.

In order to attach ship characteristics to each voyage it is important to identify the correct ship. This was done by using the listing of ships and voyages provided by Parsons (1999), for arrivals up to 1866, and by the website https://passengers.history.sa.gov.au. These provide details such as tonnage place and date of build of arriving ships together with dates of arrival and departure of each voyage, which helps to link the voyage to the correct ship, often among others with the same name. Missing details were found by using available information to find the ship in *Lloyds Register of Shipping*. The 323 voyages in the database were accounted for by 243 different ships and so there is considerable variation in ships.

Details were found for all ships except for the *Magdalena* (two voyages) which is not recorded in *Lloyds Register* or in the collection of ship plans and survey reports provided by the Lloyds Register Foundation at: https://hec.lrfoundation.org.uk/. The year and place of construction was identified for each ship but some ships that were built in India were relatively old and had often been reconstructed, the details of which are unclear. I therefore exclude the 10 voyages of Indian-built ships that were originally constructed more than 20 years before the year of departure, leaving a total of 311 voyages by 232 ships. The vessels were either square-rigged ships or barques. Barques differed from ships as the mizzenmast (the rearmost of three masts) is rigged fore and aft rather than square. It is worth noting that the rigging could be changed from ship to barque or vice versa. As the form of rigging for the year of departure listed in *Lloyds Register* sometimes differs from that reported on arrival in *Passengers in History*, the latter was used.

The tonnage of arriving ships is sometimes listed according to the 'old measurement' and sometimes according to the 'new measurement' which was gradually adopted after the reform of 1836 but subsequently refined and enforced from 1855.[18] Up to 1861 *Lloyds Register* often reported both measurements, but when only one is listed it is unclear whether this is on the old or the new basis. However, the voyages were also listed in annual reports of the *UK Emigration Commissioners*, which up to 1856, note whether the tonnage reported was by new or old measurement. For the 161 voyages for which both old and new measurement was collected the ratio of old to new is 0.88. For the 10 cases where only the old measurement could be found, new measurement tonnage was imputed from a regression on old measurement and year of build. Where, for later ships, gross and net tonnage could be distinguished, gross was chosen in order to be consistent the measurements for older ships.

Iron ships (or barques) are readily distinguished and three composite ships (wooden hull on an iron framework) are grouped with wooden ships. As noted in the main paper wooden-hulled ships, were sheathed with 'yellow metal', an alloy mainly of copper and zinc, also known also as Munz metal after its inventor. The sheathing was changed periodically (about every three years), normally prior to a voyage, and the year of last renewal could be found for 240 ship/voyages, mainly from *Lloyds Register*. However, in cases where the year of sheathing was the same as the year of departure it is not clear whether sheathing took place before the outward voyage or after the return. In cases where the years are the same *and* the ship departed in the first month of the year, the year of the previous occurrence of sheathing was used. This variable is used in Appendix 2 Table A2 (below).

Three dimensions of the ship: length, breadth and depth are not reported by Lloyds until 1863 and so this was supplemented with information (for Canadian built ships) from Wallace (1929) and web searches. Nevertheless, length and breadth were found for 240 ship/voyages. As noted in the main paper there is no easy way of categorising clipper-style ships and in any case, following the 1836 reform of tonnage measurement, aspects of the designs that characterised the clippers were incorporated into ships not specifically recognised as clippers (MacGregor 1973, p. 173). Given the

[18] Under the old system, tonnage was calculated based on length and breadth alone (under the assumption that depth would be about half the breadth) as follows: $\frac{\left(Length-\frac{3}{5}Breadth\right)\times Breadth\times\frac{1}{2}Breadth}{94}$. The 1836 rule introduced depth into the calculation to better approximate the internal volume of the ship. But this was not enforced until it was refined and formalised in the 1854 law for tonnage, known as the Moorsom system (MacGregor 1973, pp. 168-9 and 283-4).

limited information available, I designate as 'clippers' those ships with a ratio of length to beam greater than or equal to 5. This follows MacGregor (1973, p. 118) who noted of the earliest British-built full-rigged clipper ships, the *Glentanner* (1842) and the *Thomas Arbuthnot* (1841) (both of which are in the dataset) "The beam to length ratio is approximately 5:1, which inevitably assisted their sailing speeds; this ratio is higher than the average for ships at this date." See also on clippers, La Grange and La Grange (1936, p. 326) who describe a most weatherly ship (the ability to go headway across the wind and against the wind) as "from five to six times as long as she is broad". (It is worth noting also that, for the purposes of classifying seaworthiness, Lloyds required that ships must be strengthened with diagonal plates wherever length to beam exceeded five (Lloyds Register, 1863, p. 9)).

Ships to Melbourne

As noted in the main text, the tracks of voyages to Melbourne from 1854 to 1862 were obtained from ships' logs obtained and analysed by George Neumayer, Director of the Melbourne Flagstaff Observatory.[19] The results were published as a series of tables, plus some commentary, within the volume on meteorological and nautical observations principally for the years 1858-1862 (Neumayer 1864). And, as noted in the main text, these were presented in three sections: from the Lizard, 49°N, to the parallel of St Roque, 3°S, in degrees of longitude for benchmarks of latitude; from the parallel of St. Roque to the prime (Greenwich) meridian, 0°E, also in longitude for benchmarks of latitude, and finally from the prime meridian to 140°E (the approach to Cape Otway, 143.5°E, and Melbourne, 144.4°E) in latitude for benchmarks of longitude. A few ship/segments were absent, in the first leg for voyages, possibly originating in New York, and in the third leg for voyages not sailing directly for Australia.

Finding the details of these ships presents a greater challenge than for the emigrant ships to Adelaide, for three main reasons. (1) the only detail provided by Neumayer for most of the ships is its name, (2) as these are not all emigrant ships, their arrivals are less well recorded, and (3) many of the ships were not British registered (the Navigation Acts having been repealed in 1849). Unfortunately, there is no source like South Australia's *Passengers in History* to help link ship details to voyages. The first step was to search for details of the voyage in the immigration records for Victoria at: https://prov.vic.gov.au/explore-collection/explore-topic/passenger-records-and-immigration, mainly for ships carrying unassisted migrants. In addition, newspaper reports of the arrivals were searched, mainly in the *Melbourne Argus* in Trove (https://trove.nla.gov.au/).

The ship details from these sources is normally limited to tonnage but occasionally other details (type of rigging, origin, captain's name) but in some cases no details could be found and it was necessary to rely on other sources. In addition to *Lloyds Register of Shipping* several other databases were consulted in order to gather further details. Particularly for non-British registered ships, these included *Bureau Veritas* at https://www.digishelf.de/inhaltsverzeichnis/54962810X/, *American Lloyds Register*

[19] Georg Balthazar von Neumayer was an explorer and meteorologist who voyaged to South America and to Australia where he stayed from 1852 to1854. With the support of the King of Bavaria, he returned to Melbourne in 1857 with scientific instruments to establish the Melbourne Flagstaff Observatory in 1858 of which he became director. The observatory focused on measuring atmospheric electricity and various elements of terrestrial magnetism and, having studied the work of Maury, Neumayer also instigated the collection of data on coastal and oceanic navigation. He returned to Germany in 1964 where became the Hydrographer to the German Admiralty, and later, Director of German Marine Observatory at Hamburg (Howard, 1993).

of American and Foreign Shipping at https://research.mysticseaport.org/indexes/ship-registers/, and *Stichting Maritiem Historische Data* at: https://www.marhisdata.nl/. Extensive searches were often necessary to identify the right ship as there are variations in spelling and there are often a several ships with the same or similar names. Indeed, there are three cases where voyages of ships with the same name in the database (*Albert*, *Caesar Godeffroy* and *Essex)* are in fact by two different ships. Ultimately all ships were identified and linked except the *Clara Hallowell* and *Der West* (one voyage each), details of which could not be found. This leaves 294 voyages by 196 different ships.

The type of rigging and iron construction (of which there are only five cases) could be found, but the basis of tonnage measurement is less clear. As with the ships to Adelaide, old and/or new measurement was included were this was recorded, but when only a single tonnage figure is reported, the basis is often not clear. In such cases it was assumed to be old measurement if the ship was built before 1853, otherwise new measurement. Where only old measurement is available, new measurement was imputed, as with the emigrant ships to Adelaide, for 41 cases. Similarly, the length and beam of the ship could not be found for all the ships. This applies especially to older ships, those found in *Bureau Veritas,* and those that were wrecked or retired before dimensions were routinely reported. As some of the ships were built in Canada, the compilation by Wallace (1929) again proved to be useful, in addition to other ad-hoc sources from web searches. Ultimately, the variable 'clipper' (length/beam >=5) could be identified for 261 cases.

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Appendix 2: Supplementary regressions

Table A2 presents regression results for voyages to Adelaide where the sample is restricted to wooden-hulled ships, which reduces the number of observations to 249. The coefficients in column (1) are similar in magnitude to those of column (2) in Table 2 but with lower significance levels. As noted in the main paper there is evidence that metal sheathing increased ship speeds. All the ships in these data were sheathed. However, as described in Appendix 1 above, a variable is derived for the number of years since the sheathing was renewed. Over the 240 voyages for which this could be calculated, the mean is just 1.2 years. In column (2) this variable takes a negative coefficient, contrary to expectation, but is insignificant. This finding is unchanged when in columns (3) to (5) period dummies are added and the and the variable 'clipper' is included. It supports the conclusion that whether or not wooden hulls were sheathed was more important than how recently the sheathing was renewed but, in light of the fact that vessels were regularly re-sheathed, perhaps this is not too surprising. It is worth noting also that when, in columns (4) and (5), the variable 'clipper' is added, as in Table 2, it is negative and highly significant, implying a saving of around eight days on the voyage. It illustrates that this variable is important for the speed of wooden ships, the traditional clippers, and is not simply because more rigid iron hulls made for greater length to beam among iron ships.

Table A2: Days on the voyage to Adelaide and the characteristics of wooden ships

	(1)	(2)	(3)	(4)	(5)
Year of departure	-0.350***	-0.356***		-0.371**	
	(0.12)	(0.12)		(0.17)	
Departed northern port	2.969	1.383	1.198	1.561	0.369
	(2.30)	(2.42)	(2.63)	(2.53)	(2.73)
Ship tonnage (100s)	-0.703*	-0.643	-0.669	-0.184	-0.112
	(0.°)	(0.45)	(0.44)	(0.52)	(0.51)
Age of ship (years)	0.192**	0.226**	0.204**	0.092	0.083
	(0.09)	(0.10)	(0.10)	(0.12)	(0.12)
Rigged as barque	3.676**	3.502**	2.724	1.201	1.030
	(1.69)	(1.69)	(1.69)	(2.06)	(2.05)
Years since last sheathed		-0.735	-0.736	-0.523	-0.546
		(0.62)	(0.64)	(0.72)	(0.72)
'Clipper' (length/beam >=5)				-7.341***	-8.334***
				(2.16)	(2.22)
Period dummies	No	No	Yes	No	Yes
Observations	249	240	240	178	178
R-squared	0.170	0.179	0.210	0.185	0.204

Notes: OLS regressions of voyage durations in days. All regressions include three seasonal dummies: March-May, June-August and September-November; cols (3) and (5) include dummies for five year periods beginning 1848-52. Standard errors in parentheses; significance levels: *** 1%, ** 5%, * 10%.

In Tables 4, 7, and 8, of the main paper, specific sets of coordinates were used to characterise the voyages. These were chosen on the basis that they best represented the track of ships on different segments of the route. Here I present regressions of the days on each section of the voyage on different coordinates. For the first segment from the Lizard to the prime meridian, Table A3 reports the coefficient on degrees west at different latitudes, including also the dummy variable for sailing east of Cape Verde. In the first part of the table, for latitudes down to the equator, all the coefficients on degrees west at different latitudes are negative but with differing magnitudes and significance levels. The strongest coefficient and R^2 is for 25°N and so this was used in Tables 4, 7, and 8. This suggests that the optimal track involved sailing east of Cape Verde (16°N, 24°W) but nevertheless keeping to the west in order to catch the trade winds. The second part of Table A3 reports the coefficients on degrees west at different latitudes southward from 3°S (the latitude of St. Roque), which is from the second set of tables presented by Neumayer (1864). The coefficients for latitudes further south than 30°S are omitted as some voyages never reached these latitudes before crossing the prime meridian. Although the dummy for east of Cape Verde remains strongly significant, the latitude coefficients are all insignificant. The dummy for 15°S was included in col. (1) of Table 4 for illustration but subsequently dropped. This is somewhat surprising especially as there is a wide range of variation in degrees of longitude at the more southerly latitudes. As noted in the main paper, this perhaps reflects a broad equivalence between, on the one hand, reaching the roaring forties further to the west but spending more time in the doldrums and, on the other hand, steering more directly south but picking up the winds of the forties further to the east. It is worth emphasising that in these regressions, the squared term on degrees south was never significant and so it has been excluded from Table A3.

For the segment from the prime meridian to 140°E, Table A4 reports coefficients on degrees south at longitudes from 10°E to 120°E. As the table shows for all longitudes, the coefficient on degrees south is negative and highly significant. In Table A5 a squared term is added and this takes a positive coefficient, which is almost always significant. As the linear term is negative and the squared term is positive there is a clear minimum in number of days. For most of the sets of coefficients the minimum is around 50°S. This reflects the fact that, although sailing into the 'furious fifties' would make the route shorter and the winds stronger, which could reduce voyage length, it would also create hazards likely to slow the ship. The largest R-squared is for 50°E and so this is the value used in Table 2. This also makes sense as it is relatively early in the easting part of the voyage.

Table A3: Days from the Lizard to the prime meridian regressed on degrees west at given latitudes (continued below)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
East of Cape	-4.580***	-4.744***	-5.415***	-6.851***	-7.222***	-6.814***	-5.821***	-4.941***	-4.630***
Verde (=1)	(1.012)	(1.040)	(1.092)	(1.331)	(1.928)	(2.585)	(1.761)	(1.150)	(1.093)
45°N	-0.498**								
	(0.203)								
35°N		-0.351*							
		(0.183)							
30°N			-0.591***						
			(0.221)						
25°N				-0.812***					
				(0.274)					
20°N					-0.639*				
					(0.353)				
15°N						-0.472			
						(0.437)			
10°N							-0.348		
							(0.318)		
5°N								-0.229	
								(0.180)	
0°N									-0.135
									(0.143)
R-squared	0.054	0.051	0.074	0.078	0.056	0.043	0.042	0.050	0.048
Observations	290	290	290	290	290	290	290	290	290

Note: All regressions include seasonal dummies: March-May, June-August and September-November. Standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1.

Table A3 (continued): Days from the Lizard to the prime meridian regressed on degrees west at given latitudes

	(10)	(11)	(12)	(13)	(14)	(15)
East of Cape	-4.433***	-4.369***	-4.205***	-4.229***	-4.441***	-4.418***
Verde (=1)	(1.097)	(1.098)	(1.074)	(1.039)	(1.032)	(1.016)
3°S	-0.067					
	(0.146)					
10°S		-0.047				
		(0.155)				
15°S			0.015			
			(0.150)			
20°S				0.006		
				(0.136)		
25°S					-0.109	
					(0.111)	
30°S						-0.125
						(0.085)
R-squared	0.079	0.079	0.079	0.082	0.086	0.062
Observations	290	290	290	290	290	290

Note: All regressions include seasonal dummies: March-May, June-August, and September-November.
Standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1.

Table A4: Days from the prime meridian to 140°E on degrees south at given longitudes (continued below)

	(1)	(2)	(3)	(4)	(5)	(6)
10°E	-1.361***					
	(0.138)					
20°E		-1.440***				
		(0.146)				
30°E			-1.359***			
			(0.154)			
40°E				-1.424***		
				(0.144)		
50°E					-1.428***	
					(0.137)	
60°E						-1.305***
						(0.132)
R-squared	0.272	0.273	0.234	0.272	0.293	0.273
Observations	292	292	292	292	292	292

Note: All regressions include seasonal dummies: March-May, June-August, and September-November. Standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1.

Table A4 (continued): Days from the prime meridian to 140°E on degrees south at given longitudes

	(7)	(8)	(9)	(10)	(11)	(12)
70°E	-1.266***					
	(0.130)					
80°E		-1.298***				
		(0.126)				
90°E			-1.328***			
			(0.131)			
100°E				-1.367***		
				(0.143)		
110°E					-1.343***	
					(0.163)	
120°E						-1.642***
						(0.183)
R-squared	0.266	0.288	0.283	0.261	0.212	0.238
Observations	292	292	292	292	292	292

Note: All regressions include seasonal dummies: March-May, June-August, and September-November. Standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1. Meridians further east are omitted as such readings were not recorded for voyages not going directly to Melbourne.

Table A5: Days from the prime meridian to 140°E on a quadratic in degrees south at given longitudes (continued below)

	(1)	(2)	(3)	(4)	(5)	(6)
10°E	-8.720***					
	(2.421)					
10°E squared	0.089***					
	(0.029)					
20°E		-10.204***				
		(2.899)				
20°E squared		0.103***				
		(0.034)				
30°E			-3.528			
			(3.252)			
30°E squared			0.025			
			(0.038)			
40°E				-10.547***		
				(3.042)		
40°E squared				0.105***		
				(0.035)		
50°E					-11.243***	
					(2.704)	
50°E squared					0.112***	
					(0.031)	
60°E						-7.868***
						(2.543)
60°E squared						0.074**
						(0.029)
R-squared	0.294	0.295	0.235	0.294	0.324	0.289
Observations	292	292	292	292	292	292

Note: All regressions include seasonal dummies: March-May, June-August, and September-November.
Standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1.

Table A5 (continued): Days from the prime meridian to 140°E on a quadratic in degrees south at given longitudes

	(7)	(8)	(9)	(10)	(11)	(12)
70°E	-9.571***					
	(2.582)					
70°E squared	0.094***					
	(0.029)					
80°E		-10.524***				
		(2.527)				
80°E squared		0.106***				
		(0.029)				
90°E			-10.015***			
			(2.789)			
90°E squared			0.100***			
			(0.032)			
100°E				-9.469***		
				(3.539)		
100°E squared				0.094**		
				(0.041)		
110°E					-13.380***	
					(4.844)	
110°E squared					0.141**	
					(0.057)	
120°E						-17.679***
						(5.308)
120°E squared						0.188***
						(0.062)
R-squared	0.292	0.319	0.307	0.274	0.228	0.262
Observations	292	292	292	292	292	292

Note: All regressions include seasonal dummies: March-May, June-August, and September-November. Standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1. Meridians further east are omitted as such readings were not recorded for voyages not going directly to Melbourne. Standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1.

In Table A6 two variables are added to the regressions of Table 6 in the main paper. The first is a time trend, which counterintuitively gives positive coefficients. The second is whether the ship departed from a port in the Irish Sea which would place it further west at the latitude of the Lizard as compared with ships sailing down the English Channel. This gives positive coefficients for the southing leg from the Lizard to the prime meridian, as might be expected but, not surprisingly, insignificant negative coefficients for the easting leg from the prime meridian to 140° E. The important point, however, is that these additions have negligible effects, as compared with Table 6, on the coefficients on ship characteristics.

Table A6: Days on the voyage to Melbourne and ship characteristics

	(1)	(2)	(3)	(4)	(5)	(6)
	Lizard to Prime Meridian	Lizard to Prime Meridian	Prime Meridian to 140°E	Prime Meridian to 140°E	Lizard to 140°E	Lizard to 140°E
Year	0.287	0.655**	0.217	0.552**	0.411	1.146**
	(0.310)	(0.310)	(0.252)	(0.253)	(0.487)	(0.477)
Irish sea departure (=1)	3.076**	1.917	-0.898	-1.244	2.539	1.213
	(1.404)	(1.394)	(1.116)	(1.124)	(2.235)	(2.181)
Ship tonnage (100s)	-0.611***	-0.357**	-0.392***	-0.258**	-1.022***	-0.646***
	(0.150)	(0.152)	(0.121)	(0.123)	(0.239)	(0.236)
Age of ship (years)	0.076	-0.091	0.062	-0.060	0.178	-0.116
	(0.103)	(0.109)	(0.085)	(0.090)	(0.163)	(0.169)
Rigged as barque (=1)	3.253**	2.683*	6.306***	5.470***	9.862***	8.434***
	(1.371)	(1.441)	(1.102)	(1.173)	(2.159)	(2.233)
Iron hull (=1)	-0.254	0.002	-1.979	-1.756	-2.296	-1.811
	(3.609)	(3.397)	(2.937)	(2.767)	(5.651)	(5.217)
'Clipper' (length/beam >=5		-5.100***		-3.710***		-8.979***
		(1.037)		(0.844)		(1.596)
R-squared	0.143	0.184	0.291	0.296	0.252	0.293
Observations	288	259	290	258	285	256

Note: All regressions include seasonal dummies: March-May, June-August and September-November. Standard errors in parentheses; significance levels: *** 1%, ** 5%, * 10%.