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Turning Points in Leadership: Ship Size in the Portuguese and Dutch Merchant Empires*

Abstract

This paper discusses the implications of organisational control on the race for technological leadership in merchant empires. I provide an illustrative framework in which poor organisations have reduced incentives to invest, which in turn stifle technology improvements making leaders lag new entrants. In the late sixteenth century, Portugal's large ships carried more merchandise and were more fitting of the monarch's grandiose preferences, but they also were more prone to disaster. The merchant controlled Dutch East India Company however, invested in smaller but more seaworthy vessels conducting more voyages at a much lower loss rate. The surviving historical evidence shows Portugal relying on large ships well into the seventeenth century suggesting her technological edge was gone by the time the Dutch dominated the Indian Ocean.

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A. Introduction

Economic progress has often been associated with technological advancement. The age of merchant empires was perhaps the time in which this relationship became most salient as decisive developments in shipping technology shaped long-distance trade successes and failures (Maddison 1982, Modelski and Thompson 1988, Brezis et al. 1993, Israel 1989, Acemoglu et al. 2005, Unger 2006, Unger 2011). Portugal's advanced shipping proved very successful in the fifteenth century discoveries and the subsequent establishment of the first European merchant empire in Asia in the sixteenth century. By 1600 however, Portugal had lost its technological dominance, whereas the Netherlands had become the major shipbuilder in Europe. Factors affecting technology decisions in these countries become therefore vital to understand patterns of path dependence in merchant empires.

In Portugal, kings retained control of the monopoly of eastern trade while signing contracts with private agents, who temporarily traded in specific routes or products, or simply participated in the pool of capital of a voyage to get a share of profits on the return cargo (Costa 2013). The king however, remained the residual claimant of the enterprise.¹ In contrast, the trade monopoly of the Dutch East India Company (*Verenigde Oost-Indische Compagnie*, henceforth VOC) was chartered to private merchants, who managed trade according to merchant interests (De Vries and van der Woude 1997:384). Chartered companies like the VOC, were key to the rise of the corporate firm (Harris 2020; Odegard 2022); they maintained close relationships with the state and connected local-national and global entities (Pettigrew

¹ The theoretical literature on firm ownership views the firm as a collection of assets. The residual claimant will have decision power over asset use and control over the residual output of the firm, i.e., the output remaining after all assets received their remuneration (Grossman and Hart 1986). Thus, the residual claimant was the ultimate owner of the firm. In the case of Portugal, the monarch remained residual claimant even in privatised companies, for example the *Companhia Geral do Comércio do Brasil* founded in 1649, which came to an end by royal decision in 1663 when it was integrated (i.e., nationalised) into *Junta do Comércio* (Costa 2006).

and Veveers 2018) but remained real firms despite their influence on states (Wagner 2018). Dutch ownership thus, remained with merchants, who were residual claimants of the VOC.²

Whether royally or privately owned, all empires used military power to pursue and defend trade, both of which were central to Western economic success (Findlay and O'Rourke 2007). Kings and merchants however, differed substantially in their goals of empire so organisational control was not a mere label: merchants would be more willing to invest and put effort in a firm that they did control, which made their business decisions (for example on shipping) more likely to be market driven. Merchant control implied, therefore, a more efficient firm according to standard market practices. These implications stem directly from previous work on the origins of the different control structures of merchant empires (Author 2011). As such, diverging business decisions and efficiency levels across empires are exogenous in the context of this paper.

I extend the organisational argument in Author (2011) into the realm of technological decisions in merchant empires. In Section 2 I present a simple framework illustrating the relationship between a firm's organisational control and its technology decisions. Investments in research and development that allow for successive technological improvements are less attractive to the experienced incumbent than to an entrant with no notable experience record since the latter has less to lose. Technological advancements bring the advantage back to the incumbent for whom the gain from investment is now larger. When firms are equally efficient the result is continuous leapfrogging (Brezis et al. 1993). In merchant empires however, Portugal was summarily displaced by the Netherlands, which, according to the framework, suggests different levels of market efficiency. The old technology served the monarch's

² The theoretical literature on the effect of firm ownership on its internal organisation is large (Williamson 1975, Grossman and Hart 1986, Hart and Moore 1990). As such, even though the Portuguese and the Dutch empires were effectively run by private agents, residual property rights lied in different hands. The implications of the theory of the firm therefore apply with different incentives across the two organisations.

objectives better, thus Portugal remained invested in it despite its efficiency cost, whereas Dutch merchants —not subject to royal preferences— developed market-oriented technology improvements that made their empire thrive.

Guided by this framework, in Section 3 I gather historical evidence on Portuguese and Dutch shipping on the Cape Route from the sixteenth to the eighteenth centuries. In the early 1500s Portugal adapted her small and swift exploration ships to the rising needs of Asian trade, but by the end of the century Portuguese ships had grown gigantic resulting from the choice of sending small fleets of large vessels to Asia (Costa 2013). These vessels carried more merchandise and were also more fitting of the monarch's goals of empire, which involved the projection of royal power and glory in distant locations. But these monstrous ships —never replicated in other empires— were also slower, more difficult to manoeuvre and therefore more vulnerable in stormy waters or under enemy attack. In Section 4 I show Portugal's losses rose from 1 in every 10 ships in the early 1500s to nearly 1 in every 5 a century later. By then, the Dutch had become active traders in Asian markets using relatively smaller cargo vessels. Between 1602 and 1794 the VOC conducted far more voyages to Asia than Portugal had between 1497 and 1700, at less than 1 loss per 25 ships sent.³

In Section 5 I further investigate whether the gap in loss rates could emerge from factors beyond the rising vessel size. For example, Portugal's increased losses in the seventeenth century could have resulted from her reduced network of outposts in the Indian Ocean. Alternatively, the Iberian Union (1580–1640) could have raised Portugal's losses once Portuguese vessels became fair targets for England and the Netherlands. I discuss these and

³ England, Denmark, France and Sweden also engaged in long-distance trade with the East, but only England was able to effectively challenge, and later displace, the Dutch in the eighteenth century. For the complete sequence merchant empire leaders see Ames (2008). I focus on organizational impact on the transition from Portugal to the Netherlands. England's empire was also merchant controlled thus organisation would not manifest on English and Dutch technological choices, which did not much contrast in vessel size.

other potential explanations to the gap in loss rates but find no unambiguous association with Portugal's higher loss pattern.⁴

This paper sheds light on the shipping technology of merchant empires from an economic leadership perspective, since technology has not been considered in the literature a potential culprit of Portugal's demise in the Indian Ocean (Castro 2005, Costa 2013, Domingues 2004). Portugal's decline and the fast ascendancy of the Dutch around the turn of the seventeenth century are unlikely to be due to a single cause. Thus, it is not the objective of this paper to claim causality. Rather, the paper considers the existing literature on shipping technology in the early seventeenth century and brings suggestive evidence that ship size could be correlated with the turning point of leadership between the Portuguese and the Dutch merchant empires.

B. A Simple Framework of Technology Adoption

Consider a firm in the long-distance trade market making profit π_0 from technology τ_0 . The firm may invest z , which improves technology to τ_1 yielding $\pi_1 > \pi_0$ with certainty, for simplicity. Investment occurs if the net benefit is larger than the cost

$$\pi_1 - \pi_0 > z. \tag{1}$$

The higher the current profit π_0 and/or cost z , the less likely the firm will invest. The deterring effect of high π_0 is known as the Arrow replacement effect: high returns to experience in the current technology tend to slow the adoption of a new and better technology (Arrow 1962).

⁴ In the Appendix, I reconstruct Portugal's fleet with the existing (and admittedly) limited information on Portuguese losses and the full data on Dutch losses as well as all Dutch vessels sent to Asia. The results confirm Portugal's heavier reliance on large vessels when compared to the Dutch.

The replacement effect is stronger for a monopolist facing new entrants who start with $\pi_0 = 0$ and invest so long as $\pi_1 > z$ (Aghion and Howitt 1998).

All firms operate in remote markets and face similar challenges in the business of empire. Investment decisions, however, vary according to the preferences of the party in control: king and merchants both care for trade and profit, but the king also cares for glory and prestige, which distort pure trade objectives (Author 2011). Even though each firm's investment decision is optimal (utility maximizing) for the party in control, the market outcome of each decision varies with different objective functions —exogenous in the context of this paper. As a result, each firm is associated with an efficiency level $\varphi \in (0, 1]$ that affects investment returns so (1) becomes

$$\varphi(\pi_1 - \pi_0) > z. \quad (2)$$

The more efficient the organisational form ($\varphi \rightarrow 1$), the less distorted the investment decision. If all firms have access to the same technological options (equal π_0 , π_1 and z), then only φ matters in the investment decision.⁵ In poor organisational forms (low φ) the investment return is lower, so firms invest less but not necessarily nil.

Suppose now that the incumbent exploring τ_0 has efficiency level φ_L , and that a new player enters the market with technology τ_1 and a better organisational form $\varphi_H > \varphi_L$. If the replacement effect is large enough, the incumbent will not adopt τ_1 and the two firms share the market with $\frac{\varphi_L \pi_0}{\varphi_L + \varphi_H}$ of the profits going to the incumbent, and $\frac{\varphi_H \pi_1}{\varphi_L + \varphi_H}$ to the entrant. When improved τ_2 comes along, incumbent and entrant will respectively invest if

$$\frac{\varphi_L}{\varphi_L + \varphi_H} (\pi_2 - \pi_0) > z \quad \text{and} \quad \frac{\varphi_H}{\varphi_L + \varphi_H} (\pi_2 - \pi_1) > z. \quad (3)$$

⁵ Organisational control and the corresponding efficiency level affect the inner workings of firms in various ways (Williamson 1975). In this paper I focus on technology decisions. For an example in labour compensation resulting from different monitoring policies see Author (2013).

Even though the replacement effect now favours the incumbent ($\pi_2 - \pi_0 > \pi_2 - \pi_1$), for sufficiently low values of φ_L the entrant may invest in the new technology while the incumbent may not.⁶ In this case, the incumbent sticks to the old technology even if losing market share.

This simple framework does not provide the basis for a cost-benefit assessment of technology adoption, or an all-encompassing explanation for the rise and fall of merchant empires. Rather, the objective is to illustrate how Portugal, despite its less efficient organisational form, was initially able to invest in improving the sailing ship but lost momentum when countries with more efficient organisational forms entered the long-distance trade market. The Dutch were able to make technological investments that Portugal found less appealing: π_0 was relatively high since it was associated with vessels that both transported more goods and projected power, which served the monarch's interests better. To adopt a new technology would be to abandon the *raison d'être* of the fleet, which, therefore, remained technologically behind.

I now turn to the historical evidence of shipping patterns of the Portuguese and Dutch empires to evaluate whether they are consistent with the framework's implications on organisational efficiency.

C. Shipping Decisions

A successful voyage to the East depended not only on the knowledge of wind and current systems in the Atlantic and Indian Oceans, but also on the ship herself. Even in the absence of pirates at sea, danger was always present: storms, disease, and various kinds of accidents

⁶ Firms with similar organisational control (e.g., England and the Netherlands) have closer φ_L and φ_H and are more likely to follow similar technological choices on average.

played a substantial role not only in the survival of the crew, but also in the success of the voyage. If these hazards affected all on the Cape Route, then voyage completion depended crucially on vessel type. This section evaluates Portuguese and Dutch shipping decisions in light of the organisation argument already presented.

C.1 The Portuguese case⁷

In 1498 Vasco Da Gama completed the first successful maritime voyage to India at the service of the king of Portugal. The date marks the beginning of direct trade between Europe and Asia through the Cape Route, which effectively undercut high spice prices arriving in Europe via the Levant (O'Rourke and Williamson 2009).⁸ This event occurred nearly after a century of Portuguese naval exploration, which added to existing geographic, maritime, and sailing knowledge.

Unknown ports in uncharted coastlines required small and swift vessels, as the fifteenth century caravel. This lateen-rigged ship, of at most 60 tons, was handy to manoeuvre under sudden and unexpected weather changes.⁹ Rising trade replaced the light caravels by larger square-sailed vessels —offering better usage of wind power— such as *naus* (called carracks¹⁰ by the English and the Dutch) and galleons. The *nau* was lightly gunned and mainly used for

⁷ Although the Portuguese and Spanish crowns were amalgamated between 1580 and 1640, empire operations remained separate. Such was an explicit clause of the agreement attained in the 1581 Cortes of Tomar where Philip I of Portugal (II of Spain) was acclaimed king with the support of Portugal's nobility, clergy, and general estates (Boxer 1975:108, Costa et al. 2016:100). Once Philip III (IV of Spain) began to ignore this and other clauses of the 1581 agreement by the late 1630s, the support of Portugal's nobility started eroding, dissidents emerging, in a process culminating in the successful revolt of December 1640 in which Portugal regained independence (Disney 2009: 217-220). Thus, this section, and paper, focus on Portuguese (not Spanish) shipping decisions and maritime operations in the Indian Ocean in spite of the Iberian Union. For Spanish shipping activities in the Mediterranean and Atlantic see Philips (1986) and Goodman (1997).

⁸ The unequivocal downward trend of European spice prices after 1500 however, did not bring an immediate collapse of Mediterranean trade, which lingered into the seventeenth century and effectively ended once the English and the Dutch engaged in Eastern trade (Steensgaard 1974).

⁹ For further details on the caravel see Elbl (1994) and Frutuoso et al. (2011).

¹⁰ The term is frequently mentioned in medieval documents and used to describe Portuguese cargo ships since Da Gama's voyage. These early Portuguese vessels, however, were very different from those sailing to India in the late 1500s, which were famous for their stupendous size (Boxer 1948:12, Phillips 1986:38).

cargo purposes whereas the galleon was primarily a war vessel, often pressed to serve as a cargo ship since the early days of empire.¹¹

The first attempts to introduce ships larger than 500 tons on the Cape Route date from the 1520s. By 1550 there were large galleons of 900 to 1,000 tons in use, but these were not the most common vessels. Ship size increased steadily between 1551 and 1570, with a smaller number of units bringing more spices to Lisbon than ever before. Larger vessels were a natural outcome of expanding trade in the sixteenth century, but the largest vessels were also slower and less manoeuvrable than smaller vessels.

The rising loss rate in the second half of the century led the monarch in 1570 to enact a new law requiring all vessels destined to the Cape Route to be between 300 and 450 tons. In the 1580s, a new king relaxed the 1570 law, and it became common practice every year to build two or three vessels above 1,000 tons each (Boxer 1948:13).¹² By then, vessels on the Cape Route averaged 1,000 tons with some reaching 2,000 tons (De Vries 2003:44 and 50, Duncan 1986:7). A few of these great ships were built in Asia, where better timber produced more resistant hulls for tropical waters, allowing longer vessel lifespans.¹³ Though more seaworthy, these ships were even larger than those built at home. Such was the case of Cochin-built *Santa Cruz* of 1,600 tons, voluntarily burned off the Azores in 1592 to avoid English capture (size in Boxer 1948:15, fate in Guinote et al.. 1998:226). The building of very large ships in India continued into the seventeenth century as attested by the vessel *Nossa Senhora de Belém*—the largest vessel ever built for the Cape Route—lost in a storm off the Brazilian coast in 1635 (Guinote et al.. 1998:345).

¹¹ For a detailed discussion of the differences between *naus* and galleons see Boxer (1975:207).

¹² Rising ship size predated the Iberian Union (1580-1640), thus it is not a consequence of it.

¹³ European-built vessels on the Cape Route lasted about eight years, or four round trips to Asia at best (Steenngaard 1965). The implied continuous vessel replacement belies the hypothesis that Portugal would remain invested in the old technology (old ships lasting many years) before exiting the market in a strategy consistent with profit maximization.

The fast rate of vessel decay on the Cape Route and the empire's expansion, made Lisbon's shipbuilding a fast-growing industry. The conditions of haste in which shipwrights laboured, as well as the owner's cargo specifications, allowed little change in ship design. With the king as the main merchant and armour, Lisbon's shipyards quickly specialized in the construction of very large vessels pre-ordered for specific voyages (Costa 1997).

But why would monarchs choose big ships? Irrational preferences are not plausible in a context of utility maximizing agents described in Section 2. Rather, this technological option befits an empire strategy valuing elements other than the profits yielding from a large trade volume. Monarchs also valued the glory and prestige that the sight of such gigantic and massively adorned vessels —with multiple decks, forecastle and aftercastle— conveyed. These large ships became distinctive features of Portugal's naval architecture since no other nation built such "mountains of wood" (Boxer 1948:14).¹⁴ Looking powerful mattered to a king directly engaged in trade with distant sovereigns he would never personally meet. Private merchant companies valued demonstrations of power as well. Beyond conducting trade, they also administered justice and maintained their own armies, effectively becoming states within the state. But the extent to which kings cared for power and glory was different: an empire would bring the visibility and international prestige recognized by sovereigns of the time and in the future. Kings would therefore, more than merchants, distance themselves from market objectives due to their glory and prestige motivations.¹⁵

While the Dutch introduced changes that improved vessel stability and seaworthiness in the seventeenth century, Portugal kept building larger, slower, and less manoeuvrable vessels as shown by the giant India-built ships. The tendency of building large and magnificent vessels

¹⁴ Other countries never engaged in the construction of giant ships, except for warships, and even then, only occasionally (Sicking 2010).

¹⁵ In contrast to the VOC, Portugal's ships fitted the double mandate of transportation and projection of power, a difference stemming directly from organisational type (φ), exogenous in the context of this paper.

was not exclusive to Portugal's sovereign. The most notable example comes from 1625 Sweden when the king commissioned the construction of one the greatest warships ever built until then at 1,300 tons. On August 10th, 1628, the *Vasa* capsized and sank on her maiden voyage barely 1,500 yards out of Stockholm's harbour under perfect weather. The recovery of the wreckage in 1961 revealed hundreds of decorative wooden sculptures carved by Dutch, German, and Swedish artists.¹⁶ Abundant decoration clearly served the purpose of glory and prestige as noted by Jean-Baptiste Colbert, France's naval minister from 1665 to 1683: "nothing can be more impressive nor more likely to exalt the majesty of the King, than that his ships should have more magnificent ornamentation than has ever before been seen at sea" (Paine 2000:195).

Though fitting royal hubris, the deliberate increase in Portugal's vessel size proved disastrous for safety. In the 1620s the dreadful situation led a group of experienced Portuguese officers—from merchants to sea captains¹⁷—into persuading the crown to reinstate the 1570 tonnage law. The main arguments against the very large carracks included difficult manoeuvrability and excessive loading, both of which contributed to vessel instability and increased losses.¹⁸ With the king's pepper taking up most of the space, everything else was stored wherever possible sometimes outside the hull supported by ropes (Castro 2005:18). Shipwreck narratives provide various accounts of crews forced to let go of some of the hanging cargo to try and stabilize large vessels during storms. Even in the absence of bad weather, the experienced officials noted, large and overloaded vessels could and did capsize when entering

¹⁶ Soon after the *Vasa* sank there were plans for the salvage but only in 1961, was the vessel resurfaced. Massive recovery and conservation efforts ensued, which resulted in today's Vasa Museum in Stockholm. For more on this massive vessel see Hocker (2011).

¹⁷ See Guinote et al. (1998:378-407) for excerpts of the documents on the arguments against oversized ships by Portugal's governor in Goa Fernão de Albuquerque (1540-1623, writing in 1622), merchant Duarte Gomes Solis (c.1562-1632, writing in 1628), sea-captain João Pereira Corte-Real (1580-1642, writing in 1622), and historian/priest Manoel Severim Faria (1583-1655, writing in the late 1640s). Albuquerque, Faria and Solis go as far as referring to the Dutch success on Asian trade, with smaller but more ships.

¹⁸ These undesirable consequences of technological choice should not be understood as predictions of the framework. If anything, they are further indications of poor organisational form (φ).

or exiting ports. These great vessels were also slower posing problems to convoys given the different speeds of galleons and great carracks, which on their own were rather vulnerable. The slower speed also made ships more likely to winter in Mozambique further delaying voyage completions and subsequent departures.

In light of this, cargo vessels were built smaller, but the situation worsened for galleons, which previously rarely exceeded 600 tons and could now reach 1,200 tons. Such was the case of the *Santa Tereza* destroyed in the Battle of the Downs against the Dutch in 1639 (Boxer 1948:13). The ambiguous success of expert pleas suggests only a limited influence of merchant and maritime personnel on the shipping decisions of empire whose residual claimant, retaining major organisational decisions, remained the Portuguese crown.

C.2 The Dutch Case

As a country whose land was partially reclaimed from the sea, the Netherlands have a long tradition of shipbuilding suited for canals, rivers, but also the oceans. Through the fourteenth century, shipbuilding proliferated on Dutch shores and river estuaries, but by the fifteenth it mostly concentrated in towns, where gathering the necessary investment capital was easier (Unger 1978:2). Antwerp, the largest medieval city in the Low Countries, remained the major distribution centre of foreign goods in Northern Europe until 1585 when it fell under Spanish control. Such commercial prominence gave the Dutch ample experience in the transportation of bulk goods around Europe, facilitating further shipping development.¹⁹

After 1550, a new series of technically superior cargo carriers emerged in Dutch ports leading to "impressive gains in output and lower shipping costs" (Unger 1978:35). The *buyscarveel*, the *boyer*, the *vlieboot*, and finally the *fluit*, each picked on previous designs and

¹⁹ Since the end of the fifteenth century, Dutch ships carried salt from Portugal, Spain, and France to the Baltic, as well as French wine (Israel 1989).

adapted to specific navigational needs. With a size between 200 and 500 tons, the *fluit* resulted from a long sequence of modifications and experiments with sails and hull construction techniques.²⁰ The rigging over two or three short masts with some easier to handle "gaff sails" made the vessel more manoeuvrable while requiring fewer sailors. The shallow but box-like hull and round (instead of square) stern, provided larger cargo capacity than contemporary ships of similar size. The small bulk above the water line —no forecabin, and few or no guns— reduced wind resistance and improved sailing quality, but constrained *fluits* to safer routes or to sail in convoys.²¹

So successful was the *fluit*, that the Dutch supplied this and other cargo vessels of force to the French India Company, England, Hamburg and Ostend, as well as Denmark and Sweden (half these fleets was Dutch-built), and even the Spanish colonial trade (Barbour 1930:286–7).²² Though Dutch shipbuilding is difficult to estimate, exports probably never equalled domestic consumption and production for foreign buyers may have peaked at as much as 50% of total output (Unger 1978:11).

The VOC's foundation in 1602 occurred therefore in a context of constant shipping developments. The company's fleet was composed of a variety of square- and round-sterned ships. Among the first, the most common were the East Indiamen used as cargo and passenger carriers. These were the VOC's largest operating vessels, but they never reached the size of the great Portuguese carracks, as no other empire pursued the operation of such giant ships (De Vries 2003). The Indiamen carried guns but had greater hulls than the more heavily armed

²⁰ The *fluit's* measures held constant until c.1800, though they were adapted to specific routes. There was no technical restriction on building larger sailing ships in the seventeenth and eighteenth centuries, but smaller units were more profitable. The increased trade volume of the nineteenth century and the availability of new materials from the industrial revolution resulted in the emergence of the British and American iron hull clippers —as large as 2,000 tons— as a response to steamers (Graham 1956).

²¹ For further details on the *fluit* see Eriksson (2014).

²² The pervasiveness of the *fluit* and other Dutch vessels in seventeenth century Europe, justifies the assumption that all countries had access to the same technology (equal π_0 , π_1 and z). By 1600 Portugal was still rather active on the Cape Route so it could have opted for a new technology; failure to do so indicates a less efficient organisation in light of the presented framework.

warships, which could also be used as cargo carriers of smaller capacity. Beyond war and cargo vessels on the Cape Route, the Dutch (as all other empires) employed other vessels according to the navigation needs of empire, for instance the intra-Asian trade.²³

Among the round-sterned ships, *fluits* played a permanent role in the company's fleet. The *fluit*'s hull design with a low centre of gravity gave it more stability in bad weather, and the use of pine instead of oak (except in the hull) made it an exceptionally light vessel of large cargo capacity (Unger 1978). Regarded as cheap to build, man, and maintain, bigger *fluits* were fairly common on the Cape Route next to the larger East Indiamen well into the eighteenth century when the latter dominated (Bruijn et al. 1987:55).

The VOC built its own ships, but it also resorted to the purchase and hire of vessels from private shipyards, especially *fluits*. This practice was standard at an early stage when the company's own production was insufficient but ceased by the late 1600s. During and after the Fourth Anglo-Dutch War (1780–1784) external purchases and hires of smaller vessels resumed. Overall, the company's shipbuilding prevailed: in nearly two centuries of operation the VOC bought or hired 378 vessels and built 1,461 (Bruijn et al. 1987).

Table 1 shows the VOC's shipbuilding by size. In the seventeenth century the Company constructed mostly small- and medium-sized vessels below 800 tons, which represented 86% of the company's naval production.²⁴ Large cargo vessels served only a fraction of the needs of the establishing empire, which also required smaller ships to defend ports and engage in the intra-Asian trade.

Table 1 HERE

The continuous presence of the Dutch in Asia reduced the needs of small and medium vessels to a replacement level in the eighteenth century (33%). A higher trade volume on the

²³ For the composition of the VOC's fleet in 1660 see Parthesius (2010:65).

²⁴ The percentage of these small and medium vessels on the company's fleet was probably higher, given the purchase and hiring of ships from private shipyards, mostly *fluits* and other small vessels.

other hand, especially in the early 1700s, led to a rise in the construction of vessels above 800 tons (67%). Overall, vessels above 1,000 tons were never the biggest fraction of output in the VOC's shipyards, representing only 19% of total construction over the two centuries of operation. As Portugal, the VOC increased vessel size with time, but the largest Dutch vessels never reached the size of Portugal's, showing a distinct manifestation of shipping technology decisions in this organisation.

D. Shipping Losses

Organisational choices, here in the form of shipping decisions, ultimately reflected in losses at sea. In this section I present and analyse Portuguese and Dutch loss rates by time period according to each empire's shipping decisions.

D.1 The Portuguese case

Duncan (1986) provides aggregate numbers per decade for Portuguese voyages on the Cape Route, including losses, from 1497 to 1700. Table 2 summarizes this information in fifty-year periods. The initial loss rate of 9.7% jumped by almost a third in the second half of the sixteenth century, as ships grew larger. In the 1600-1650 period, Portugal's losses reached their peak at 18.5%: nearly 1 in every 5 Portuguese ships was lost on the Cape Route, compared to 1 in 10 one century earlier. This rising loss rate partially reflects Portugal's rising opposition in the high seas during the Iberian Union (1580-1640) when Spain's traditional enemies — England and the Netherlands— regarded Portuguese ships as legitimate targets. Though more losses resulted from enemy attacks in the first half of the seventeenth century than in all other periods combined, such losses represented only 3.8% of voyages in that period. The rise in the net loss rate from 9.5% between 1500 and 1550, to 14.7% between 1600 and 1650 is still

remarkable and coincides with the building of larger vessels and the complaints of experienced officers.

After regaining independence in 1640, Portugal either made diplomatic concessions to the English (e.g., Bombay in 1661²⁵) or lost key battles with the Dutch (e.g., Malacca in 1641, Ceylon in 1658), thus having a negligible contribution on the Cape Route. In the late seventeenth century Portugal's presence in the East was limited to three ports in India (Goa, Daman, and Diu) and two in East Asia (Macau and East Timor).²⁶ By then, Portugal merely maintained annual communication between Europe and Asia with returning ships often stopping in Brazil. The decline in Eastern trade reduced voyage needs and, likely, ship size as suggested by the decline of the loss rate to 8.7% (or 8.2% net) between 1651 and 1700.

Table 2 HERE

Guinote et al.. (1998) provide a list of all 237 losses of Portuguese ships on the Cape Route with information on vessel name, the stage of the voyage (outbound or inbound), date of shipwreck, and, whenever known, the location and cause of loss. Unfortunately, this list does not include vessel type or size. I found this information, for some of the wrecked vessels, in secondary sources such as: narratives of shipwrecks based on reports of survivors and close witnesses (Brito 1959 and 1968, Burman 1967 and 1968, Duffy 1955);²⁷ studies by naval historians including excerpts of letters of missionaries surviving one or more shipwrecks, as well as studies of naval archaeologists (Guinote et al.. 1998 and Castro 2005, respectively); and also, English or Dutch sources that refer to captures of Portuguese vessels returning from Asia (Latham and Youings 1999, Boxer 1948, Boxer 1965).

²⁵ The marriage contract between Catherine of Portugal and Charles II of England secured Bombay and Tangiers to England in exchange for military and naval support against Spain.

²⁶ Although Portugal's Eastern empire endured well after the VOC's demise in 1799 it never regained the wide extension, or the economic prowess, of earlier days.

²⁷ This literature became rather popular in Portugal especially after the publication of the two-volume collection of twelve shipwreck narratives in *The Tragic History of the Sea* by Brito in 1735-6. Historians have revisited the theme adding narratives from previously unpublished documents.

Table 3 HERE

These secondary sources do not report on all of Portugal's losses at sea (many vessels simply disappeared in remote locations of the ocean without witnesses) but they report losses in ships of different sizes, so it is not the case that authors just wanted to impress readers by reporting losses of very large vessels alone. Of all the shipwrecks described in these sources, the 18 listed in Table 3 have information on ship size or type. The reported sample represents roughly 8% of all Portuguese losses at sea between 1500 and 1700, and 12% of losses between 1552 and 1686, the start and end dates in Table 3. Even though if small, the sample is very informative of the gigantic nature of some lost vessels. In particular, the two 1,600-ton carracks lost in 1592 provide a clear indication of the dimensions of this type of vessel never replicated by other empires.

Two of the vessels in Table 3 sank on the outward voyage and, evidently, were not overloaded. Of the remaining 16 vessels, eight were overloaded while there is no information on whether that was also the case of the other eight vessels. The prevalence of overloading in inbound losses further underlines the magnitude of this problem in Portuguese voyages. By contrast, only four vessels in the sample (*Madre de Deus*, *Santa Cruz*, *Santiago*, and *São João Baptista*, all carracks sunk between 1592 and 1622) underwent enemy attacks, reinforcing the idea that losses for this reason were not too prevalent.

There are eight wrecks of carracks, not all of which reached sizes above 1,000 tons. The rising ship size started in the 1520s, but only after the repeal of the 1570 law does the literature mention great carracks such as the *Madre de Deus* or the *Santa Cruz* at 1,600 tons, and the *Nossa Senhora de Belém*—the largest vessel ever built for the Cape Route (Guinote et al. 1998:345). I therefore take a conservative approach and consider carracks before 1580 as large vessels while those after that date as very large, a criterion consistent with the changing nature of the term *carrack* throughout the sixteenth century (Boxer 1948:12). This classification is

further justified by the arguments against excessive vessel size by Portuguese officers in the first half of the seventeenth century when the loss rate peaked.

Of the 18 reported losses, eight are very large (*Garça, Madre de Deus, Nossa Senhora de Belém, Santa Cruz, Santo Alberto, Santiago, São João Baptista, and São Thomê*). Eight ships belonged to the large category (between 800 and 1,000 tons) since they were reported to have 900 tons (*São João, São Bento, and Santiago*), were simply referred as "large" or "carrack" before 1580 (*São Gonçalo, Santíssimo Sacramento and Águia and São Paulo*). I also consider *Nossa Senhora dos Milagros* in this category since it was overloaded and had 30-gun cannon on board. Finally, *Nossa Senhora dos Mártires* was a 600-ton medium-size ship, and I assume *Nossa Senhora da Atalaia* also to be of medium-size since it had 18 guns on board.

Overall, 16 out of the 18 wrecks occurred in large or very large vessels while small vessels do not figure in this sample, which is clearly not realistic.²⁸ This void may result from smaller wrecks having fewer survivors whose recollections would less likely get published. It is implausible however, that only the losses of large and very large ships survived in secondary sources, otherwise all narratives would have information on vessel size or type, which is not the case. All in all, the evidence in Table 3 strongly suggests (without absolutely proving) that Portugal relied on large and very large vessels well into the seventeenth century when her loss rates rose considerably, yet another manifestation of poor organisational choices.

D.2 The Dutch case²⁹

Table 4 shows a generally low loss rate for Dutch vessels, when compared to the Portuguese counterpart in Table 2. Though the absolute number of Dutch losses was higher than the

²⁸ I ensure this bias does not affect the estimations of the Portuguese fleet in the Appendix by imputing a fraction of small ships equal to that of the Dutch fleet.

²⁹ Volumes II and III of Bruijn et al. (1979) provide extensive details for all outbound and inbound voyages of the VOC from 1602 to 1794. The Dutch shipping data come from that exhaustive data base.

Portuguese (310 vs 237), the Dutch sent more than four times as many ships to and from Asia (8,081 vs 1,930) during a similar time window of 200 years. Less than 1 in 25 Dutch ships was lost in two centuries of voyages, but losses rose slightly from in the eighteenth century.

Table 4 HERE

Captured ships nearly doubled in the same period, but these were only a very small fraction of the total voyages of the Dutch company, which remained relatively constant (0.81%-0.78%).³⁰ Of the 310 vessels lost by the VOC on the Cape Route, eight lack information on tonnage (six outbound and two inbound) leaving a total of 302 vessels with information on size, which I summarize in Table 5.

Table 5 HERE

The VOC lost vessels of all sizes, but the distribution of total losses (middle column in each panel) changed with time. In the seventeenth century over 70% of the losses occurred in small and medium-sized vessels, but in the eighteenth most losses occurred in the large and very large categories (66.3%). This trajectory is consistent with the evolving needs of empire: early on, smaller vessels were needed to defend newly conquered outposts and conduct local trade; as trade increased, so did the demand for larger vessels on the Cape Route and more of these were lost. In nearly two centuries, most of the VOC's losses occurred in large and medium vessels (32.8% and 29.8%), followed by very large vessels (22.2%) and small vessels (15.2%).

The last column in each panel of Table 5 shows loss rates per tonnage class. In the early history of the VOC, the probability of loss was monotonically increasing in vessel size suggesting that larger ships were more dangerous. The more intense nature of operations in the eighteenth century resulted in an overall loss-size relationship rising until 1,000 tons and decreasing thereafter. Such non-monotonic pattern suggests that larger size did not make

³⁰ Dutch sources indicate capture as one of the possible loss causes, whereas Portuguese sources refer to enemy attack. The latter includes the former: a lost ship that was attacked could have been captured or sunk, but a captured ship was necessarily attacked. The eventual bias overestimates Portuguese losses by capture and underestimates Dutch losses by enemy attack but the results hold even net of enemy action.

Dutch vessels more vulnerable in the 1700s, a result that is not necessarily surprising since the largest Dutch vessels never reached the grandiose, and perilous, scale of Portugal's. Of all Dutch ships sent to Asia, the single largest was the 1,300-tonner *Admiraal de Suffren* built at the Amsterdam yards in 1785 and lost in a storm in the South China Sea on her first return voyage to Europe in 1787. There was no other vessel of this size. Indeed, the most common tonnage among the Dutch Indiamen was barely above the said threshold at 1,150 tons, and well below the size of the *Madre de Deus* or the *Santa Cruz* (1,600 tons) and other India-built carracks (Boxer 1975:208).

In sum, even if the largest Dutch ships were not more likely to sink, Portugal's oversized (and much larger) vessels still might have been responsible for her higher loss rates, in a direct manifestation of differing organisational forms. I now explore alternative explanations for the divergent pattern of loss rates in the Portuguese and Dutch merchant empires. The objective is not to completely dismiss alternative causes, but to shed light on vessel size as a driver for the observed disparity in loss rates.

E. Potential Causes of the Disparity in Loss Rates

The VOC's overall loss rate of 3.8% was less than a third of Portugal's at 12.3%, although the Dutch conducted more voyages (8,081 vs 1,930). The different timing of operations in the East could explain the gap in loss rates due to evolving shipping technology. Over time, the production of better ships benefitted the Dutch whose voyages started 104 years after the Portuguese and lasted to 1794 while Portugal's data stop in 1700. Sailing ships in 1498 were surely different from those of 1794, but the corresponding technology improvements did not translate into falling loss rates for either Portugal or the Netherlands while they operated on

the Cape Route.³¹ The Dutch variation —from 3.4% in the seventeenth century to 4.1% in the eighteenth— is rather small, but Portugal’s loss rate nearly doubled between 1550 and 1650! In the seventeenth century the contrast is even greater —3.4% vs 15.3%— suggesting the two empires were already on different technological paths. Thus, despite the non-overlapping timeframes of operation in the East, the Portuguese and Dutch data are comparable.

Portugal’s higher loss rate could also result from competition with other empires, especially after the Iberian Union during which, England and the Netherlands, Spain’s long-term enemys also became Portugal’s. Excluding losses resulting from enemy action brings Portugal’s loss rate down to 11.1% in Table 2. Though Portugal was relatively more affected by enemy attacks —especially in between 1600 and 1650 when it started competing directly with the Dutch and the English— the large disparity relative to the Dutch net loss rate (3% in Table 4) remains unexplained.

A less obvious way competition could have raised Portugal’s losses lies in the changes of her network of outposts in Asia. In the seventeenth century the English and Dutch companies started using the Cape Route and expanding their reach in the Indian Ocean, ousting the previously established Portuguese. As Portugal’s network of ports shrank, her vessels could have become more vulnerable at sea due to the potential lack of shelter. But Portugal’s lost ports were ports of trade, not ports of call. Such was the case of Kochi, Ceylon, Malacca, or the Moluccas, which were gone by 1650 when Portugal’s Asian trade was already minimal. Mozambique, Portugal’s traditional port of call since Da Gama, remained in Portugal’s control throughout providing shelter to passing vessels as well as a place to wait the change of season if needed. Thus, Portuguese vessels were no more vulnerable at sea in the seventeenth century than they were when they started venturing on the Cape Route in 1498.

³¹ This evidence does not preclude the continuous technological progress in other shipping outcomes, such as sailing speed (O’Grada and Kelly 2014).

Similarly, Portugal may have faced different military needs in the Indian Ocean, which could have affected not only ships sent to Asia but also the casualties suffered en route. More pressing military needs could, however, have different implications on the loss rate: they could result in better defence and less losses, but they could also imply overextension and more losses. A thorough comparison of Portuguese and Dutch military objectives is beyond the scope of this paper, but it is unclear they were that different since both empires clashed with locals upon arrival. Portugal focused mostly on India and disputed port cities in the Red Sea, South-East Asia, and the Far East. The Dutch on the other hand, fought the natives in South-East Asia while sharing efforts with the English to displace the Portuguese elsewhere.

Portugal's higher losses could still result from factors unrelated to competition such as the lax practice of convoys, excessive loading, and different labour skills, all of which are associated with either vessel size, poor organisation, or both. First, Dutch ships could have been more resilient as they travelled in large convoys on the homeward voyage after the Cape, the VOC's traditional port of call.³² Convoys were also in effect in Portugal in the sixteenth century before vessels became excessively large. Since the early 1500s, one or more fleets departed Lisbon yearly, each typically composed of five or six well-armed cargo vessels eventually joined by smaller ships usually destined to remain in the East. Cargo vessels returned home with other vessels of the same fleet, and sometimes also with vessels from previous fleets that had wintered in Mozambique.³³ As ship size increased however, Portuguese vessels became slower and often travelled solo or with other large, and equally vulnerable, vessels (Solis 1955). The original cause of rising vulnerability, therefore, seems to be vessel size, with the lax convoy practice as the unintended inefficiency thus associated.

³² Loaded with spices, returning ships were very attractive to pirates and foreign competitors in the Atlantic. Sailing in groups offered better chance of defence and could potentially deter attacks from solo pirate ships, which would likely avoid facing an entire fleet with more firepower. Overall, convoys made ships less vulnerable.

³³ See Falcão (1859:137-190) for a list of all vessels that left Lisbon to the East (and their dates of return) each year between 1497 and 1612.

Second, excessive loading of Portuguese ships could well be behind the disparity of losses at sea. There is no indication that the VOC faced this problem —unsurprising since Dutch ships were smaller but many— whereas Portuguese sources repeatedly mention overloaded vessels after 1550, always in connection with excessive tonnage. The very rationale of carrying more merchandise with fewer but larger units could have naturally raised the probability of overloading in a scenario of expanding markets and poor organisation. Contemporaries note that larger vessels carried more people, and therefore more liberty chests —allowed to royal employees for carrying spices— and other belongings all piled on deck, at times reaching the height of the aft castle (Guinote et al.. 1998:388). Such occurrences surely denote inadequate management, yet another symptom of poor organisation that, in this case, cannot be disentangled from vessel size.

Third, Dutch labour could have just been better skilled, resulting in better ships and relatively fewer overall losses. This claim is consistent with a more efficient organisation overall, and without dismissing a labour productivity argument (Lucassen and Unger 2011), both the Portuguese and the Dutch dominated naval technology at some point because their labour force, though different, was skilled enough to achieve such feat. Vessel quality, on the other hand, seems to be inversely related to vessel size since: (a) the only cargo vessels known for their improved stability in this early modern period were the Dutch *fluits*, which were considerably smaller than the East Indiamen, the VOC's heavy carriers; and (b) the largest Dutch ships were still smaller than Portugal's great carracks notorious for their occasional capsizing when manoeuvring in and out of port. Even if Dutch ships were superior this still does not explain Portugal's rising loss rates between 1550 and 1650 when vessel size rose to unprecedented, and never repeated, levels.

A more serious contender behind the disparity in loss rates involves the sea-routes in which each country specialized: if Portugal's route was more prone to disaster, that would naturally

result in more losses. In the Atlantic both empires followed similar paths, save the Dutch specific segment north of the Iberian Peninsula and through the English Channel (or around the British Isles, depending on the season). But in the Indian Ocean the routes diverged substantially according to the different headquarter locations: headed to Goa on India's western coast, Portugal's ships sailed mostly along the west-Indian Ocean through the Mozambique Channel (or outside of Madagascar, depending on the monsoon); the Dutch also sailed to India (particularly to Bengal in the north-eastern coast, or Ceylon today Sri Lanka), but their headquarters in Batavia (today Jakarta, Indonesia) gave them far more exposure to the south- and east-Indian Ocean.³⁴ Varying routes and times of entry implied different navigational learning. The Portuguese pioneered the Cape Route single-handedly and learned about Atlantic currents and winds by trial and error, and from Muslim pilots on the Indian Ocean. The VOC had, perhaps, a less daunting task when it started sending ships to Asia given the pre-existing knowledge of the eastern passage through the Cape, but it still faced a fair amount of learning, especially in the less travelled areas of the east Indian Ocean.

The difficult sections of both routes can be gleaned from Table 6 with the geographic dispersion of losses. There were losses throughout the entire route with particularly high incidence in shallow waters close to shore. Thus, the Portuguese had a higher share of losses near their ports of call in the Azores (5.1%) and the Iberian coast (9.7%) than the Dutch (0.6% and 1.6%, respectively), even though ships from both countries sailed these waters. Similarly, the Dutch lost relatively more ships in the South Atlantic-Cape-Natal section (26.4%) than the Portuguese (11.4%), whose ships passed by but hardly ever called at the Cape. For this reason, the share of Dutch losses in every common segment of the routes is not necessarily lower than the Portuguese, as it would be expected of a more efficient organisation. This relationship,

³⁴ For maps of the Portuguese and Dutch routes see Castro (2005:15) and Bruijn et al. (1987:65), respectively. Sea routes were shaped by wind and current systems experienced but not fully understood at the time. Today we know the monsoon affects different areas of the Indian Ocean differently (Schott and McCrearey Jr. 2001). A rigorous comparison of the relative difficulty of the routes however, is a task for oceanographers.

however, is visible in the last column of each panel in Table 6 where losses are shown as fractions of all voyages. Each common segment of the routes (for example, the Cape) necessarily saw all ships corresponding to the 8,081 Dutch voyages and the 1,839 Portuguese voyages so the Dutch fractions are obviously lower.

The more dangerous segments of each route were nearly exclusive: while most Portuguese losses (24.7%) occurred in the Mozambique Channel —home to Portugal’s main port of call— which the Dutch hardly ever sailed, the Dutch lost most of their ships (28.7%) north of Iberia (along the Dutch coast, in the English Channel, or north of Scotland) where the Portuguese did not sail at all. Weather in the North Atlantic makes Dutch losses in this section of the route inevitable, but did the VOC keep losses down by avoiding the areas of the Indian Ocean where Portuguese ships perished more? The answer is not clear-cut due to the endogenous choice of sea routes and corresponding headquarters and ports of call. But even if the common segments that the Dutch sailed little are deemed more dangerous, Portugal’s losses in these areas correspond to 4.1% of all her voyages, still leaving a loss rate of 8.2% —more than double of the Dutch at 3.8%— to be explained by factors other than the more difficult route.

Table 6 HERE

In sum, among the identifiable elements associated with poor organisation, Portugal’s rising ship size seems to be an unavoidable element behind the disparity in loss rates. The lack of systematic evidence on vessel size, has led most of the literature to either dismiss or discount this potential reason behind Portugal’s decline in the Indian Ocean in favour of an overextension beyond her arguably natural Atlantic scale. This claim seems corroborated by the successful defence of Brazil in the sixteenth and seventeenth centuries (Domingues 2004).³⁵ The Netherlands however, were an even smaller country that did not seem to incur in

³⁵ Portugal’s successful defense of Brazil in the seventeenth century, may, at least partially, be the result of joint Iberian efforts, such as the 1625 expedition to recapture Bahia from the Dutch’s West India Company (Goodman (1997:34) and Disney (2009, 1:244)), thus casting some doubt on the “natural Atlantic scale” argument.

this overextension problem, which may be an indicator of better organisational choices consistent with the argument in the current paper.

The remaining question is, therefore, whether there could be another economic rationale for building large vessels beyond the glory and prestige motives associated with crown control. Economies of scale would be the most natural justification for very large vessels if construction or maintenance costs were lower relative to the volume of goods carried. This argument applies to both empires since both saw rising trade volumes in Asia. But the Dutch, whose trade dwarfed that of the Portuguese, would have faced the lowest shipbuilding cost per volume and thus a greater incentive to build larger vessels, which never materialised. Economies of scale, therefore, cannot have been the decisive factor behind the construction of the great carracks. Portugal's early incumbent status in a context of expanding trade could have led to naval experimentation and, consequently, to overshooting vessel size. The delay in adapting to best market practices, however, is yet another sign of poor organisation.

F. Conclusion

Organisation has profound implications in the general governance of firms. In this paper I focus on the leadership transition in merchant empires from the Portuguese to the Dutch and provide a simple framework where low organisational efficiency is associated with reduced incentives to invest in technological improvements. I investigate the implications of the framework in shipping technology.

In the Age of Discovery, Portugal used small and easily manoeuvrable vessels, ideal for sailing in unknown waters and unchartered coasts. The establishment of empire in the 1500s and the rising volume of trade increased ship size. Large vessels carried more merchandise but became less seaworthy beyond a scale, when slowness and poor manoeuvrability made

them more likely to perish in storms or under attack. As a result, Portugal's loss rate soared in the late sixteenth century and into the seventeenth. Such massive ships were however more fitting of the monarch's objective of empire, which included not only profit but also the demonstration of glory and power, in far distant nations.

In the early seventeenth century the Dutch specialized in the construction of smaller and more seaworthy cargo vessels, which they used and sold to other merchant empires. Upon the foundation of the VOC in 1602, eastern trade was still on the rise, but the largest Dutch ships never reached the size of Portugal's. In fact, this merchant-controlled organisation conducted far more voyages than Portugal at a much lower loss rate.

Relatively better skilled labour from the Dutch side is a plausible cause behind this discrepancy (Lucassen and Unger 2011). In light of the framework in section 2 this is consistent with a poorer organisational structure for Portugal. From a shipping technology perspective however, only the lax practice of convoys and the excessive loading of Portuguese ships could plausibly explain the difference. These clear organisational inefficiencies can be understood as the unintentional consequences of vessel size, which seems to be the unavoidable culprit behind the divergent performance of Portuguese and Dutch vessels.

To date, the literature on the Portuguese empire has dismissed shipping technology and, in particular, ship size, as a potential cause of its decline in Asia due to lack of systematic evidence on vessel dimensions (Castro 2005, Costa 2013, Domingues 2004). I use data on reported Portuguese losses and the complete database of Dutch voyages to suggest that indeed ship size could be one of the plausible reasons explaining this turning point in leadership in merchant empires.

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Tables

Table 1: Ships Built in VOC Shipyards

	1602-1699		1700-1794		1602-1794	
<500t	412	58%	78	10%	490	34%
500-800t	199	28%	175	23%	374	25%
800-1,000t	42	6%	283	38%	325	22%
≥1,000t	53	8%	219	29%	272	19%
Total	706		755		1,461	

Source: Bruijn et al.. (1987, I:52).

Table 2: Portuguese Losses on the Cape Route³⁶

	Outbound		Inbound		All losses /	Attacked	Loss rate
	voyages	losses	voyages	losses	All voyages	(% voyages)	net of attacks
1497-1550	493	48	325	31	9.7%	2 (0.2%)	9.5%
1551-1600	260	17	225	45	12.8%	5 (1.1%)	11.7%
1601-1650	272	46	149	32	18.5%	16 (3.8%)	14.7%
1651-1700	124	9	82	9	8.7%	1 (0.5%)	8.2%
1497-1700	1,149	120	781	117	12.3%	24 (1.2%)	11.1%

Sources: Duncan (1986:22-3) for Portuguese voyages and losses per decade; Guinote et al. (1998) for losses resulting from attacks.

³⁶ The discrepancy between inbound and outbound voyages, after accounting for losses, is justified by the building of empire. Many ships stayed in Asia for defence and maintenance purposes.

Table 3: Reported Portuguese Losses on the Cape Route by Size (sample)

Name	Date	Size/Type	Trip	Attacked	Overloaded
<i>São João</i> ^{(c) (d) (e)}	1552	900	inbound	no	yes
<i>São Bento</i> ^{(b) (d) (e)}	1554	900	inbound	no	yes
<i>Garça</i> ^{(a) (d)}	1559	1,000	inbound	no	yes
<i>Águia</i> ^{(a) (d) (e)}	1559	carrack	inbound	no	yes
<i>São Paulo</i> ^{(a) (d) (e)}	1561	carrack	outbound	no	no
<i>Santiago</i> ^{(c) (d) (e)}	1585	900	outbound	no	no
<i>São Thomé</i> ^{(a) (d) (e)}	1589	carrack	inbound	no	?
<i>Santa Cruz</i> ^{(e) (f) (h)}	1592	1,600/carrack	inbound	yes	?
<i>Madre de Deus</i> ^{(e) (f) (h)}	1592	1,600/carrack	inbound	yes	?
<i>Santo Alberto</i> ^{(a) (d) (e)}	1593	carrack	inbound	no	yes
<i>Santiago</i> ^(g)	1602	carrack	inbound	yes	?
<i>Nossa Senhora dos Mártires</i> ^{(c) (e)}	1606	600	inbound	no	?
<i>São João Baptista</i> ^{(a) (d) (e)}	1622	carrack	inbound	yes	yes
<i>São Gonçalo</i> ^{(b) (c) (e)}	1630	large	inbound	no	yes
<i>Nossa Senhora de Belém</i> ^(e)	1635	largest carrack	inbound	no	?
<i>Santissimo Sacramento</i> ^{(c) (d)}	1647	large	inbound	no	?
<i>Nossa Senhora da Atalaia</i> ^{(c) (d) (e)}	1647	18 guns	inbound	no	?
<i>Nossa Senhora dos Milagros</i> ^(b)	1686	30 guns	inbound	no	yes

Sources: ^(a) Brito (1959, 1968), ^(b) Burman (1967, 1968), ^(c) Castro (2005), ^(d) Duffy (1955), ^(e) Guinote et al. (1998), ^(f) Latham and Youngs (1999:78), ^(g) Boxer (1965), ^(h) Boxer (1948).

Table 4: Dutch losses on the Cape Route

	Outbound		Inbound		All losses / All voyages	Captures (% voyages)	Loss rate net of captures
	voyages	losses	voyages	losses			
1602-1699	1,822	55	1,030	43	3.4%	23 (0.81%)	2.6%
1700-1794	2,900	86	2,329	126	4.1%	41 (0.78%)	3.4%
1602-1794	4,722	141	3,359	169	3.8%	64 (0.79%)	3.0%

Source: Bruijn et al. (1979, II and III) lists all Dutch outbound and inbound voyages, including the losses and their details.

Table 5: Dutch losses on the Cape Route by size

	1602-1699			1700-1794			1602-1794		
	losses	% total	% class	losses	% total	% class	losses	% total	% class
<500t	31	34.1%	7.5%	15	7.1%	19.2%	46	15.2%	9.4%
500-800t	34	37.3%	17.1%	56	26.6%	32.0%	90	29.8%	24.1%
800-1,000t	8	8.8%	19.0%	91	43.1%	32.2%	99	32.8%	30.5%
≥1,000t	18	19.8%	34.0%	49	23.2%	22.4%	67	22.2%	24.6%
Total	91			211			302		

Source: Bruijn et al. (1979, II and III) for absolute losses.

Table 6: Geography of losses on the Cape Route

	Portugal			Netherlands		
	#	% losses	% all voyages	#	% losses	% all voyages
North of Iberia [§]	-	-	-	89	28.7%	1.1%
Iberian Coast	23	9.7%	1.2%	5	1.6%	0.1%
Azores	12	5.1%	0.6%	2	0.6%	0.0%
South Atlantic, Cape, Natal	27	11.4%	1.4%	82	26.4%	1.0%
Mozambique Channel*	59	24.9%	3.1%	2	0.6%	0.0%
Madagascar, Mauritius	-	-	-	14	4.5%	0.2%
East African Coast	23	9.7%	1.2%	-	-	-
West Indian Ocean*	19	8.0%	1.0%	5	1.6%	0.1%
South and East Indian Ocean [§]	-	-	-	47	15.2%	0.6%
Indian Coast	34	14.3%	1.8%	-	-	-
Other	16	6.8%	0.8%	19	6.2%	0.2%
Unknown	24	10.1%	1.2%	45	14.6%	0.5%
Total	237	100%	12.3%	310	100%	3.8%

[§]Exclusive Dutch segment.

*Common segments across routes used much less often by the Dutch.

Sources: Portugal: Guinote et al.. (1998:124) for all 1,114 voyages from 1497 to 1650. Netherlands: imputed data from all 8,081 voyages between 1602 and 1794 listed in Bruijn et al.. (1979), Vols. II and III.

Table 7: Portugal's imputed fleet

	Based on early VOC fleet		Based on late VOC fleet		Based on overall VOC fleet	
<500t	877	58%*	61	10%*	284	34%*
500-800t	96	6%	51	8%	68	8%
800-1,000t	345	23%	205	33%	216	26%
≥1,000t	194	13%	294	48%	267	32%
	1,513		611		835	

*Assumed equal to Dutch fleet share in Table 1.

Appendix: Comparing Fleets³⁷

If vessel size was a driving force behind the technology transition from Portugal to the Netherlands in the early seventeenth century, then Portugal's fleet should have been more reliant on very large ships than the Dutch fleet. Unfortunately, there is no systematic information on Portugal's ship sizes, which prevents a direct comparison of both fleets. The evidence on Table 3 however, shows very large Portuguese shipwrecks well into the first decades of the seventeenth century. I therefore estimate the composition of Portugal's fleet combining the information on all Portuguese losses and the reported Portuguese losses by size with the information on all Dutch ships by size and all Dutch losses by size. The resulting estimate of very large vessels of Portugal's imputed fleet is a lower bound because I assume

³⁷ A note on naval metrology. Tonnage is a notoriously difficult subject due to the changing nature of measurement units and the non-matching units of measurement across countries even if the nomenclature is the same. Despite these challenges, tonnages (cargo capacity plus ship weight) presented so far, are comparable for two reasons. First, the sizes of Dutch ships in Table 1 are reported in metric tons equivalent to 1,000 kg (for a discussion on the conversion into metric tons see Bruijn et al., 1987, I:42-44). Second, Portuguese vessel sizes come from several different sources, but they are consistent with the values in Duncan (1986) where ship sizes are reported in sixteenth century Portuguese maritime tons. This measure was based on the ton of wine equivalent to 1,023 kg, which overstates the regular ton by 2.3% (for exact calculations see Duncan 1986:9). Moreover, both Duncan (1986:7) and De Vries (2003:50) agree on the maximum range of carracks at 2,000 tons even though these two sources come from different national origins. In sum, the comparison of fleets is plausible and does not favour Portugal's large ships, if anything, their sizes are slightly understated in the comparison (vessels of 1,000 tons should in fact have 1,023 tons).

identical loss rates by tonnage class in both fleets and the largest VOC vessels were smaller than Portugal's largest vessels. Portugal's imputed fleet per tonnage class is then:

$$Reported\ PT\ losses_{size} \times \frac{All\ PT\ losses}{Reported\ PT\ losses} \times \frac{All\ NL\ built_{size,time}}{Reported\ NL\ losses_{size,time}} \quad (4)$$

The first term comes from Table 3, which contains 18 Portuguese losses: eight in very large ships (above 1,000 tons), eight in large ships (800-1,000 tons), two in medium-sized ships (500-800 tons), and none in small ships (below 500 tons). It is implausible to assume that Portugal's fleet had no small ships so I impose an equal fraction on this category to that of VOC built ships in Table 1.³⁸ The second term does not vary with ship size and provides an indication of the representativeness of the reported Portuguese losses: between 1552 and 1686 Portugal lost a total of 148 ships, but only 18 are reported by size, therefore this constant term is 148/18. The last term combines data from Tables 1 and 5 varying with size and period, which allows for the estimated fleet to adjust to the different naval needs of empire.

Table 7 shows three potential imputed fleets for Portugal according to the time period of the last term in (4). On the left panel, I used Dutch data from the seventeenth century corresponding to the early history of the VOC. Biased towards small ships, this early imputed fleet reflects the establishment of empire with navigation needs relating mostly to defence and communication purposes in Asia so there is a larger fraction of small ships. In contrast, the fleet in the middle column uses Dutch data from the eighteenth century when the VOC's trade was already well established. This imputed late fleet is therefore geared towards larger cargo vessels that met rising trade needs. The fleet on the right-hand-side uses data for the entire history of the VOC in Asia and provides a more balanced picture of the overall shipping needs of empire. The question is now whether any of the estimated fleets in Table 7 is plausible.

³⁸ This imposed condition likely overestimates the number of Portugal's small ships given the indirect evidence that suggests that, on average, Portugal's ships were larger than those of the Netherlands.

Table 7 HERE

In its 8,081 voyages, the VOC used 1,839 vessels (own-built or outside purchased/hired). Accordingly, Portugal's 1,930 voyages should have been possible with 439 vessels. Correcting for the higher loss rate (12.7% vs 3.8%), Portugal's fleet should have been comprised of 478 ships, a lower value than any of the estimates in Table 7 probably for two reasons. First, the 478-vessel fleet assumes different loss rates across empires, but identical depreciation rates of capital. Portugal, however, could have faced faster ship decay, since her vessels were the first to sail in tropical waters where shipworm (also known as termites of the sea) infiltrate wooden hulls creating leaks, which ultimately render vessels useless. This problem affected vessels of all empires but hull preservation techniques, such as sheathing, improved with time making the Dutch benefit from late entry.³⁹ Second, the 478-fleet also assumes identical capital utilization across empires, but the Dutch were exceptionally efficient in reducing idle time in ports when compared to the Portuguese (Parthesius 2010:57).

Monsoons in the Indian Ocean and difficulties rounding the Cape in winter could force long stays at intermediate ports affecting voyage duration and vessel turnover. The average duration of Dutch voyages was 8.1 months outbound and 7.8 inbound (Bruijn 1987, I:74 and 89). In the absence of unexpected delays, Portugal's voyages lasted 5.8 and 6.5 months respectively, as expected of a shorter route.⁴⁰ However, one in every nine Portuguese vessels between 1500 and 1635 wintered in a port of call, stretching the outward voyage to 12 or even 18 months (Godinho 1993:12). If the Dutch had a better capital utilization, Portugal would need more ships for any given number of voyages. The multiplier's magnitude depends on the

³⁹ Copper sheathing was fully effective against shipworm, but this practice only started in the mid eighteenth century. Before that, lead sheathing and pine planking had limited success (Parthesius 2010:103). Indian timber was hard and seasoned —unlike Iberia's where supply was short— and arguably more resistant to shipworm (Scammell 1989:125).

⁴⁰ The Dutch route took 15,000 nautical miles outbound and 13,400 inbound plus 600 miles when sailing around the British Isles; Portugal's route took 12,100 and 11,550 nautical miles, respectively, via the Mozambique Channel (Ravenstein 1898:202). For details on wind and current systems, departing dates, and voyage duration see Bruijn et al. (1987) for the Netherlands, and Godinho (1993) for Portugal.

idle time Portuguese vessels spent in ports waiting for the change of season: half a year would require twice as many ships, four months 1.66, three months 1.5, two months 1.33, and so on.⁴¹ Monsoons in the Indian Ocean last five months but only two of those months have intense rains and winds, whereas winter can take up to four months. If these were the two major events halting Portuguese ships in port, any idle time up to six months of the year would be sensible. The maximum multiplier would be 2 corresponding to a fleet no larger than 956 ships.

All told, shipworm and lower capital intensity both render the baseline fleet size of 478 vessels too small. But the 1,513-fleet with a bloated multiplier of 3.25 corresponding to 13.5 months idle in port per year waiting for the change of season, is manifestly absurd. The remaining two fleets of 611 and 835 vessels provide, therefore, plausible lower and upper bounds with implicit multipliers of 1.28 and 1.75 corresponding to nearly two months and four-and-a-half months of idle time in port in a year, respectively, which seems sensible.⁴²

In the lowest capital utilization scenario of the 835-fleet, the 32% share of very large vessels is higher than any of the corresponding shares of ships built in the VOC's shipyards in Table 1. Given the Company's outside purchases and hires of small and medium vessels, the share of very large ships in the Dutch fleet would only be lower than that of its own ship building making the comparison with Portugal's estimated fleet even more stark. Portugal's heavy reliance on very large vessels befits an empire where shipping decisions stemmed from the crown, whose objectives involved not only trade but also glory and prestige.

⁴¹ The corresponding formula for the multiplier is $1 + 2 \times \frac{\text{months idle}}{12}$.

⁴² Plausible as these fleet sizes may be, their estimation relies on the sample of Portuguese shipwrecks with information on ship size, which may be biased towards larger vessels possibly overrepresented in the surviving historical sources. The potential bias is however countered by (a) the possible overstatement of Portugal's fraction of small vessels, assumed equal to that of the VOC's in Table 1; and (b) the assumption of identical loss rates for the same tonnage class in both empires, though Portugal's likelihood of loss of vessels above 1,000 tons was likely higher than the VOC's that never produced great carracks. Thus, Portugal's higher frequency of large and very large losses in the sample does not seem unreasonable so the eventual bias may not even exist.