

Turning Points in Leadership: Shipping Technology in the Portuguese and Dutch Merchant Empires

Claudia Rei*

Vanderbilt University

claudia.rei@vanderbilt.edu

December 10, 2013

Abstract

This paper discusses the implications of organizational control on the race for economic leadership in merchant empires. Poor organizations have reduced incentives to invest, which in turn stifle technological improvements making leaders lag behind new entrants. Portugal's large ships carried more merchandize and were more fitting of the monarch's grandiose preferences, but they also were more prone to disaster in stormy waters. 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 enforced their presence in the Indian Ocean.

*I thank Bob Margo and Andy Newman for early stage discussions and Jeremy Atack, Bill Collins, Mauricio Drelichman and Richard Unger for detailed suggestions on earlier drafts. I also thank Ben Eden, Boyan Jovanovic, Giacomo Ponzetto, Peter Rousseau, Ken Snowden, Jan de Vries, participants at the annual meetings of the Economic History Association in Boston, the annual meetings of the Southern Economic Association in Washington DC, and the Frontier Research in Economic and Social History meeting in Saint Pierre d'Entremont for helpful comments.

1 Introduction

Economic progress has often been associated with technological advancement. The age of merchant empires was perhaps the period of history in which this relationship became most visible as decisive developments in shipping technology dictated the success or failure of long-distance trade (Maddison 1982, Brezis et al 1993, Israel 1989, Acemoglu et al 2005). Portugal maintained a technological edge in shipping that proved very successful in the fifteenth century discoveries and the subsequent establishment of the first European merchant empire in the East. By 1600 however, Portugal had lost its technological dominance to the Netherlands which had become the major shipbuilder in Europe. The factors affecting technology decisions across countries become therefore vital to understand the sequence of leaders in merchant empires.

In Portugal, the residual claimant of long-distance trade was the king who hired merchants to run the business whereas in the Netherlands, private merchants managed long-distance trade according to their own interests. The control structure was no mere label: merchants would be more willing to invest and put effort in a firm they did control in which case business decisions (e.g. shipping) were more likely to follow a standard market approach (Rei 2011). Merchant control implied, therefore, a more efficient firm.

In this paper I present a simple framework that illuminates the relationship between a firm's organizational control and its technology decisions. Technical progress results from continuous investments in research and development that allow for successive improvements. Initially the more experienced incumbent is less likely to invest in improvements than an entrant with no notable experience record since the latter has less to lose; further technological improvements bring the advantage back to the incumbent for whom the gain from investment is now larger. The result is continuous leapfrogging (Brezis et al 1993). In merchant empires however, Portugal (the incumbent) was summarily displaced in Asia by the Netherlands (the entrant), I argue, because of organizational control. If shipping decisions were subject to the monarch's whims and wills, Portugal should have lagged behind in the

adoption smaller and more seaworthy ships. This technological option would translate into higher loss rates at sea all else the same.

Guided by this framework, I gathered historical evidence on Portuguese and Dutch shipping from the sixteenth to the eighteenth centuries to understand Portugal's loss of technological leadership. In the early 1500s, Portugal used small and easily maneuverable ships, but the increased volume of trade gave rise to large cargo vessels by the late sixteenth century. Though more fitting of the monarch's grandiose preferences, larger ships were less seaworthy and therefore more likely to perish in stormy waters. Consequently, Portuguese loss rates rose from one in every ten voyages in the early sixteenth century to nearly one in every five one-hundred years later. By then the Dutch had become active in Asian markets using smaller ships. Between 1602 and 1794 the Dutch East India Company (*Verenigde Oost-Indische Compagnie*, henceforth VOC) conducted far more voyages on the Cape Route than Portugal did between 1497 and 1700, at less than one loss for every 25 ships sent.

The Portuguese always sustained relatively higher losses than the Dutch on the Cape Route. However, Portugal's loss rates began increasing in the second half of the sixteenth century, coinciding with the introduction of large vessels, and continued to do so onto the seventeenth in the presence of foreign competition. I discuss this and other potential alternatives for the disparity in loss rates across empires—such as Portugal's reduced influence in the Indian Ocean in the seventeenth century, or the variations of the Cape Route in which Portugal and the Netherlands specialized—, but none can unambiguously be associated with the higher Portuguese values.

There is no systematic information on the size distribution of Portugal's fleet, but narrative evidence describes Portuguese shipwrecks of very large vessels well into the mid-seventeenth century. I use this information to reconstruct the Portuguese fleet assuming identical loss rates (to the Dutch) for the same tonnage class while using different fleet structures of the VOC according to the early or late shipping needs of empire. The results show a heavier reliance on large ships by Portugal relative to the Netherlands, which is con-

sistent with the slower adoption of technological improvements highlighted in the framework. The historical evidence shows that the less efficient organizational form lost the technological race at a time when the Portuguese eastern empire plunged together with its large ships.

2 A Simple Framework of Technology Adoption

Consider a firm in the long-distance trade market making π_0 profit from the current shipping technology τ_0 . The firm can choose to invest z , which results in technological improvement τ_1 yielding $\pi_1 > \pi_0$ with certainty, for simplicity. Investment will occur 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 the cost (z), the less likely the firm is to 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). The replacement effect is stronger for a monopolist facing new entrants who start with $\pi_0 = 0$ and who invest so long as $\pi_1 > z$ (Aghion and Howitt 1998).

All firms operate in remote markets and face similar challenges associated with long-distance travel. 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 (Rei 2011).¹ As a result, each firm is associated with an efficiency level $\varphi \in (0, 1]$ that affects investment returns so (1) becomes

$$\varphi(\pi_1 - \pi_0) > z. \tag{2}$$

The more efficient the organization ($\varphi \rightarrow 1$), the less distorted the original investment decision in equation (1). If all firms have access to the same technological options (π_1, π_0

¹Each firm's investment decision is optimal as it stems from the maximization of the objective function of the party in control –king or merchants–, which is exogenous in the context of this paper.

and z equal across firms), then only φ matters in each firm's investment decision. In poor organizational forms (low φ) the return for each investment is lower, in which case, firms invest less but not necessarily nil.²

Suppose now that the incumbent exploring τ_0 exhibits a low efficiency organizational form φ_L , and that a new player enters the market with an improved technology τ_1 and also a better organizational form $\varphi_H > \varphi_L$. If the replacement effect is large enough the incumbent will not adopt τ_1 . The two firms therefore share the market while exploring different technologies, 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 improvement τ_2 comes along, incumbent and entrant will invest if

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

$$\text{and } \frac{\varphi_H}{\varphi_L + \varphi_H}(\pi_2 - \pi_1) > z, \quad (4)$$

respectively. Even though the replacement effect now favors the incumbent ($\pi_2 - \pi_0 > \pi_2 - \pi_1$), for sufficiently low values of φ_L condition (4) may hold whereas condition (3) may not. In such a case, the entrant would invest while the incumbent would stick to the old technology even if losing market share and forgoing leadership.

This simple framework helps to understand why Portugal, despite its less efficient organizational form, was initially able to invest in the improvements of sailing technology that allowed for a period of economic leadership. When more efficient firms entered the market, they were able to make the technology investments that Portugal found less appealing.

The next section provides a discussion of the historical findings on the divergent shipping patterns of the Portuguese and the Dutch empires in the late sixteenth and early seventeenth centuries. Once technological innovations were available throughout Europe the lack of adoption by the Portuguese may indicate yet another impact of organization on economic performance.

²For an example in monitoring, see Rei (2013).

3 Shipping Decisions in Merchant Empires

A successful round-trip 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, these were dangerous ventures: storms, disease, and various kinds of accidents played a role not only in the survival of the crew, but also in the success of the voyage. If pirates, bad weather, disease, and other accidents affected all on the Cape Route, then the completion of trips depended crucially on vessel type. The aim of this section is to evaluate the Portuguese and Dutch shipping decisions in light of the organization argument already presented.

3.1 The Portuguese case

In 1498 Vasco Da Gama completed the first successful trip to India in 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 the high prices of spices arriving in Europe via the Levant (O'Rourke and Williamson 2009).³ Da Gama's feat came after a century of maritime voyages, in which the Portuguese explored the West African coast, adding to existing geographic and sailing knowledge.

Unknown ports in uncharted coasts required small and swift vessels, such as the caravel. This lateen rigged ship, of at most 60 tons, was handy to maneuver under sudden and unexpected weather changes or enemy attacks. As the volume of trade soared in the sixteenth century, caravels were replaced by larger square sailed vessels –for better usage of wind power–, such as *naus* (carracks if very large) and galleons. The *nau* was lightly gunned mainly used for cargo purposes whereas the galleon was primarily a war vessel, which was often pressed to serve as a cargo ship from the early days of empire.⁴

³The unequivocal downward trend of European spice prices during the sixteenth century did not imply an immediate collapse of Mediterranean trade, which persisted into the seventeenth century (Steensgaard 1974).

⁴For a detailed discussion of the differences between *naus* and galleons see Boxer (1975:207).

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. From 1551 to 1570 there was a steady increase in ship size, with a smaller number of units bringing to Lisbon more spices than ever before. Such large vessels –usually overcrowded and overloaded⁵– proved less seaworthy than vessels of smaller tonnage. Accordingly, in 1570 the monarch enacted a new law requiring all *naus* to be sent on the Cape Route to be between 300 and 450 tons. But ten years later, under Spanish rule (1580-1640), the 1570 law was relaxed and it became common practice every year to build two or three vessels above 1,000 tons each (Boxer 1968:13).⁶

By the 1580s, Portuguese carracks on the Cape Route ranged between 1,000 and 2,000 tons (De Vries 2003). These heavily decorated and armed monster ships with multiple decks and forecastle carried more merchandise, but they were also slower and less maneuverable (Phillips 1994). Cargo ships were also built in Asia where better timber was readily available allowing for an increased vessel lifespan. Though more seaworthy, these ships were even larger than those produced at home. Such were the cases of Cochin-built: *Santa Cruz* of 1,600 tons, which sailed to Lisbon in 1589 after serving in the Japan trade (Boxer 1968:15); and *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).

The fast rate of vessel decay on the Cape Route and the empire's expansion, made Lisbon's shipbuilding a fast growing industry.⁷ The conditions of haste in which shipwrights labored, as well as the owner's cargo specifications, allowed for little change in ship design. With the king as the main merchant and armor, Lisbon's shipyards quickly specialized in the construction of very large vessels pre-ordered for specific voyages (Costa 1997).

⁵The king's pepper took up most storage space. All else was stored in every possible corner, "sometimes hanging outside the hull supported by ropes" (Castro 2005:18). Shipwreck narratives often provide accounts of crews forced to let go of some of the hanging cargo in an attempt to stabilize large vessels during storms.

⁶The Spaniards are not to blame for the rising ship size, as the construction of larger ships predated 1580.

⁷The lifespan of vessels on the Cape route was at most eight years, which corresponded to four round-trips to Asia at best (Steensgaard 1965). The implied continuous replacement belies the hypothesis that Portugal would stick to the old technology (old ships lasting many years) before exiting the market in a strategy consistent with profit maximization.

But why would monarchs prefer big ships? This technological option befits a strategy concerned not only with profits yielding from a large volume of trade, but also with the glory and prestige that the sight of such gigantic vessels conveyed. These were the largest ships afloat at the time and became distinctive features of Portugal's naval architecture since no other nation built such "mountains of wood" (Boxer 1968:14). Looking powerful was valuable to the king who was directly engaged in trade with distant sovereigns that he never actually met.⁸ Such large ships would therefore be an expression of glory and military power to impress distant rulers, especially after other countries in Europe started competing for spices in the Indian Ocean. As the Dutch introduced changes that improved vessel stability and seaworthiness in the seventeenth century, Portugal kept building larger and less maneuverable vessels (Duffy 1955:51).

Though fitting royal hubris, the deliberate increase in vessel size proved disastrous for safety. The dreadful state of affairs in the first half of the seventeenth century led a group of experienced Portuguese officials—from merchants to sea captains⁹—into persuading the crown for the reinstatement of the 1570 tonnage law. The central arguments against Portugal's very large carracks involved excessive loading and more difficult maneuverability, which often resulted in losses entering and exiting ports even in the absence of enemy attack. These qualified officials also noted that very large vessels travelled slower which posed additional problems. On the one hand, the practice of convoys became more difficult given the different speeds of galleons and carracks, which by themselves were rather vulnerable. On the other, the longer trip duration made ships more likely to winter in Mozambique further delaying voyage completions as well as subsequent departures.

The success of the pleas of experts to bring down vessel tonnage was only partial. *Naus*

⁸Private merchant companies could similarly have valued demonstrations of power. Not only did they conduct trade, but they also administered justice and had their own armies, effectively becoming states within the state. But the extent to which kings cared for power and glory was different: the empire would bring visibility and international prestige recognized by other sovereigns of the time and in the future.

⁹See Guinote et al (1998:378-407) for contemporaneous arguments against oversized ships by Portugal's governor in Goa Fernão de Albuquerque (1540-1623), merchant Duarte Gomes Solis (ca 1562-1632), sea-captain João Pereira Corte-Real (1580-1642), and historian and priest Manoel Severim Faria (1583-1655). Albuquerque, Faria and Solis refer to the Dutch success on Asian trade, with smaller but more ships.

were built smaller but galleons, which previously rarely exceeded 600 tons, would now be built up to 1,200 tons. Such was the case of the *Santa Tereza* destroyed in battle against the Dutch in 1639 (Boxer 1968:13). This evidence suggests that merchant and maritime personnel had limited influence on the shipping decisions of empire.

3.2 The Dutch Case

As a country whose land was partially reclaimed to the sea, the Netherlands have a long tradition of shipbuilding vessels suited for rivers and canals, but also the ocean. Through the fourteenth century, shipbuilding proliferated on Dutch shores and river estuaries, but by the fifteenth it concentrated mostly in towns, where it was easier to gather the necessary investment capital (Unger 1978:2). Antwerp, the largest medieval city in the Low Countries, remained the major distribution center 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, which further facilitated shipping development.¹⁰

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 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.¹¹ The rigging over 2 or 3 short masts with easier to handle "gaff sails" made the vessel more maneuverable while requiring fewer sailors. The shallow but box-like hull and round (instead of square) stern, provided larger cargo capacity than contemporary

¹⁰Since the end of the fifteenth century, the Dutch were shipping salt from Portugal, Spain and France to the Baltic, as well as French wine (Israel 1989).

¹¹The *fluit's* measures held constant until ca. 1800, though they could be 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—reaching as much as 2,000 tons—as a response to steamers (Graham 1956).

ships of similar size. The small bulk above the water line –no forecastle, and few or no guns– reduced resistance to the wind and improved sailing quality, but constrained *fluits* to safer routes or to sail in convoys.

So successful was the *fluit*, that the Dutch supplied this cargo vessel to the French India Company, England, Hamburg and Ostend, as well as Denmark and Sweden (half of whose fleets was Dutch-built), and even the Spanish colonial trade (Barbour 1930:286-7). The pervasiveness of Dutch vessels all over Europe in the seventeenth century, suggests that these technologically advanced ships were generally available outside the Netherlands. Though Dutch shipbuilding is difficult to estimate, exports probably never equaled 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-sterned and round-sterned ships. Among the first, the most common were the East Indiamen used as cargo and passenger carriers on the Cape route. These were the largest vessels in operation for the VOC but they never reached the sizes of carracks, as no other empire followed Portugal in the operation of such giant ships (De Vries 2003). The Indiamen carried guns but had greater hulls than the more heavily armed warships, which could also be used as cargo carriers of less capacity. Beyond war and cargo vessels used on the Cape Route, the Dutch (as all other empires) employed other vessels according to its navigation needs, for instance the intra-Asian trade.¹²

Among the round-sterned ships, *fluits* played a permanent role in the company's fleet. The *fluit's* hull design with a low center of gravity gave it more stability under bad weather, and the use of pine instead of oak (except in the hull) made it an exceptional light vessel of large cargo capacity (Unger 1978). Regarded as cheap to build, man and maintain, bigger *fluits* were fairly common vessels on the Cape Route next to the larger East Indiamen well

¹²For the particular composition of the VOC's fleet in 1660 see Parthesius (2010:65).

into the eighteenth century when the latter was dominant (Bruijn et al 1987:55).

The VOC built its own ships but 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 size vessels resumed. Overall, the company’s shipbuilding prevailed: in nearly two centuries of operation the VOC bought or hired 378 vessels and built 1,461.¹³

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. (1987:52).

Table 1 shows the size distribution of all vessels built in the Company’s shipyards. In the seventeenth century the VOC concentrated mostly on small and medium ships below 800 tons, which represented 86% of the company’s naval construction.¹⁴ The large cargo vessels sailing around the Cape only served a fraction of the needs of the establishing empire, which also required smaller ships to defend ports and to engage in the intra-Asian trade. 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%). Rising trade levels on the other hand, especially in the first decades of the 1700s, led to a rise in the construction of large and very large vessels above 800 tons (67%). Nevertheless, very large ships above 1,000 tons were never the biggest fraction of output in the company’s shipyards, representing only 19% of the VOC’s overall naval construction.

¹³The information on bought and hired vessels was extracted from the lists of all VOC ships sent to and from Asia in Bruijn et al (1987).

¹⁴The corresponding percentage in the company’s fleet was probably higher, given the purchase and hiring of ships from private shipyards, mostly *fluits* and other small vessels.

4 Shipping Losses in Merchant Empires

Shipping decisions ultimately reflected in the empire’s losses at sea. In this section I present and analyze Portuguese and Dutch loss rates by time period in light of the shipping decisions just described.

4.1 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 for every fifty-year period.

Table 2: Portuguese Losses on the Cape Route¹⁵

	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 the Portuguese voyages and losses per decade; Guinote et al (1998) for the losses resulting from attacks.

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 first half of the seventeenth century, Portugal’s losses reached an all-time high of 18.5%. Nearly one in every five Portuguese ships was lost on the Cape Route between 1600 and 1650, compared to one in ten one century earlier. This rising loss rate is partially explained by Portugal’s intensified opposition in the high seas after the Iberian union of 1580 after which Spain’s enemies —England and the Netherlands— regarded Portuguese ships as legitimate targets. Though more losses resulted from enemy attacks between 1600 and 1650, these represented only 3.8% of the voyages in the same time period leaving still a very high loss rate of 14.7% to be explained. The increase in loss rates net of attacks was not as dramatic but it was still impressive: it rose by more than a half

¹⁵The discrepancy between in- and outbound voyages, after accounting for losses, is justified by the building of empire. Many ships stayed in Asia for defense and maintenance purposes.

from the first half of the sixteenth century to the first half of the seventeenth, which coincides with the increase in vessel size.

After 1650 the Portuguese contributed only negligibly to the Cape Route's traffic. In the first half of the seventeenth century Portugal lost most of her outposts in the Indian Ocean in conflicts with competing empires. The remaining prominent ports were conceded through diplomatic agreements that recognized Portugal's restored independence after 1640.¹⁶ By 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). At this stage, Portugal merely maintained annual communication between Europe and Asia with returning ships often partaking in the Brazil trade. The decline in trade reduced voyage needs and, likely, ship size as suggested by the decline of the loss rate to 8.7%.

Guinote et al (1998) provide a list of all 237 Portuguese losses with details such as the stage of the voyage (out- or inbound), the date, location, and cause of the loss. Unfortunately this list does not include vessel type or size, which I found in other sources such as: narratives of shipwrecks based on reports of survivors and close witnesses (Brito 1959 and 1968, Burman 1967 and 1968, Duffy 1955);¹⁷ studies by naval historians that include excerpts of letters of Portuguese missionaries that survived one or more shipwrecks and studies of naval archeologists (Guinote et al 1998 and Castro 2005, respectively); and finally, English or Dutch sources that may refer to captures of Portuguese vessels returning from Asia (Raleigh 1999, Boxer 1965).

The sources contain more shipwreck reports than the eighteen listed in Table 3 but only those have information on ship size or type. The reported sample represents roughly 8% of Portugal's losses at sea between 1500 and 1700, and 12% of the losses between 1552 and

¹⁶One such example is the 1661 marriage contract between Catherine of Portugal and Charles II of England, which secured Bombay and Tangiers to England in exchange for military and naval support for Portugal against Spain.

¹⁷This 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 other narratives from previously unpublished documents. The narratives do not correspond to an exhaustive collection of all Portuguese losses, many of which consisted of ships that simply disappeared in unknown locations of the high seas without witnesses.

1686, the start and end dates in the table. Despite its small number, the sample is very informative due to the reported sizes of the lost vessels. In particular, the 1,600-ton *Madre de Deus* —captured by English privateers off of the Azores Islands— which also mentioned as a carrack, provides an indication of the enormous size of this type of vessel never replicated in other empires.

Table 3: Reported Portuguese Losses 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> ^{(c) (f)}	1592	carrack	inbound	yes	?
<i>Madre de Deus</i> ^{(c) (f)}	1592	1,600	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	carrack	inbound	no	?
<i>Santíssimo 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, Frutuoso and Lopes (1998), ^(f) Raleigh (1999:78), ^(g) Boxer (1965).

Out of eighteen reported wrecks, ten belong to very large ships above 1,000 tons, which were either mentioned by size (*Garça* and *Madre de Deus*) or by type (*Águia*, *Madre de Deus*, *Nossa Senhora de Belém*, *Santa Cruz*, *Santo Alberto*, *Santiago*, *São João Baptista*, *São Paulo* and *São Thomé*). Five 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*), or were simply referred as *large* (*São Gonçalo* and *Santíssimo Sacramento*). *Nossa Senhora dos Milagros*, was also likely a large vessel since it was overloaded and had 30 gun cannons on board. Finally, *Nossa Senhora dos Mártires* was a 600-ton medium sized ship, and I assume *Nossa Senhora da Atalaia* also to be of medium size since it had 18 guns on board.

Many of the vessels in the sample were overloaded, which suggests their great size. Excessive cargo would be far more tempting in larger vessels, which would result in worsened maneuverability and increased likelihood of loss. Moreover, only four of the reported vessels (*Madre de Deus*, *Santa Cruz*, *Santiago* and *São João Baptista*, all carracks) were attacked by enemies, reinforcing the idea that losses resulting from enemy attacks were not too prevalent in Portugal's overall losses. In sum, sixteen out of eighteen wrecks in the sample occurred in large or very large vessels, in which Portugal seems to have relied well into the seventeenth century.

4.2 The Dutch case¹⁸

The Dutch loss rate was generally low as seen in Table 4, when compared to the Portuguese counterpart from Table 2. Though the absolute number of Dutch losses is higher than the Portuguese (310 vs 237) the Dutch sent more than four times as many ships to and from Asia than the Portuguese did (8,081 vs 1,920) over a similar time period of 200 years. Less than one in 25 ships was lost throughout the two centuries of VOC voyages, but the losses rose slightly from the seventeenth to the eighteenth centuries.

Table 4: Dutch Losses on the Cape Route

	Outbound		Inbound		All losses /	Captures	Loss rate
	voyages	losses	voyages	losses	All voyages	(% voyages)	net of captures
1602-1699	1,822	55	1,030	43	3.4%	23 (0.8%)	2.6%
1700-1794	2,900	86	2,329	126	4.1%	41 (0.7%)	3.4%
1602-1794	4,722	141	3,359	169	3.8%	64 (0.8%)	3.0%

Source: Bruijn et al (1987), vol. II and III list all Dutch outbound and inbound voyages, including the losses and their details.

Captured ships nearly doubled in the same time period, but these were only a very small fraction of the total voyages of the Dutch company, which remained relatively constant (0.7%-0.8%).¹⁹ Of the 310 vessels lost by the VOC on the Cape Route, eight lack information on

¹⁸Volumes II and III of Bruijn et al (1987) provide extensive details for all out- and inbound voyages of the VOC from 1602 to 1794. The Dutch shipping data comes from that exhaustive database.

¹⁹Dutch 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 sustained an enemy attack could have been

tonnage (six in outbound voyages and two inbound) leaving a total of 302 lost vessels with information on size, which is summarized in Table 5.

Table 5: Dutch losses by size

	1602-1699		1700-1794		1602-1794	
<500t	31	34.4%	15	7.1%	46	15.2%
500-800t	34	37.8%	56	26.5%	90	29.8%
800-1,000t	8	8.9%	91	43.2%	99	32.8%
≥1,000t	18	18.9%	49	23.2%	67	22.2%
Total	91		211		302	

Source: Bruijn et al (1987), vols. II and III.

The VOC lost vessels of all sizes but the distribution of the losses changed with time. In the seventeenth century over 70% of the losses occurred in small and medium sized vessels, but in the eighteenth the majority of losses occurred in the large and very large categories (66.4%). This trajectory is consistent with that of Table 1: as more large vessels were built in the company’s shipyards and used on the Cape Route, 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 the very large vessels (22.2%) and the small vessels (15.2%).

This evidence clearly shows that, in the Netherlands, larger vessels were not more vulnerable. But the smaller loss rate of ships above 1,000 tons is perhaps due to the fact that 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-toner *Admiraal de Suffren* built in Amsterdam’s yards in 1785 and sent to Asia the year after. This ship was lost in the South China Sea on the subsequent return voyage to Europe. The VOC shipping records show no other vessel of this same size. Indeed, the most common tonnage among the indiamen was 1,150 tons, well below that of the *Madre de Deus* (1,600 tons) and the India built carracks (Boxer 1975:208). Oversized vessels may have been responsible for Portugal’s higher loss rates, but there is a wide range of other potentially explanatory factors, which I now explore.

captured or sunk, but a captured ship was necessarily attacked. The eventual bias is that I may overestimate Portuguese losses due to captures and underestimate Dutch losses resulting from enemy attacks. The results however still hold even net of enemy action.

5 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%, even though the Dutch conducted more voyages and handled a larger volume of trade. Other than vessel size, the higher Portuguese loss rate could be justified by reasons directly associated with competition from other merchant empires.

Excluding the losses resulting from enemy action brings the net loss rates down to 3% and 11.1%, respectively. Though Portugal was relatively more affected by enemy attacks — especially in the first half of the seventeenth century when it started competing directly with the Dutch and the English— the large disparity in the net loss still needs further explanation.

A less obvious way in which competition could have raised Portugal's losses at sea 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 at the expense of the Portuguese. As the number of ports under Portugal's control became smaller, her vessels could have become more vulnerable at sea given the lack of potential shelter. But Portugal's lost ports were ports of trade, not ports of call. Such was the case of Cochim, Ceylon, Malacca, or the Moluccas, which were gone by 1650 when Portugal's Asian trade was already minimal. Mozambique on the other hand, remained under Portuguese control all through the seventeenth century (and even longer) providing shelter to vessels passing by as well as a place to wait for the change of season if necessary. This was Portugal's traditional port of call on the Cape Route ever since Da Gama's voyage so 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.

Portugal's high losses could still result from other causes unrelated to competition. First, Portugal may have faced different military needs as it specialized in different areas of the Indian Ocean, which affected not only the ships sent to the East but also the casualties suffered en route. More pressing military needs could however have different implications on the loss rate: on the one hand they could result in better defense and less losses, on the

other they could imply overextension and more losses. In any event it is unclear that the military needs of the Portuguese and the Dutch in the Indian Ocean were all that different given that both fought locals upon arrival. Portugal concentrated mostly in India but also disputed territory in the Red Sea, South-East Asia and the Far East. The Dutch on the other hand, fought natives mostly in South-East Asia while sharing efforts with the English to displace the Portuguese in all other locations.

Second, Dutch ships could have been more resilient because they travelled in large convoys on the homeward voyage after convening at the Cape of Good Hope the traditional port of call for the VOC. The convoy practice was also common in Portugal in the sixteenth century before vessels reached excessive proportions. From the early sixteenth century, every year there would be one or more armadas sailing out of Lisbon, 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 in company of other vessels of the same armada, and sometimes also with vessels from previous armadas that had wintered in Mozambique.²⁰ As ship size increased however, Portuguese vessels became slower and often travelled solo or in the company of other large and equally vulnerable vessels (Solis 1955). The original cause of increased vulnerability was therefore vessel size, not convoy practice.

Third, the disparity in loss rates could result from the different routes in which the two countries specialized. Save the Dutch specific segment north of the Iberian Peninsula and through the English Channel or around the British Isles, in the Atlantic the empires followed fairly similar paths. Outbound voyages headed mostly south until reaching the Equator, roamed southwest until the Tropic of Capricorn, and then east to the Cape of Good Hope. In the Indian Ocean however, the routes differed substantially. Portugal's ships sailed along the eastern coast of Africa, through the Mozambique Channel or outside of Madagascar, en route to their headquarters in Goa on India's western coast. The Dutch used a similar route from October to March, on their way to their outposts of Ceylon (today Sri-Lanka) or Bengal

²⁰See 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.

on India’s eastern coast; in the other half of the year, the Dutch sailed further east after the Cape and then north to Ceylon. But the Dutch had far more exposure to the southern and eastern sections of the Indian Ocean given the location of the VOC’s headquarters in Batavia (today Jakarta, Indonesia). After reaching the Cape the Dutch sailed further east until they nearly touched Australia’s western coast before turning north to Indonesia.²¹

Different routes implied different navigational learning, which could explain different loss rates across empires. The Portuguese pioneered the Cape Route single-handedly in the sixteenth century, learning about ocean currents and winds by trial and error on the Atlantic, and from Muslim pilots on the Indian Ocean. The VOC may have had a less difficult task when it started sending ships to Asia in the early seventeenth century, given the established knowledge of the eastern passage through the Cape of Good Hope. However, the different European locations and those of overseas headquarters and outposts required navigational learning in different areas of the Atlantic and Indian Oceans. Table 6 shows the geographical dispersion of losses on the Cape Route for both countries.

Table 6: Geography of Losses on the Cape Route

	Portugal		Netherlands	
North of Iberia	-	-	89	28.7%
Iberian Coast	23	9.7%	5	1.6%
Azores	12	5.1%	2	0.6%
South Atlantic, Cape, Natal	27	11.4%	82	26.4%
Mozambique Channel*	59	24.9%	2	0.6%
Madagascar, Mauritius	-	-	14	4.5%
East African Coast	23	9.7%	-	-
West Indian Ocean*	19	8.0%	5	1.6%
South and East Indian Ocean	-	-	47	15.2%
Indian Coast	34	14.3%	-	-
Other	16	6.8%	19	6.2%
Unknown	24	10.1%	45	14.6%
Total	237	100%	310	100%

* 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. (1987), Vols. II and III.

Losses occurred throughout the route with particular incidence in shallow waters near

²¹For specifics on ocean wind and current systems that dictated the shape of the sea routes in the Portuguese and Dutch empires see Castro (2005:15) and Bruijn et al. (1987:65), respectively.

ports of call. For this reason, the Portuguese lost a larger fraction of ships off the Azores Islands and the Iberian coast than the Dutch, even though both countries sailed in these locations. Similarly, the Dutch lost relatively more ships in the South Atlantic-Cape-Natal section than the Portuguese, whose ships hardly ever called at the Cape. A comparison of the relative difficulty of the routes is objectively impossible. Nonetheless, the evidence in Table 6 suggests that the higher loss rate of the Portuguese was not associated with a route more prone to disaster. While most Portuguese losses (24.7%) happened in the Mozambique Channel, which the Dutch sailed little, most Dutch losses (28.7%) happened to the north of the Iberian Peninsula (along the Dutch coast, in the English Channel and north of the British Isles), where the Portuguese did not sail at all. Both variations of the Cape Route had difficult sections but none was clearly harder than the other.

Lastly, the Dutch could have just built better ships and used better skilled labor in their naval construction, which could have resulted in relatively fewer overall losses. Both these claims are consistent with a more efficient organization overall, but they are also unverifiable. Both the Portuguese and the Dutch dominated naval technology at some point in their histories supposedly because they were technologically advanced and their labor force skilled enough to achieve such feat. Even if such direct comparison could be verified, it would still not explain Portugal's increased losses between 1550 and 1650 when vessel size rose to unprecedented, and never repeated, levels.

6 Comparing Fleets

Since none of the alternatives discussed so far can convincingly explain Portugal's higher loss rates at sea, I now focus on the comparison of vessel size between the Portuguese and the Dutch empires. The objective is to evaluate whether the available historical evidence supports the argument that large and less seaworthy Portuguese vessels could have been associated with a higher loss rate.

Since there is no systematic information on vessel size for Portugal, I use the reported Portuguese losses with information on ship size in Table 3, the information on tonnage for the Dutch fleet in Table 1, and the information on tonnage for all Dutch losses in Table 5 to estimate the composition of Portugal’s fleet. Assuming identical loss rates by vessel size, the imputed Portuguese fleet is:

$$\text{Reported PT losses}_{size} \times \frac{\text{All PT losses}}{\text{Reported PT losses}} \times \frac{\text{All NL built}_{size,time}}{\text{Reported NL losses}_{size,time}} \quad (5)$$

The first term comes from Table 3, which contains eighteen Portuguese losses: ten in very large ships above 1,000 tons, six in large ships between 800 and 1,000 tons, two in medium sized ships between 500 and 800 tons, and none in small ships below 500 tons. It is implausible to assume that Portugal’s fleet had no small ships whatsoever so I impose an equal fraction on this category to that of ships built by the VOC in Table 1.²² 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 eighteen are reported by size, therefore the second term is the constant $148/18 = 8.22$. The last term combines data from Tables 1 and 5 varying with size and time period, which allows for the estimated fleet to adjust to the different needs of empire.

Table 7 shows three potential imputed fleets for Portugal according to the time period of the last term in (5). In the first column 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 defense and communication purposes in Asia. The fleet in the second column, on the contrary, uses Dutch data from the eighteenth century when the VOC’s trade was already well established. This imputed late fleet is therefore naturally geared away from small ships. The fleet in the last column uses data for the entire history of the VOC in Asia and provides a more

²²This assumption likely overestimates the number of Portugal’s small ships given the indirect evidence which seems to indicate that on average Portugal’s ships were larger than those of the Netherlands.

balanced picture of the overall shipping needs of empire. The question is now whether these estimated fleet sizes are plausible.

Table 7: Portugal's Imputed Fleet

	Based on early VOC fleet		Based on late VOC fleet		Based on overall VOC fleet	
<500t	825	58%*	64	10%*	291	34%*
500-800t	96	7%	51	8%	68	8%
800-1,000t	259	18%	153	24%	162	19%
≥1,000t	242	17%	367	58%	334	39%
Total	1,422		636		855	

*Assumed equal to the Dutch fleet's share.

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 estimations 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 the tropics. Most common in warm waters, shipworms (also known as termites of the sea) infiltrated wooden hulls creating leaks, which ultimately rendered the vessels useless. No doubt shipworm affected vessels from all empires but hull preservation techniques, such as sheathing, improved with time.²³

Second, the 478-fleet also assumes identical capital utilization across empires, but the Dutch were exceptionally efficient in reducing idle time in ports (Parthesius 2010:57). Monsoons in the Indian Ocean and difficulties rounding the Cape in the winter could force long stays at intermediate ports affecting voyage duration and vessel turnover. The Dutch average voyage lasted 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

²³Copper 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).

expected of a shorter route.²⁴ However one in every nine Portuguese vessels between 1500 and 1635 wintered in a port of call, which could stretch 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 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.²⁵ Monsoons in the Indian Ocean last five months but only two have intense rains and winds, whereas the winter on the Cape could take up to four months. If there were the two major events halting Portuguese ships in port, any idle time up to 6 months of the year would be sensible. The maximum multiplier would be 2 corresponding to a fleet no larger than 956 ships.

Shipworm and lower capital intensity both render the 478-fleet too small, but how do the imputed fleets in Table 7 fare with respect to all of Portugal's voyages and idle time of vessels in port? The 1,422-fleet is way too large for 1,930 voyages and its bloated multiplier of 2.79 corresponds to more than ten months of idle time in port, which did not happen systematically. The 636-fleet and the 855-fleet are more plausible with implicit multipliers of 1.33 and 1.79 (relative to the 478-fleet) corresponding to two and almost five months of idle vessels in port, respectively. The former may be interpreted as a lower bound corresponding to the case of vessels stopping just for the two months of intense rains in the Indian Ocean. The latter is a more credible candidate.

These fleets may still be biased towards larger vessels likely to be overrepresented in the narratives of shipwreck, as they may have counted more survivors whose recollections would get published. The share of vessels above 1,000 tons however, is not resulting from an understated fraction of small vessels, assumed equal to that of the VOC's shipbuilding.

²⁴The Dutch route took 15,000 nautical miles outbound and 13,400 inbound plus 600 miles every time the path around the British isles was taken; Portugal's route took 12,100 and 11,550 nautical miles, respectively, via the Mozambique Channel (Velho 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.

²⁵The corresponding formula is $multiplier = 1 + 2 \times \frac{months\ idle}{12}$.

Furthermore, (5) assumes identical loss rates across empires for the same tonnage class; but if Portugal's carracks were larger than the largest Dutch ships, Portugal's likelihood of loss of large vessels should have been higher. Observing many losses of Portuguese large vessels is therefore not unexpected.

In this more plausible scenario of the 855-fleet, the 39% 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 purchase and hire of small and medium vessels, the share of very large ships in the Dutch fleet would only be lower than that of its own shipbuilding 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 monarch, whose objectives involved not only trade but also glory and prestige. Royal hubris made Portugal stick to the old technology well into the seventeenth century when smaller ships became dominant. In this light, Portugal's rapid decline is hardly surprising.

7 Conclusion

Organization has profound implications in the governance of firms. In this paper I provide a simple framework where lower organizational efficiency is associated with reduced incentives to invest in technological improvements. The goal is to understand Portugal's loss of leadership to the Netherlands in the early seventeenth century context of merchant empires. I investigate the implications of the framework with respect to technological investments in the workhorses of the empire – the sailing ships.

In the Age of Discovery, Portugal used small and easy to maneuver vessels ideal for sailing in unknown waters and uncharted 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 after a certain scale, when poor maneuverability 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, especially 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 also 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 organization conducted far more voyages than Portugal at a much lower loss rate. The higher Portuguese loss rates were not associated with a more difficult sea route nor with more enemy attacks, suggesting vessel seaworthiness could have been behind the discrepancy.

Using data on reported Portuguese losses and the entire database of Dutch voyages, I estimate Portugal's fleet and find it relied more on very large ships than the VOC. Royal hubris prevented the adoption of better shipping technology by the Portuguese, which may have been a factor behind the loss of leadership of Portugal's merchant empire in the early seventeenth century.

References

- [1] Acemoglu, Daron; Simon Johnson; and James Robinson. "The Rise of Europe: Atlantic Trade, Institutional Change, and Economic Growth," *American Economic Review* 95, 3 (2005): 546-579.
- [2] Aghion, Philippe and Peter Howitt. *Endogenous Growth Theory*. Cambridge, Massachusetts: MIT Press, 1998.
- [3] Arrow, Kenneth J. "The Economic Implications of Learning-by-Doing." *Review of Economic Studies* 29, no. 1 (1962):155-173.
- [4] Barbour, Violet. "Dutch and English Merchant Shipping in the Seventeenth Century," *Economic History Review* 2, no. 2 (1930): 261-290.
- [5] Boxer, Charles R. *The Dutch Seaborne Empire 1600-1800*. New York: Alfred A. Knopf, 1965.
- [6] Boxer, Charles R. *Fidalgos in the Far East 1550-1770*. Second revised edition. Oxford: Oxford University Press, 1968.
- [7] Boxer, Charles R. *The Portuguese Seaborne Empire 1415-1825*. Second edition. New York: Alfred A. Knopf, 1975.
- [8] Brezis, Elise S., Paul Krugman and Daniel Tsidon. "Leapfrogging in International Competition: A Theory of Cycles in National Technological Leadership," *American Economic Review* 83, no. 5 (1993): 1211-1219.
- [9] Brito, Bernardo Gomes de. *The Tragic History of the Sea 1559-1565*. Translated and edited from the original Portuguese by Charles R. Boxer. Cambridge: Published by the Hakluyt Society at the University Press, 1968 [1735-6].

- [10] Brito, Bernardo Gomes de. *The Tragic History of the Sea 1589-1622*. Edited from the original Portuguese by Charles R. Boxer. Cambridge: Published by the Hakluyt Society at the University Press, 1959 [1735-6].
- [11] Bruijn, J. R., F. S. Gaastra and I. Schöffer editors, with assistance of E. S. van Eyck van Heslinga. *Dutch-Asiatic shipping in the 17th and 18th centuries. Vol. I: Introductory Volume* [1987]. *Vol. II: Outward-bound voyages from the Netherlands to Asia and the Cape (1595-1794)* and *Vol. III: Homeward-bound voyages from Asia to the Netherlands (1597-1795)*. The Hague: Martinus Nijhoff, 1979.
- [12] Burman, Jose. *Great shipwrecks off the coast of Southern Africa*. Cape Town: Struik, 1967.
- [13] Burman, Jose. *Strange shipwrecks of the southern seas*. Cape Town: Struik, c.1968.
- [14] Castro, Filipe Vieira de. *The pepper wreck: a Portuguese Indiaman at the mouth of the Tagus river*. College Station: Texas A&M University Press, c2005.
- [15] Costa, Leonor Freire. *Naus e galeões na ribeira de Lisboa: a construção naval no século XVI para a Rota do Cabo*. Cascais: Patrimonia, 1997.
- [16] De Vries, Jan. "Connecting Europe and Asia: A Quantitative Analysis of the Cape-route Trade, 1415-1795," *Global Connections and Monetary History, 1470-1800*, edited by Dennis O. Flynn, Arturo Giráldez and Richard von Glahn. Burlington, VT: Ashgate, 2003: 35-106.
- [17] Duncan, T. Bentley. "Navigation Between Portugal and Asia in the Sixteenth and Seventeenth Centuries," *Asia and the West: Encounters and Exchanges from the Age of Explorations*, edited by Edwin J. Van Kley and Cyriac K. Pullapilly. Notre Dame, IN: Cross Cultural Publications, 1986: 3-25.

- [18] Duffy, James. *Shipwreck & Empire: Being an Account of Portuguese Maritime Disasters in a Century of Decline*. Cambridge, Mass: Harvard University Press, 1955.
- [19] Falcão, Luiz de Figueiredo. 1859. *Livro em que se contém toda a fazenda real e património dos reinos de Portugal, India e das ilhas adjacentes e outras particularidades*. Lisboa: Imprensa Nacional (Orig. pub. ca. 1607).
- [20] Godinho, Vitorino Magalhães. "The Portuguese and the "Carreira da India" 1497-1810," *Ships, Sailors, and Spices: East India Companies and their Shipping in the 16th, 17th and 18th Centuries*, edited by Jaap R. Bruijn and Femme S. Gaastra. Amsterdam: NEHA, 1993: 1-43.
- [21] Graham, Gerald S. "The Ascendancy of the Sailing Ship 1850-85," *Economic History Review* 9, no. 1 (1956): 74-88.
- [22] Guinote, Paulo, Eduardo Frutuoso and António Lopes. *Naufrágios e outras perdas da "Carreira da Índia": séculos XVI e XVII*. Lisboa: Grupo de Trabalho do Ministério da Educação para as Comemorações dos Descobrimentos Portugueses, 1998.
- [23] Israel, Jonathan I. *Dutch Primacy in World Trade, 1585-1740*. Oxford: Clarendon Press, 1989.
- [24] Maddison, Angus. *Phases of Capitalist Development*. Oxford: Oxford University Press, 1982.
- [25] O'Rourke, Kevin H. and Jeffrey G. Williamson. "Did Vasco da Gama Matter to European Markets?" *Economic History Review* 62, 3 (2009): 655-84.
- [26] Parthesius, Robert. *Dutch Ships in Tropical Waters – The Development of the Dutch East India Company (VOC) Shipping Network in Asia 1595-1660*. Amsterdam: Amsterdam University Press, 2010.

- [27] Phillips, Carla Rahn. "The Caravel and the Galleon: The Galleon," *Cogs, Caravels and Galleons: The Sailing Ship 1000-1650*, edited by Robert Gardiner. London: Conway Maritime Press, 1994: 98-114.
- [28] Raleigh, Walter. *The Letters of Sir Walter Raleigh*, edited by Latham, Agnes and Joyce Youngs. Exeter: University of Exeter Press, 1999.
- [29] Rei, Claudia. "The Organization of Eastern Merchant Empires," *Explorations in Economic History* 48, no. 1 (2011): 116-135.
- [30] Rei, Claudia. "Incentives in Merchant Empires: Portuguese and Dutch Labor Compensation," *Econometrica* 7, no. 1 (2013): 1-13.
- [31] Scammell, G. V. "European Shipowning in the Estado da India, 1500-1700," *Indica* 26, (1989): 119-134.
- [32] Solis, Duarte Gomes. *Alegación en favor de la Compañía de la India Oriental comercios ultramarinos, que de nuevo se instituyó en el reyno de Portugal*. Edição organizada e prefaciada por Moses Bensabat Amzalak. Lisboa, [Editorial Impériol] 1955.
- [33] Steensgaard, Niels. "Freight Costs in the English East India Trade 1601-1657." *Scandinavian Economic History Review*, 13, no. 2 (1965): 143-62.
- [34] Steensgaard, Niels. *The Asian Trade Revolution of the Seventeenth Century – The East India Companies and the decline of the Caravan Trade*. Chicago: The University of Chicago Press, 1974.
- [35] Unger, Richard W. *Dutch Shipbuilding Before 1800*. Amsterdam, Assen: Van Gorcum, 1978.
- [36] Velho, Alvaro. *A Journal of the First Voyage of Vasco da Gama, 1497-1499*. Translated and edited with notes, an introduction and appendices, by E.G. Ravenstein. London: Printed for the Hakluyt Society, 1898.