TURNING POINTS IN LEADERSHIP: SHIPPING TECHNOLOGY IN THE PORTUGUESE AND DUTCH MERCHANT EMPIRES

by

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Working Paper No. 11-W23

November 2011

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

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October 26, 2011

Abstract

This paper focuses on the implications of organizational control on the race for economic leadership across merchant empires. Poor organizational choices reduce incentives to invest, which in turn stifle technological improvements and make leading empires lag behind new entrants. Using historical evidence on shipping technology, I show that this may have been a factor behind the loss of leadership of the Portuguese merchant empire in the late sixteenth century.

1 Introduction

Economic progress has often been associated with technological advancement. The age of merchant empires was perhaps the time when this relationship was more visible as decisive

*I thank Bob Margo and Andy Newman for early stage discussions and Jeremy Atack and Bill Collins for detailed suggestions on previous drafts. I also thank Jan de Vries, the participants at the annual meetings of the Economic History Association in Boston, and the participants of the Frontier Research in Economic and Social History meeting in Saint Pierre d'Entremont for helpful comments.

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 which allowed for success in the fifteenth century discoveries and the subsequent establishment of the first European merchant empire in the East. By 1600 however, Portugal lost its dominance to the Netherlands who became the major shipbuilder in Europe at the time. 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, such position belonged to private merchants who managed long-distance trade according to their own interest.[1] The control structure is no mere label and manifests throughout the firm: first, merchants are more willing to invest in a firm they do control; second, business decisions are more likely to follow a standard market approach when merchants are in charge. Merchant control implies, 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 remarkable 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 by the Netherlands (the entrant), I argue, because of organizational control. If shipping technology decisions in Portugal were subject to the whims of the monarch and did not follow a standard business perspective, then we should be able to observe slower adoption of better ships in higher wreckage rates, all else the same. This pattern seems to emerge from the historical

[1] For a model on the choice and implications of organizational control in merchant empires see Rei 2011.

evidence gathered for the Portuguese and Dutch merchant empires.

Guided by this framework, I have gathered evidence on shipping to understand the loss of technological leadership of the Portuguese merchant empire. Initially, Portugal used small and easily maneuverable ships, but the increased volume of trade gave place to large cargo vessels in the late sixteenth century. Though carrying more merchandise, larger ships were less sailable and therefore more likely to perish in stormy waters, as confirmed by higher loss rates from 1580 to 1607. In the seventeenth century, smaller and more efficient Dutch ships, ideal for long-distance cargo transportation, were used throughout Europe but not by Portugal. Moreover, narrative evidence describes Portuguese shipwrecks of large vessels well into the mid seventeenth century, when smaller and more navigable Dutch ships were sold all over Europe.

The slower adoption of technological improvements, in terms of ship size and design, was associated with the less efficient organizational form, at a time when the Portuguese eastern empire plunged together with its large ships.

2 The History of the Sailing Ship (1400-1800)

The sailing ship went through dramatic changes according to the navigation needs of each time period. Prior to the age of discovery rowed galleys – oared ships combined with sails – were commonly used in the Mediterranean to transport merchandise and crusaders. In Northern Europe the Baltic, Hanseatic, and Scandinavian trades were conducted in single-masted cogs, which could also be rowed for short distances. These medieval ships were modest in size, except for the great war galleys whose construction tested the limits of contemporary design, reaching length to beam ratios of 8:1 and 25 to 30 benches on each side with three men per bench (Unger 1980:180).

In the fifteenth century discoveries, open sea navigation required smaller but sturdier ships. Travelling greater distances created an incentive for a better usage of wind power, which allowed for reduced crews with the elimination of oarsmen. The Portuguese mastered the construction of the caravel: a light 2 or 3 mast ship of 18 to 60 tons and approximately 5:1 length-to-beam ratio. This highly maneuverable vessel with lateen sails was adequate for sailing into the wind, and was especially useful in unknown waters or wind systems – for example, when chartering the coasts of Africa and the Americas (Elbl 1994).

The establishment of direct trade between Europe and Asia after 1498, rose the demand for larger cargo carriers. Ships grew very much in size to take advantage of economies of scale in long-distance transportation. By the 1580s Portugal was using galleons and carracks of 3 or 4 masts with trapezoidal spritsails and 3.5:1 length-to-beam ratio, averaging over 1,000 tons, some reaching 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).

In the seventeenth century the Dutch-built *fluit* became the most successful cargo ship of the time, its measures holding constant until ca. 1800 when technical change and greater trade volume made larger sailing vessels feasible (Unger 1994).[2] The *fluit* resulted from two centuries of modifications and experiments with sails and hull construction techniques. With a size between 200 and 500 tons and a 5-6:1 length-to-beam ratio, these vessels had more efficient rigging over 2 or 3 short masts with easier to handle "gaff sails" that allowed for better maneuverability while reducing the crew. On the one hand, the long but shallow hull and round (not square) stern, gave the *fluit* larger cargo capacity than contemporary ships of similar size. On the other, the small bulk above the water line –no forecastle or roundhouse, and few or no guns– reduced the wind resistance and improved sailing quality, but constrained these more vulnerable ships to safer routes or to sail in convoys.

So successful was the *fluit*, that Holland 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).

[2] Only in the nineteenth century did British and American iron hull clippers – reaching as much as 2,000 tons – emerge on the eve of the steam age (Graham 1956).

The next section provides an explanation for the technological sequence described above in order to better understand why Portugal lagged behind the Netherlands in the leadership of merchant empires.

3 A Simple Framework of Technology Adoption

Consider a firm in the long-distance trade market getting profit π_0 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 the firm is likely to invest. The deterring effect of high π_0 is 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).

Firms operate in the same long-distance market, but their business strategies may differ according to the party in control – king or merchants – who organizes business according to its objective function.[3] Each firm is associated with an efficiency level $\varphi \in (0, 1]$, which affects the returns of investment decisions so (1) becomes

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

The more efficient the organization ($\varphi \longrightarrow 1$), the less distorted the original investment decision problem in equation (1), and the more likely the technological investments. If all firms have access to the same technological options, i. e. if π_1, π_0 and z are equal across

[3] In the context of the current paper, the choice of organization is therefore exogenous.

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.[4]

Suppose now that the incumbent exploring τ_0 exhibits a low efficiency organizational form characterized by $\varphi_L \in (0, 1]$. The new player enters the market with an improved technology τ_1 and a high efficiency organizational form $\varphi_H > \varphi_L$. If the replacement effect is large enough the incumbent will not adopt τ_1, so the two firms share the market while exploring different technologies, with $\frac{\varphi_L \pi_0}{\varphi_L + \varphi_H}$ 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

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

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

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 this case we will have the entrant investing while the incumbent sticks to the old technology even if losing market share.

This simple framework explains why Portugal, despite its less efficient organizational form, was initially able to invest in improvements of the sailing ship that allowed for a period of economic leadership. Once more efficiently organized 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. In a time when technological innovations were available throughout Europe the delayed adoption by the Portuguese may indicate yet another impact of organization on economic performance.

[4] For an example in monitoring, see Rei 2012.

4 Shipping Decisions in Merchant Empires

A successful round-trip voyage to the East depended not only on the knowledge of wind and current systems of the Atlantic and Indian oceans, but also on the ship herself. Even in the absence of pirates in the high seas, these were dangerous ventures: storms, disease, and accidents played a role not only on the survival of the crew, but also on the success of the venture. Assuming that pirates, bad weather, disease and other accidents affected all voyages equally along the Cape route, then the success of the venture depended crucially on the type of ship used in the voyage. The aim of this section is to evaluate the Portuguese and Dutch shipping decisions in the light of the organization argument presented above.

4.1 The Portuguese case

In 1498 Vasco Da Gama completed the first round-trip to India, setting off direct trade between Europe and the East via the Cape Route with the goal of undercutting the high prices of spices arriving in Europe via the Levant. This feat came after a century of maritime voyages, in which the Portuguese explored the West African coast, adding to the geographical and sailing knowledge of the time. Unknown ports in uncharted coasts needed small and swift vessels, handy to maneuver under sudden and unexpected weather changes or enemy attacks. However, the stormy waters of the South Atlantic required sturdy ships to brave the sea currents.[5]

As the Portuguese became more experienced in the Cape Route and as new trade agreements with local Indian sovereigns were secured, the small ships were replaced by larger *naus* (or carracks) and galleons. The *nau* was a large merchant ship, broad at the beam and lightly gunned, whereas the galleon was primarily a war vessel, lighter and with heavier guns.[6] However, the empire was not far advanced before galleons were frequently pressed to

[5]Before naming the Cape of Good Hope in 1487, when it was rounded successfully for the first time, the Portuguese called it *Cabo das Tormentas* – which translates into Cape of Torments – due to the severe hardships endured in several failed attempts to cross such stormy waters.

[6]For a detailed discussion of the differences between *naus* and galleons see Boxer (1968: 12-15).

service as cargo ships (Duffy 1955:50).

The first attempts to introduce ships larger than 500 tons in the Cape Route dates from the 1520s. By the 1550s, large galleons of 900-1,000 tons started being used, 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 overloaded[7] – proved less seaworthy than ships of smaller tonnage. Accordingly, in 1570 the monarch passed a law requiring all *naus* to be sent on the Cape Route to be between 300 and 450 tons. Under Spanish rule (1580-1640) however, the 1570 law was relaxed and it became practice every year to build two or three *naus* over 1,000 tons each (Boxer 1968:13). In 1588 upon royal initiative, Lisbon witnessed the construction of large galleons of 700-900 tons.[8] The royal involvement on Eastern trade as the main merchant and armor led to a clear specialization of the Lisbon yards (relative to other Portuguese shipyards) in the construction of large vessels, and depending directly on the administration of the Guinea and India warehouses in Lisbon (Costa 1997).

The frequent mixing of roles of the monarch as owner, shipman, or merchant, made construction for sale or rent the exception to the rule: vessels were generally pre-ordered for specific voyages (Costa 1997). In a context of expanding empire, Lisbon's shipbuilding was a fast growing industry in which the demand for ships far exceeded supply. The conditions of haste in which shipwrights worked, as well as the owner's cargo specifications, allowed for little change in ship design. As the English, French and Dutch introduced changes which improved stability and seaworthiness, Portugal kept building larger and less maneuverable vessels (Duffy 1955:51).

[7] As the king's pepper took up most of the storage space, all else was stored in every possible corner, "sometimes hanging outside the hull suported by ropes" (Castro 2005:18). Also, contributing to the overloading of ships were the *caixas de liberdade* – liberty chests – seamen were tolerated to bring as the crown frequently defaulted on the payment of salaries. The narratives of shipwrecks are abundant in the descriptions of storms and how the crew was compelled to throw some cargo at sea in order to stabilize the large ships (Brito 1959).

[8] The timing coincides with the venture of the Spanish Armada, in which the Spanish – and at the time, also Portuguese – king was heavily involved. It is therefore not surprising that the crown intervened in the construction of large war ships.

Naus for the India trade were also built in the East at Goa, Daman and Cochin, where there was access to better wood, which increased the life span of the vessels. Though more seaworthy, these were even larger vessels than the ones produced at home, such as the Cochin-built *Santa Cruz* of 1,600 tons, which sailed to Lisbon in 1589 after serving in the Japan trade (Boxer 1968:15).

Ship size caused, at least initially, great impression. In the literature these are often mentioned as the "largest ships afloat then," as well as distinctive features of Portuguese naval architecture, which, as no other nation, built such "mountains of wood" (Boxer 1968:14). Later on, however, the disparity of ship sizes across nations became very apparent. At a particular naval engagement the English, with extremely fast ships, are said to have looked at the Portuguese *naus* with contempt "instead of fearing them because of their great size" (Faria e Sousa 1945:195).

The deliberate increase in vessel size proved disastrous for safety with an alarming rise in the shipwreck rate. Such was the state of affairs that in 1622-35, a group of experienced Portuguese officers tried to persuade the crown to bring back the 1570 tonnage law, but it met only partial success. Galleons which previously rarely surpassed 600 tons would now be built up to 1,200 such as the *Santa Tereza* destroyed in a battle against the Dutch in 1639 (Boxer 1968:13).

Table 1: Ships on the Cape Route 1497-1612

	1497-1579		1580-1612		1497-1612	
	#	%	#	%	#	%
Sent	620	100.0	186	100.0	806	100.0
Returned	325	52.4	100	53.7	425	52.7
Aborted voyage	6	1.0	14	7.5	20	2.5
Lost	31	5.0	35	18.8	66	8.2
Taken by enemies	0	0.0	4	2.2	4	.5
Burned	2	.3	4	2.2	6	.7
Stayed in the East	256	41.3	29	15.6	285	35.4

Source: Falcão (1859) lists the absolute numbers.

Falcão (1859) presents a detailed list of all ships that sailed out of Lisbon to the East from 1497 to 1612, as well as whether the ships returned to Lisbon or were lost at sea. Table 1 summarizes this information in two periods 1497-1579 and 1580-1612, after the take over of the Portuguese Crown by the Spanish king.

Out of 806 ships sent to the East over the complete period, 425 returned safely, a return rate of 52.7%. Of the ships that did not return to Lisbon after completing the round trip voyage, 35.4% stayed in the East for defense purposes. Summing the two rates, we get 88.1% of success voyages. Out of the 11.9% ships that ended in failed voyages, 2.5% returned after aborting the voyage, 8.2% were lost in shipwreck, 0.5% were taken by enemies, and 0.7% were voluntarily burned.

The return rate did not change much from the first period to the second, but all other components suffered significant variations. Understandably, the percentage of ships that stayed in the East got reduced from 1580 to 1612: the already well established empire needed just a few ships to remain in the East in order to replace the existent ones. The rise in the percentage of ships taken by enemies also makes sense: Portugal certainly faced rivals in the seas before 1580, but afterwards Portugal "adopted" a whole new set of enemies that opposed Spain – notably the English and the Dutch – who then took control of the Portuguese empire in the East.

The most striking rise in the percentage of failed voyages is that of shipwrecks: before 1580 one in every twenty ships was lost, whereas after 1580 one in every five suffered that same fate. Assuming Portuguese navigation malpractices – delayed departures, ship overcrowding and overloading – remained unchanged throughout the period, then the increase in ship size seems to be the only other factor capable of raising the loss rate.

Guinote, Frutuoso and Lopes (1998), provide a detailed study on Portugal's losses on the Cape Route from 1497 to 1650. Table 2 summarizes the causes of such losses by period.

Table 2: Cape Route's Losses by Cause 1497-1650

	Poor navigation	Storm	Ship decay	Overload	Attack	Fire	Unknown	TOTAL
1497-1550	16 *20%*	12 *15%*	2,5 *3,1%*	0,5 *0,6%*	2 *2,5%*	5 *6,3%*	42 *52,5%*	80
1551-1600	10 *15,4%*	6,5 *10%*	9,5 *14,6%*	11,5 *17,7%*	5,5 *8,5%*	4 *6,1%*	18 *27,7%*	65
1601-1650	9 *12,2%*	9,5 *12,8%*	10 *13,5%*	0 *0%*	15,5 *21%*	6 *8,1%*	24 *32,4%*	74
1497-1650	35 *16%*	28 *12,8%*	22 *10%*	12 *5,5%*	23 *10,5%*	15 *6,8%*	84 *38,4%*	219

Source: Guinote, Frutuoso and Lopes (1998:116)

According to the authors, it is not surprising that the overall dominant cause of loss remains unknown: the nature of the phenomenon has in fact to do, in many cases, with the complete disappearance of ships without survivors. Throughout the 1497-1650 period, poor navigation was the chief of the known causes with 16%. Breaking the analysis by periods, however, we see an increase in the percentage of losses by ship decay and overload, which together account for 32,3% of the losses from 1551 to 1600, the period corresponding to the usage of larger ships.

Increased size in the second period, may also have increased the vulnerability of the vessels under storm, however we observe a decrease in these losses from 15 to 10%. It can be argued that the period of 1497-1550 was one of learning about the navigation on the Cape Route and therefore the probability of braving a storm would be lower. On the other hand, ship size may also have increased the difficulties of swift maneuvering under enemy attack, and there was an increase in losses due to attacks in the overall period. This increase however, cannot be solely attributed to ship size, as the Portuguese vessels were subject to more attacks from 1580 to 1640 when Portugal lost its independence to Spain. Though exhaustive on the loss causes, the Guinote *et al* study does not associate tonnage with each lost vessel, which significantly hampers the analysis.

Table 3: Shipwrecks in the Cape Route 1552-1686

Name	Date	Size/type	Trip	Attacked	Overloaded	Passengers
São João[c] [d] [e]	1552	900	inbound	no	yes	25 of >600
São Bento[b] [d] [e]	1554	900	inbound	no	yes	20 survived
Garça[a] [d]	1559	1,000	inbound	no	yes	all safe
Aguia[a] [d] [e]	1559	carrack	inbound	no	yes	1037 safe
São Paulo[a] [d] [e]	1561	carrack	outbound	no	no	330 of 400
Santiago[c] [d] [e]	1585	900	outbound	no	no	few survived
São Thomé[a] [d] [e]	1589	carrack	inbound	no	?	200 survived
Santo Alberto[a] [d] [e]	1593	carrack	inbound	no	yes	few losses
Nossa Senhora dos Mártires[c] [e]	1606	600	inbound	no	?	>200 died
Santo Espiritu[c] [e]	1609	?	inbound	no	?	?
Nossa Senhora da Luz[c] [e]	1615	?	inbound	no	?	200 died
São João Baptista[a] [d] [e]	1622	carrack	inbound	yes	yes	28 of ???
São Gonçalo[b] [c] [e]	1630	large	inbound	no	yes	130 of >500
Santa Catarina de Ribamar[c] [e]	1636	?	inbound	no	?	few survived
Santa Maria da Madre de Deus[c]	1643	?	inbound	?	?	?
Santissimo Sacramento[c] [d]	1647	large	inbound	no	?	very few
Nossa Senhora da Atalaia[c] [d] [e]	1647	18 guns	inbound	no	?	very few
Nossa Senhora dos Milagros[b]	1686	30 guns	inbound	no	yes	32 of >200

Sources: [a] Brito (1959, 1968), [b] Burman (1967, 1968), [c] Castro (2005), [d] Duffy (1955), [e] Guinote Frutuoso and Lopes (1998).

I now turn to the narratives of Portuguese shipwrecks in the Cape Route available in a few sources, notably Brito's *Tragic History of the Sea*, first published in 1735-6. Some of these wrecks have been the object of study of naval archeologists, interested in determining the characteristics of the Portuguese ships sent to the East. Table 3 summarizes what is known about these shipwrecks.

Out of eighteen wrecks reported in Table 3, only five are referred by tonnage, four being above 900 tons. Of the thirteen remaining vessels there are five carracks (*Águia*, *São Paulo*, *São Thomé*, *Santo Alberto*, and *São João Baptista*), two (*São Gonçalo*, and *Santissimo Sacramento*) are referred to be large vessels, and one (*Nossa Senhora dos Milagros*) to have 30 gun cannons on board. These eight vessels seem therefore to be comparable to those whose large tonnage is explicitly mentioned. Finally, there is a ship (*Nossa Senhora da Atalaia*) of 18 guns, which could possibly be of medium size.

There are four ships (*Santo Espiritu*, *Nossa Senhora da Luz*, *Santa Catarina de Ribamar*, and *Santa Maria da Madre de Deus*) for which the narratives are imprecise with respect to the size of the vessel. In total, twelve out of eighteen wrecks occurred in large vessels, which seem to have been in use even later in the period. This tendency indicates a delayed adoption of better and smaller ships by the Portuguese.

4.2 The Dutch Case

As a country whose land was partially conquered to the sea, it is not surprising that the Netherlands have a long tradition of shipbuilding in both vessels suited for rivers and canals, but also seagoing vessels. Through the fourteenth century, ship construction proliferated on Dutch shores and river estuaries, but by the fifteenth century construction of new ships concentrated in towns, where it was easier to gather the necessary investment capital (Unger 1978:2). Ad hoc construction continued to exist mainly for personal use, whereas towns specialized in the construction of vessels for sale.

The Dutch experience in the transportation of bulk goods around Europe certainly facilitated the development of the shipping industry. Until 1585, when it fell under Spanish control, Antwerp remained the distribution center of foreign goods – including the Far Eastern spices brought by the Portuguese – in Northern Europe, but the ships carrying merchandise were Dutch. From 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). After 1550, a series of new technically superior designs for 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 the specific required jobs at hand.

As a result of the Dutch specialization in naval construction, shipbuilding in Holland was cheaper than in England by a third or a half. The Amsterdam shipping industry was so developed that it became independent from Dutch merchant interests, and people with no seafaring or trading experience would invest their savings in shipping shares (Barbour 1930:275-8). The pervasiveness of Dutch ships all over Europe, is consistent with the conclusion that these technologically advanced ships were generally available to all countries and not just the Netherlands. Though Dutch shipbuilding is difficult to estimate, exports probably never equalled domestic consumption and production for foreign buyers may have been as much as 50% of total output (Unger 1978:11).

Table 4: Composition of the VOC fleet in Asia in 1660

Type	**Number**
Undefined vessels	171
Prefabricated vessels	45
Miscellaneous vessels	142
Small yachts	202
Small to middle sized *fluits*	23
Middle sized yachts	141
Big *fluits*	75
Big yachts	62
Ships	102
Big men-of-war	31
Homeward-bounders	61

Source: Parthesius (2010:65).

Founded in 1602, the Dutch East India Company's (*Verenigde Oost-Indische Compagnie*, henceforth VOC) partly purchased ships in private shipyards and partly built its own. Once the shipyards became well established around the mid-seventeenth century, own shipbuilding was continuous. Yet, capacity must have been insufficient as outside purchases (especially *fluits*) continued throughout the century. Table 4 shows the composition of the VOC fleet in Asia in 1660 in ascending order of size.

The company's fleet was composed by a variety of square stern and round-backed ships. Among the first, the most common were the homeward-bounders solely used as carriers of cargo and passengers in the Cape route. These were the largest vessels of the VOC but never reached the sizes of carracks, as no other empire followed the Portuguese in the operation of such giant ships (De Vries 2003). Though carrying guns, these ships had greater hulls (i.e. cargo capacity) than the more heavily armed warships, which could also be used as cargo carriers of less capacity.

Beyond war and the transportation of merchandise through the Cape route, the VOC (as well as all other empires) had other types of ships in use according to the multiple navigation needs of the company in the Indian Ocean, for example local transportation or intra-Asian trade. In the early seventeenth century vessels were indiscriminately called *ships* with no differentiation of type and the difference between these and yachts, the multi-purpose vessels that varied much in size, was unclear. The categories of prefabricated and miscellaneous vessels would include small vessels loaded onto larger ships to be assembled en route and then sail independently according to necessity, as well as small vessels mostly used for local transport or roadsteads (Parthesius 2010:71-86).

Among the round-backed ships, the *fluits* played a permanent role in the company's fleet together with the larger homeward-bounders. 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, the bigger *fluits* were at times preferred to the regular homeward-bounders for the return trip to Europe. Until 1630, most *fluits* were still purchased from private shipbuilders, but in the long run the Company built its own adapting the vessel to the specific needs of the Asian routes.

Table 5: Ships Built in VOC Shipyards

	<500t	500-800t	800-1,000t	>1,000t	TOTAL
1600-49	182	68	14	14	278
	66%	*24%*	*5%*	*5%*	
1650-99	230	131	29	39	428
	54%	*31%*	*6%*	*9%*	
1600-99	412	199	42	53	706
	58%	*28%*	*6%*	*8%*	

Source: Bruijn, Gaastra, Schöffer (1987:52).

Table 5 shows the sizes of the ships built in the Company's shipyards in the seventeenth century. Though the share of large ships of 800 tons or more rises from the first (10%) to the second half of the seventeenth century (14%), the overwhelming majority of vessels built in the company's yards have smaller tonnage – 86% throughout the period. This value is likely to be understated, given the purchase of ships to private shipyards, mostly *fluits* and other smaller vessels. I now turn to Table 6 to investigate the losses in VOC voyages throughout the same century.

Table 6: Losses of Ships in the VOC voyages

	Wrecked		Captured		% Total Voyages	
	outbound	inbound	outbound	inbound	outbound	inbound
1600-49	18	11	2	2	2.7%	3.5%
1650-99	23	23	12	7	3.2%	4.5%
1600-99	41	34	14	9	3.0%	4.2%

Source: Bruijn, Gaastra, Schöffer (1987:75, 91).
Notes: 715 (368) outbound (inbound) voyages from until 1649 and 1,107 (662) after.

The percentage of losses due to wreckage or capture rises from the first to the second half of the century for both out- and inbound voyages, however, the increase is rather small (0.5% in outbound voyages, and 1% inbound). Overall losses throughout the period vary between 3 and 4.2%, a much lower number than that verified for Portuguese ships (results in Table 1 – 8.2% in the period 1497-1612, 5% in 1497-1580, and 18.8% in 1580-1612). Handling a larger volume of trade, the Dutch conducted more voyages with a much lower loss rate.

Granted the Portuguese had a period of adaptation and learning to the Cape route that may have increased the loss rate, but so did the Dutch: ships could be seen (and copied) in ports throughout Europe, but navigation knowledge was treated with most secrecy, which could be effective up to a certain extent. Moreover, the Dutch specialized in a slightly different route in the Indian Ocean, given the VOC headquarters were located in Batavia (now Jakarta) and therefore the Dutch also faced some learning process of their own. The smaller loss rates of the Dutch relative to the Portuguese seem therefore associated with vessel seaworthiness and not so much with the learning cost associated with the sea routes.

5 Conclusion

Organization has profound implications in the governance of firms. I provide a simple framework that links technological decisions and organizational form and shows that less efficient organizations are associated with reduced incentives to invest in technological research and development.

I use this framework in the context of merchant empires in order to understand Portugal's loss of leadership to the Netherlands in the late sixteenth century. I investigate the implications of the framework with respect to technological investments in the workhorses of the empire – the sailing ships.

Portuguese ships grew in size in the second half of the sixteenth century. Larger vessels were able to accommodate the increased volume of trade, but these ships were less maneuverable and therefore less seaworthy as they were more likely to perish in the event of storms or attacks. As a result of the Portuguese large ship policy, shipwrecks increased and losses of men and cargo soared. By the end of sixteenth century, shortly before they entered Eastern trade, the Dutch specialized in the construction of smaller but more seaworthy vessels that, were used not only in the Dutch empire, but also by the remaining European merchant empires of England, France, Denmark, and Sweden. The delayed adoption of more efficient ships by the Portuguese may, therefore, have been a factor behind the loss of leadership of the Portuguese merchant empire in the late sixteenth 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(1):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. *Fidalgos in the Far East 1550-1770.* Second revised edition. Oxford: Oxford University Press, 1968.

[6] 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.

[7] 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].

[8] 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].

[9] 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.

[10] Burman, Jose. *Great shipwrecks off the coast of Southern Africa*. Cape Town: Struik, 1967.

[11] Burman, Jose. *Strange shipwrecks of the southern seas*. Cape Town: Struik, c.1968.

[12] 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.

[13] Costa, Leonor Freire. *Naus e galeões na ribeira de Lisboa: a construção naval no século XVI para a Rota do Cabo*. Cascais: Patrimonia, 1997.

[14] 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.

[15] Duffy, James. *Shipwreck & Empire: Being an Account of Portuguese Maritime Disasters in a Century of Decline*. Cambridge, Mass: Harvard University Press, 1955.

[16] Elbl, Martin. "The Caravel and the Galleon: The Caravel," *Cogs, Caravels and Galleons: The Sailing Ship 1000-1650*, edited by Robert Gardiner. London: Conway Maritime Press, 1994: 91-98.

[17] Falcão, Luiz de Figueiredo. *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, 1859 [1607].

[18] Faria e Sousa, Manuel de. *Ásia Portuguesa*, vol. III. Porto: Livraria Civilização, 1945 [1666-75].

[19] Graham, Gerald S. "The Ascendancy of the Sailing Ship 1850-85," *Economic History Review* 9, no. 1 (1956): 74-88.

[20] 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.

[21] Israel, Jonathan I. *Dutch Primacy in World Trade, 1585-1740.* Oxford: Clarendon Press, 1989.

[22] Maddison, Angus. *Phases of Capitalist Development.* Oxford: Oxford University Press, 1982.

[23] Parthesius, Robert. *Dutch Ships in Tropical Waters – The Development of the Dutch East India Company (VOC) Shipping Netwrok in Asia 1595-1660.* Amsterdam: Amsterdam University Press, 2010.

[24] 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.

[25] Rei, Claudia. "The Organization of Eastern Merchant Empires," *Explorations in Economic History* 48, no. 1 (2011): 116-135.

[26] Rei, Claudia. "Incentices in Merchant Empires: Portuguese and Dutch Compensation Schemes," forthcoming in *Cliometrica* (2012).

[27] Reinganum, Jennifer F. "Uncertain Innovation and the Persistence of Monopoly," *American Economic Review* 73, no. 4 (1983): 741-748.

[28] Sanceau, Elaine. *Good Hope: The Voyage of Vasco Da Gama.* Lisboa: Academia Internacional da Cultura Portuguesa, 1967.

[29] Steensgaard, Neils. "European Shipping to Asia 1497-1700." *Scandinavian Economic History Review*, 18, no. 1 (1970): 1-11.

[30] Unger, Richard W. *Dutch Shipbuilding Before 1800.* Amsterdam, Assen: Van Gorcum, 1978.

[31] Unger, Richard W. *The Ship in the Medieval Economy 600-1600.* Montréal: McGill-Queen's University Press, 1980.

[32] Unger, Richard W. "The Fluit: Specialist Cargo Vessels 1500 to 1650," *Cogs, Caravels and Galleons: The Sailing Ship 1000-1650*, edited by Robert Gardiner. London: Conway Maritime Press, 1994: 115-130.