Productivity Gains and Technological Change. Venetian Naval Architecture at the End of the Middle Ages

Jean Claude Hocquet
Université Charles De Gaulle,
Lille

Numerous types of vessel plied the Mediterranean, although they are not always easy to categorise. Some historians classify a number of these ships as long vessels, like the sailing and rowing galley. Others place these same vessels in the category of large merchant sailing ships. There is current agreement about the nautical capacities of the galley, the lateen sail's ability to sail against the wind, the northern origins of the cog or *kogge,* known as the *cocca* in the Mediterranean where it was introduced together with the stern-post rudder, with the abandonment of the so-called «clinker-built technique», and those innovations which led to the invention of the caravelle. We have also to consider the discoveries made by historians during the last thirty or forty years: our knowledge of technological aspects, building techniques, masts, rigging, sails and tonnage has increased significantly but there are still several blind spots.

Leaving aside two very stable types of vessel which continued to be regularly employed beyond the Middle Ages, namely the merchant galley and the *nef,* all the other types of sea-going vessel had a brief existence: in the period after 1310 the *taride* soon became obsolete, while the cog, which had flourished for three-quarters of a century, was most definitely out of use by the 1390s. The *panfile* lasted for only 40 years, the *ligno* gave way to the *navilio* and it was only towards the end of the fourteenth century and in the fifteenth century that new, and seemingly more durable, types of vessels appeared, as if ship building, navigation and nautical arts had at last found a more solid

basis after the long period of trial and error from the twelfth to the fourteenth centuries.

These new kinds of vessels have not all been accurately identified, quite the contrary. Even vessels whose names remained unchanged, as an indication of their apparent longevity, underwent significant changes which enabled them to survive: the *nef,* for example, only survived by borrowing from the innovations introduced into the Mediterranean with the advent of the cog, and the *taride* disappeared because it merged into the category of *nefs.*

In Venice, ever since the Middle Ages, the merchant class had always found technical solutions to the problems of transporting particular kinds of merchandise. The *marano* at first specialised in transporting stone from Istria which was used in the building trade for embellishing palaces and in the construction of powerful stone dams that protected the coast from future sea erosion. The *marciliana* was employed everywhere for coastal trade along the Adriatic and for journeys to and from the Apulian ports where Venice picked up the oil it needed for food consumption, soap manufacture and exporting abroad. The old *taride* was abandoned and modified by adding supplementary decks, thereby converting it into a *nef* which was a taller vessel. This happened as a result of a grain shortage when Venice could no longer procure its grain supplies from the countryside and was forced to import grain from Rumania. When the grain shortage was over, the owners of these powerful *nefs* were encouraged to load salt in the hold and to ship it to the city warehouses[1]. When the expansion of Cretan and Peloponnesian viticulture brought quality products onto the international market, the Venetian navy used new methods of calculation and replaced the old way of measuring dry goods by

[1] J.C. Hocquet, *Le sel et la fortune de Venise*, vol. 1, *Production et monopole*, second revised and enlarged edition, Lille 1982, p. 360, vol. 2, *Voiliers et commerce en Méditerranée 1200-1650*, Lille, 1979, p. 739, and J. Heers, «Types de navires et spécialisation des trafics en Méditerranée à la fin du Moyen Age», in *Le navire et l'économie maritime du Moyen Age au XVIIIe siècle, principalement en Méditerranée*, M. Mollat ed., Paris, 1958, pp. 107-118.

a new system measured in Candie tuns. In order to place these tuns flat, and probably in alternate rows between decks, changes had to be introduced in the design of the ship to heighten the space between the main deck and the upper deck so that at least two tuns could be placed on top of one another.

Nonetheless, it is impossible to have a precise description of the hold and cargo space. In the fifteenth century, travellers — especially those who undertook the long pilgrimage to the Holy Land — left accounts of the journey which provide us with a mine of information about ports of call, the behaviour of the crew, the uncomfortable sleeping arrangments and the poor food, the incompetence of the pilot and the greed of the captain, but much less information regarding the design of ships. Not being seamen, travellers would have been very careful about describing exactly what they saw. The transport of passengers, however, required special facilities. In 1227 the maritime laws of Doge Pietro Ziani authorised the owners of *nefs* to convert a portion of available space into cabins if the pilgrims who had hired the ship paid for two-thirds of the total freight [2]. Among the pilgrims able to pay the cost of passage to the Holy Land there were many distinguished passengers accompanied by their servants. In return for the payment of two-thirds the freight cost and on account of their status, these passengers were given more spacious accommodation in a cabin that was especially provided for the occasion. The *nefs* were more suitable for transporting goods than passengers and the merchants who continued to accompany their cargoes had much less comfortable accommodation.

One type of vessel in particular played such an important role in Venice's ascendency that the city's maritime trade has long been associated with this type of ship and with the precious merchandise it carried: namely, the galley and its cargoes of spices, silks, brocades, gold and silver pieces. On the other hand, we are now more certain

[2] U. Tucci, «I servizi marittimi veneziani per il pellegrinaggio in Terrasanta nel Medioevo» in *Studi Veneziani*, n.s. IX (1985), p. 44, «Si autem navi aliqua naulizata fuerit peregrinis, sic quod persolvant duas partes nauli navis, tunc liceat patronibus in suis navibus faciendi camerellas».

that Venice's supposed decline was at first a transformation that enabled the Serenissima to stop importations of foodstuffs, notably cereals and salt, and raw materials, owing to the agricultural and industrial development of its countryside and of certain sectors of the Stato da Mar. As a result, Venice could dispense with the long-distance large tonnage vessels which up till then had been used in the conveyance of such commodities. Foreign trade was replaced by short-distance domestic trade for which smaller tonnage vessels were more suited [3].

It is not easy to describe exactly how new types of trade led to technological change, to ships being adapted according to the commodities they carried and the trade routes they were employed on [4]. Among the factors which influenced Venetian naval architecture we can pick out and link up various factors, namely:

1. In the period of sailing ships, natural constraints to navigation were, of course, crucial factors, starting with the force and direction of the main winds and currents. Being a lagoon port, Venice imposed its own specific constraints upon navigation in the lagoon which gave its ships their own particular characteristics.

2. To obviate the geographical constraints, Venice continued to use an ancient type of vessel which it modified considerably. By using triremes for the conveyance of precious commodities, the circulation of capital was speeded up. This was an important factor since the purchase of precious goods required large amounts of capital, and the

[3] J.C. Hocquet, «La gente di mare, squeri e unita mercantili, l'armamento privato» in Storia di Venezia vol. XII, *Il mare,* edited by A. Tenenti and U. Tucci, Edizione dell'Enciclopedia italiana, Rome, 1992, pp. 313-526.

[4] There is very little literature on the naval architecture of Venetian vessels and writers have mostly dealt with the size of ships: R.C. Anderson, «Italian Naval Architecture about 1450» in *The Mariner's Mirror. The Journal of the Society for Nautical Research,* London, XI (1925), R. Bastard du Péré, «Navires mediterranéens au temps de Saint Louis» in *Revue d'Histoire Economique et Sociale,* Paris, 3 (1972), L. G. Carr Laughton, «The Roccafortis of Venice, 1268», in *The Mariner's Mirror,* 42 (1956) pp. 267-278, F.C. Lane, «Naval Architecture about 1500», in *The Mariner's Mirror,* XX (1934) pp. 24-49 and *Venice and History,* Baltimore, 1966, pp. 163-188, U. Tucci, «Architettura navale veneziana. Misure di vascelli della metà del Cinquecento», in *Bollettino dell'Atlante linguistico italiano,* Venice, 5-6 (1963-1964) pp. 290 et seq.

owners did not want to keep such capital locked up for too long a period.

3. The seriousness of the demographic crisis of the mid-fourteenth century soon led to the adoption of the cog which was introduced into the Mediterranean at the beginning of the century but which had still not fully established itself in the Venetian Republic.

4. Defence and military protection needs obliged Venice to keep costly ships which were large consumers of labour but which guaranteed its independence. These same needs, particularly the fact that war galleys became the main military weapon in naval warfare, caused the Republic to keep merchant galleys running and, after these had been abandoned, to keep two traditional types of vessel in its trade fleet: square-rigged vessels and ships which carried a lateen sail. In this way, crews trained to manoeuvre these two types of sail were always available, for the galley used a lateen rigging which was complicated to handle.

5. The shorter the journeys, the smaller the tonnage of the vessels employed. Conversely, for longer voyages, greater tonnage was required. This was a period when Venice traded with all parts of the known world and when Venetian shipowners operated with ships of very large tonnage. When, however, Venetian trade took on a more regional dimension and Venetian ships did not venture beyond the Ionian Islands, shipowners and merchants turned to small-tonnage vessels.

It is clear that such diversities all stemmed from the essential need to provide speed and productivity in sea transport from the point of view of both labour and capital. However, while this would appear to be a purely economic and technical consideration, we may also discern another aspect to the question which in some way concerned the preservation of Venetian hegemony, its thalassocracy and its shipping lines.

1. We need to consider the relationship between the seasonal changes in winds and currents in the Adriatic and the Mediterranean, the times of the year when voyages were undertaken and the type of sails rigged onto ships' masts. In Alexandria in the era of the merchant galley, in the fourteenth and fifteenth century, the *muda* (the period when spice cargoes were taken on) lasted for only twenty days after arrival and, at the

very latest, until 20 November. Saint Andrew's Day (30 November) marked the beginning of winter, beyond which date ships could not undertake a return voyage to Venice but could only complete a journey that they had already begun. The choice of date depended on several considerations: at this time of the year ships had a very good chance of picking up winds which would carry them directly in sight of the coasts of Crete and home in time for the Christmas fair[5].

The Christmas fair was a winter fair which carried on into January and February. The choice of this season favoured the Republic's most important customers and visitors, the German merchants, who, owing to the snow on the Alpine routes which prevented them from returning to Germany, were forced to stay in Venice with their goods[6]. Winter did not obstruct all navigation. Sailors feared above all having to face fierce northerly headwinds (the *bora*) when they sailed up the Adriatic in January and February. On the other hand, many ships, including the *navi del gennaio* (the January Ships), left Venice in winter in order to return home in the spring in time for the second cycle of fairs which brought the city to life around Ascensiontide, the festival of the Sensa[7].

It was equally important to shorten the delays in the Levantine ports so as to save on the wages paid out to the large crews who were paid on a daily basis and who demanded payment, the so-called *refusure,* on their arrival in Venice. Later, when the *muda* runs were stopped, the Venetian Government continued to oblige ships to travel in convoy for security reasons. This was contrary to the opinion of the merchants who wanted more freedom of initiative and wanted to undertake trips individually so as to be able to strike more profitable transactions. Therefore they wanted to put an end to the mass competition caused by sailing in convoy. The ships joined up in

[5] F.C. Lane, *Venice, a Maritime Republic*, Baltimore & London, 1973, pp. 338-339.
[6] G. Luzzatto, «Vi furono fiere a Venezia?», in *Studi di storia economica veneziana*, Padua, 1956, p. 206; F. C. Lane, «Fleets and Fairs. The Functions of the Venetian Muda», in *Studi in onore di Armando Sapori*, (1957), vol 1., pp. 651-663 and *Venice and History*, Baltimore 1966, p. 135.
[7] Lane, «Fleets and Fairs», cit., p. 132.

Corfu, where the port, which was often closed due to unfavourable winds, afforded them protection from pirates. They set sail twice a year in February and January, escorted by warships, and sailed to Smyrna and then Alexandria, returning via the ports of Syria and Cyprus. Two months later, they began their return journey to Corfu. This schedule was worked out in accordance with seasonal changes which affected shipping in the Adriatic: on the outward-bound voyage the ships benefitted from the *maestrale* winds and on the journey they were carried by the *scirocco* [8].

It was not the peculiar characteristics of their sails which in bad weather prevented vessels from sailing. According to Doge Tiepolo's maritime laws (1229), 400-ton ships had to carry 40 crew members, 12 anchors but also "*artimonem, terzarolum et dolonum, aut de fustagno aut bambacino, in proda, et parpallionem de lino, et in medio velum unum et dolonum de bambacino vel barachano*" [9]. If we interpret the logic of this text correctly, from the beginning of the thirteenth century ships carried several types of sail which corresponded to the different masts: the main sail, called simply *velum*, on the large mid-mast, another cotton sail (*dolo*), possibly a spare sail in case of bad weather, a triangular sail (*terzarolum*) and a mizzen-sail (*artimon,* a linen topsail or perhaps simply a kite (*parpalio*) which indicated the small triangular sail attached to the top of the masts. These sails were made from different materials and were designed to resist the changes in weather; there were sails made of cotton, fustian, linen and *barachano* (hemp?). It is difficult to know precisely how the sails were rigged in all weather conditions. Certainly it was through their sails that vessels could be best identified, since they were the most visible part of the ship and could be distinguished far off on the horizon.

[8] U. Tucci, «La marina mercantile veneziana nel Settecento», in *Bollettino dell'Istituto di storia della società et dello stato veneziano*, II, (1960), p. 159; on general sailing conditions in the Mediterranean, J. H. Pryor, Geography, *Technology and War. Studies in the Maritime History of the Mediterranean, 649-1571*, Cambridge University Press, 1988, p. 236.

[9] R. Predelli & A. Sacerdoti, *Gli statuti marittimi veneziani fino al 1255*, Venice, 1903, also in *Nuovo Archivio Veneto*, n. IV (1902) 1, pp. 113-161, 2, pp. 267-291; V (1903) 1, pp. 161-251, 2, pp. 314-356. Cf. 1902-2, p. 270.

The Venetians faced other difficulties, especially in the Lagoon. In Venice the port was situated «in the roads at the entrance of the narrows» which, breaking up the Lido, connected the Lagoon with the sea. The unloading of ships began on lighters (*libi*) which reached the docks and entrepots situated on both sides of the Giudecca Canal. With her cargo unloaded, the *nef* was now light enough to enter the «port» and could now be gently towed, since 15 kms of Lagoon separated Malamocco from the San Marco basin [10].

These special conditions affecting sailing within the Lagoon, and in particular the conveyance of salt in large vessels which travelled long distances to pick up their cargoes, have forced ship-builders to observe certain rules. One of the most curious of these, adopted by the Maggior Consiglio in 1229, «imposed minimum measurements on ship building: a length of 56 feet, a width of 24 feet and a height of 9 feet [11]». In actual fact I do not know how we should interpret these minimum measurements which were perhaps more related to a policy to incite shipowners to increase their tonnage and to compete with large vessels than to the need to keep within proportions. In fact it seems remarkable that the length (of the keel?) had to be six times the height of the cog, as if it were necessary to compensate both for the height, which was kept within certain limits, and for the weak draught, by a much greater length. It was a constant preoccupation of the authorities to ensure that Venetian ships, including those purchased abroad, responded to Venetian ship-building standards and could therefore be registered as Venetian and carry the San Marco flag.

Conversely, in 1305, the government authorised three owners of *nefs,* which were «too big for the port of Venice» to sell their cumbersome vessels abroad. In 1422 the Senato reminded the authorities of the Arsenal, which was beginning the construction of two two-deck cogs measuring 1200 *botti*, that they should be made in

[10] Hocquet, *Voiliers et commerce en Mediterranée*, *cit.*, pp. 166 and 185.
[11] U. Tucci, «La navigazione veneziana nel Duecento e nel primo Trecento e la sua evoluzione tecnica», A. Pertusi ed., *Venezia e il Levante fino al secolo XV*, Florence 1973-1974, vol. I, t. 2, p. 830.

such a way and according to such instructions as to enable them to enter and leave our port (of Venice). The natural configuration of the Lagoon «ports» at St. Nicolò and Malamocco imposed upon Venetian ships special technical characteristics regarding the draught, the shape of the hull and the keel and the size of the hold. If a ship was too heavy to venture into the canals of the Lagoon or the port, there remained only one solution: a detour by way of Istria, Parenzo or Umago, considered in 1299 and still in 1527-1529 as the out-ports of Venice where ships with heavy cargoes were unloaded onto smaller vessels [12].

The peculiarity of the Lagoon, which was also called — and quite rightly — the estuary (*estuario*), was that the rivers flowing into it formed under-water canals but also deposited sediment in the lagoon itself and off the «ports». In the mid-sixteenth century only a few ships used the port of S. Nicolò; others remained at the entrance of the port without entering the Lagoon so as to be ready to leave again more quickly while the large majority entered by the port of Malamocco which did not serve as an outlet to any river and was thus very useful to shipping [13].

However, there was another natural constraint on navigation, namely, the nature of the sea bed, the quality of the moorings, the erosion of the shore caused by the swell; in other words, all the physical conditions which the sea afforded to shipping as anchorage. For a long time Venice used a large cargo vessel, the *marciliana* which was forbidden to go beyond the Otranto Straits, not because it was too small but because it was unarmed. The authorities were continually obliged to repeat the restriction since the owners of these vessels were extremely anxious to dispatch them as far as Alexandria where government vigilance was more relaxed [14]. In the eyes of the government official responsible for

[12] M. Bertoša, «I porti istriani e Venezia nel 1528», *Atti del centro di ricerche storiche*, Rovigno, XVII (1987), pp. 160-171.
[13] Hocquet, *Voiliers et commerce en Méditerranée*, *cit.*, pp. 516-19.
[14] F. Braudel, *La Méditerranée et le monde méditerranéen à l'époque de Philippe II*, 2e ed., Paris 1966, I, p. 284.

the Republic's defences, the problem with the *marciliana* was that it was unarmed, being purely a merchant ship and was of no use in military operations since it had no castles nor tops. Like the *nef*, it sailed with square sails but its crew was smaller and it did not carry soldiers and therefore its running costs were smaller than those of mixed vessels used for both trade and warfare. It was, of course, on account of its smaller running costs that it appealed so much to charterers.

These large vessels were equally suited to sailing up estuaries, thereby avoiding breaking bulk in the out-ports [15]. We can trace the history of the *marciliana* from the mid-thirteenth century up to the first half of the eighteenth century, but we still do not know whether the vessels of the thirteenth century already sailed with square rigging. Tonnage size usually ranged from 100 to 300/350 *botti*. The *marciliana* was widely used by the seafaring families of Chioggia, rather than by Venice which had a predilection for armed ships and left unarmed vessels to its loyal subjects. What was the relationship, then, between the *marciliana* and the shape of the coast? Why was it that after being employed for centuries it quietly disappeared in the first half of the eighteenth century?

A valuable clue is provided by a reply of the V Savi alla mercanzia (1 April 1697):

«esser questi legni proprij e particolari di questa piazza già secoli con pubblica permissione instituti poiche servono alla navigazione del Golfo (...). Essersi la qualita d'essi inventata per resistere alle spiagge massime della Puglia ove capitano a caricar ogli, le mandorle et altre merci di quei contorni (...). La qualita poi specifiche di questa sorte di bastimenti sono il poco fondo che pescano, e percio sono habilitati ad avvicinarsi in ogni luoco; la proprieta di resistere nelle spiagge all'ingiurie del mare stando sorte (= all'ancora) senza alcun nocumento per haver piana la prora; e la modesta spesa che si ricerca della fabbrica, delli armizi e della poca ciurma» [16].

[15] Hocquet, *Voiliers et commerce en Méditerranée*, *cit.*, pp. 97-99 and 512-518.
[16] D. Sella, *Commerci e industria a Venezia nel secolo XVII*, Florence, 1961, p.106.

The *marciliana* was well-suited to leeward navigation along the shallow and sandy coast from Apulia to the mouth of the Po, and the Chioggia sailors exploited this fact to engage extensively in smuggling to Ferrara's advantage. The *marciliana's* fate was sealed when, after having developed oil production in its own territories, notably in the Ionian Islands in Corfu, Zante and Santa Maura, and afterwards in Istria, Venice stopped importing oil from Apulia [17]. Henceforth, Venice relied on ships with a stronger draught and mixed rigging, like the *polacca* or the *tartane,* to bring its imports on the windward side in deep water where the coast was amply sheltered by the Dalmatian islands. The ability of ships to adapt to different coastlines and ports was always an important factor.

The difficulties caused by river flooding in the Lagoon have also prompted F.C. Lane to raise the question as to whether Venetian loyalty to the galley might not have been a response to the peculiarities of its port: the merchant galley was abandoned when works to divert the course of the lagoon rivers were speeded up. Ennio Concina has recently re-examined this problem on the basis of evidence found in reports by foreign military engineers concerning the poor capacity of the port of Venice and the usefulness of its Istrian out-ports [18].

2. Just exactly when Venice adopted the *muda* galley system is not certain, but the reason for doing so seems evident enough. On account of her crew which provided extra motive power, the galley was never becalmed and since this large crew of free rowers was armed and since she never sailed alone, for a long time the galley did not fear attack at sea. The galley was a vessel which, sailing according to a precise schedule, facilitated forecasting, that is to say, economic forecasting in a dual sense. Clients who awaited the arrival of their

[17] I. Mattozzi, «Crisi, stagnazione e mutamento nello Stato veneziano sei-settecentesco: il caso del commercio e della produzione olearia», in *Studi Veneziani,* n. 5. IV (1980), pp. 199-276.

[18] E. Concina, «Venezia: arsenale, spazio urbano, spazio marittimo. L'età del primato e l'età del confronto», in E. Concina (ed.), *Arsenale e città nell'Occidente europeo*, Rome, 1987, pp. 25-27. By the same author, *L'arsenale della Repubblica di Venezia. Tecnica e istituzioni dal Medioevo all'Eta moderna,* Milan, 1984.

goods knew exactly when to go to Venice to conduct their business. Investors who had advanced money belonging to companies and other *colleganze* knew the dates when they would be repaid with interest and could renew the operation to obtain more profits.

It probably needed about half a century to develop a comprehensive system of navigation with galleys after so much hesitation which destabilised the Rialto market for such a long time. The convoy system could be controlled at the place of exportation by a Venetian colony which obeyed orders from a consul and which prepared for the *mudas* arrival by setting up stocks in the *fondouks* provided for the purpose. On the other hand, it greatly encouraged speculation because merchants caused a double price movement as they sought to raise prices for the products they intended to sell contemporaneously, and to lower them for the goods they intended to purchase. In this way, at brief periods during the year, the galley convoys from the Levant arrived at the Rialto market with large cargoes of valuable merchandise and there was a great risk of prices plummeting at the market end, to the benefit of foreign customers who could take advantage of a saturated market. It was therefore necessary to regulate stocks and prices by distributing goods over a much more widespread market. This meant no longer waiting for the arrival of foreign merchants in Venice, but entrusting other galleys with the task of conveying the products of the East to western markets, by calling on any port along the route where it was possible to sell spices, silks and other luxury goods at monopolistic prices. Time is a valuable commodity in trade and the problem lay in speeding up the circulation of capital: "*venir presto sul denaro per un altro viazo*" [19]. Before the Flemish route was established with its twin destinations, the out-ports of Bruges and London, the main concern of investors in the *colleganze* seemed to be that of making sure that their capital made a full circle so as to procure double profits both on

[19] F. Braudel and A. Tenenti, «Michiel da Lezze, marchand vénitien (1497-1514)», *Festschrift zur 65. Geburtstag von F. Lütge*, Stuttgart, 1966, p. 50; B. Doumerc, «La crise structurelle de la marine vénitienne au XVe siécle: le problème du retard des mude», *Annales E.S.C.*, 1985, p. 606.

the outward journey and on the return journey to Venice (*destinari et redestinari*), as U. Tucci points out [20].

3. The productivity of sea transport continued to grow as a result of technological developments which greatly improved the nautical qualities of vessels. It was not just the transition from *biremes* to *triremes*. Since the drawing up of maritime laws under Doge Tiepolo in 1229, a 200-ton *nef* carried a crew of twenty and a 1000 ton-*nef* required 100 men. Thus each sailor handled about 5 tons worth of cargo. The size of some of these Venetian vessels which operated in the first decades of the thirteenth century is quite striking. Less than two centuries later, around 1400, the *cog* measuring 500 *botti* carried 27 seamen, those of 600 *botti* carried from 33 to 37 men and those of 700 *botti* carried on average 43 crew members. These cogs were employed on long distance voyages to Tana, Beirut and Alexandria. According to their tonnage they carried one man for every 16.5 to 18.5 *botti*. The productivity of a 500-ton cog was greater than that of ships measuring 700 *botti*. In the first case a man handled 18.5 *botti*, in the second only 16.5. Despite the intrinsic instability of the volume-mass or *bottemilliaire* ratio, we can calculate the productivity gain which rose three and a half times between 1229 and 1400. While in 1200 a sailor handled 5 tons, two centuries later he handled 17.5 Venetian tons.

This progress was possible owing to the double substitution of the stern rudder-post for the old and cumbersome side-rudders and of the square sail laced onto the yard [21] — whose size could be quickly increased or reduced thanks to studded sails and reef points — in place of the old lateen sails which were much more delicate to manoeuvre. Nonetheless, the new ships' progress had been very slow. Although the *cocca* was already in use in Venice in 1310, for a long time it remained a small-sized vessel with a cargo capacity which was 4 to 5 times less than that of a lateen *nef*. It was only following Venice's demographic problems during the second half of the

[20] U. Tucci, «La navigazione veneziana nel Duecento», cit., pp. 821-842.
[21] L. Carbonell Relat, «La 'coca', nave del Medioevo» in *Rivista de historia naval*, Instituto de Historia y Cultura naval, Armada española, ano IV (1986), n. 15, pp. 45-64.

fourteenth century — which were probably more related to the negative effects that the loss of Dalmatia and Ragusa had on the number of seamen Venice could put to sea than to the Black Death — that cogs enjoyed a brief period of expansion. This period was short-lived because the Venetians very quickly discovered the vessel's limited capacity to manoeuvre owing to its having a single sail which was effective only when there were carrying winds. Further progress followed with the invention of the fully rigged *nef,* whose sails were mixed and spread over several masts and were soon divided up into smaller sails on each mast. These innovations increased the nautical capacity of these vessels at the end of the fifteenth century and possibly led to a slight fall in labour productivity at sea, since more men were needed to manoeuvre such heavy and complicated rigging aloft and from the deck.

4. The overall progress in productivity was in fact concealed by defence needs, especially against pirates. Each boat carried extra men, not for navigation purposes but to fight in a possible combat against the crews of other ships. When the shipowners responded to the Senate's request to place their cogs at the government's disposal for public service, they reported to the *Collegio* (a kind of executive body of the Senate) the tonnage of their ship and the number of crew members, leaving the Sages the task of calculating, on the basis of this information, the ship's fighting capacity and the number of soldiers to be embarked. As long as Venice managed to assert its political authority in the Gulf, the risks on the long-distance routes taken by armed vessels, *nefs* and cogs were higher in the Mediterranean. Thus unarmed ships were not allowed to leave the peaceful waters of the Adriatic and venture beyond Corfu. It is misleading therefore to assume that the total number of men carried by ships was limited to crew members only, without considering those who were employed in the ship's defence. A ship which could have been manned by a crew of only 30 to 35 seamen actually employed around sixty men in its service. In 1426, 7 of the largest Venetian ships were sent on the Syrian cotton *muda,* each vessel carrying ten men per hundred *botti*. Due to insecurity at sea the

number of men needed to run the ship was doubled. In this way, labour output was halved. In practice, it was the very progress in offensive and defensive armaments which held back progress in productivity. In the thirteenth century when fighting was carried out mainly with bows and arrows, each sailor was also a soldier. In the fourteenth century the invention of the cross bow, obligatory training and the high cost of defensive weapons, helmets and breastplates had already led to differentiation among seamen, only some of whom had access to the new weapons. As a result of the use of firearms, artillery and *arquebuses,* a category of professional soldiers was formed among the crew members [22].

For defence purposes, Venice and the other Mediterranean powers continued to rely on a fleet of galleys, *triremes* and other rowing vessels which had the task of providing military protection and customs defence, especially along the coast. The superiority of this kind of vessel stemmed from its great mobility and its ability to face almost all winds, even though its instability in rough seas was a handicap which often prevented it from taking to the sea in winter. For a long time galleys required a logistic support and this was supplied by *nefs* which carried reinforcements and food provisions and extra equipment. A change occurred with the introduction of naval artillery, which was not very suited to the structure of the galley since cannon could not be used along the sides of ships which were occupied by oars and oarsmen, but only at the bow or, in some cases, at the stern. In the prow, these cannon weighed down dangerously the front of the ship which had a tendency to nosedive and to lose speed and the capacity to manoeuvre.

[22] Hocquet, *Voiliers et commerce en Méditerranée, op. cit,* pp. 108, 112 and 125. These studies draw heavily on the works of F. C. Lane, for example, «Tecnologia e produttività dei trasporti marittimi», *5ª settimana di studio,* Prato 1973, French translation in *Revue Historique,* 510 (1974) pp. 277-302 and English translation in *Studies in Venetian Social and Economic History,* London 1987 IX, «The Crossbow in the Nautical Revolution of the Middle Ages», in *Economy, Society and Government in Medieval Italy. Essays in Memory of Robert L. Reynolds,* Kent (Ohio) 1969-1970, pp. 161-171, «Venetian Seamen in the Nautical Revolution of the Middle Ages» in *Venezia e il Levante fino al secolo XV, cit.,* vol 1, pp. 403-430 and *Studies in Venetian Social and Economic History,* 1987, VII.

At the end of the fifteenth century, war squadrons comprised both types of ship: galleys carrying a large sea infantry made up of crossbowmen, and afterwards *arquebusiers*; *nefs* and other round vessels reinforced by powerful artillery. Henceforth, the difficulty lay in getting these very different kinds of vessel to manoeuvre as a single unit. The first Venetian experience in this respect — during the Second Turkish War — was a complete disaster, the responsibility for which fell on to the shoulders of the General Commander Antonio Grimani[23]. Despite this, the galley was not abandoned, although a kind of mixed galley, the *galleasse,* was created as a result, whose role at Lepanto is well known. The *galleasse* was as imposing as a large round vessel, but it was moved by oarsmen who sat in banks of five to pull an enormous oar.

The effort required of oarsmen, whatever the type of galley, was arduous and could not be sustained for a long period. To spare human energy whenever it was possible, the large lateen yard and sails were raised. The galley thence carried a numerous crew, which was rarely complete, consisting of around 120 to 180 oarsmen, plus seamen employed to manoeuvre the sail[24]. These men required an apprenticeship which they could not receive on a *nef* or other vessels

[23] F. C. Lane, Naval Actions and Fleet Organisation in J. Hale editor, *Renaissance Venice*, London 1973, pp. 153-154. See also, G. Cogo, «La guerra di Venezia contro i Turchi» in *Nuovo Archivio Veneto*, XIX (1900), which continues to be very useful owing to its judicious use of sources, C.M. Cipolla, *Guns, Sails and Empires: Technological Innovations and the Early Phases of European Expansion (1400-1700)*, New York, 1965, J.F. Guilmartin Jr., *Gunpowder and Galleys: Changing Technology and Mediterranean Warfare at Sea in the Sixteenth Century* (Cambridge Studies in Early Modern History), Cambridge UP 1974.

[24] E. Fasano-Guarini, Au XVI[e] siècle: comment naviguent les galères» in *Annales E.S.C., 1961*, pp. 279-296; J.C. Hocquet, «Gens de mer à Venise. Diversité des statuts, conditions de vie et de travail sur les navires (XIIIe-XVIIIe siecles), 18e Congrès d'Histoire maritime, Naples 1980, in R. Ragosta (ed.), *Le genti del mare mediterraneo*, 2 vols., Naples 1981, I, pp. 103-168; A. Tenenti, *Cristoforo da Canal. La marine vénitienne avant Lépante*, Paris 1962, has studied the many changes which occurred in Venetian sea warfare and the status of oarsmen in the course of the sixteenth century. U. Tucci, «Costi e ricavi di una galera veneziana ai primi del Cinquecento», in *Studi Veneziani*, XVI (1974). pp. 109-175, has shown that galleys *da mercato* very rarely travelled with a complete crew of 180 oarsmen. These rowing vessels were often manned by no more than 125-130 oarsmen, with a third of the places for crew members unoccupied.

which ran *alla quarra*. Consequently Venice kept a kind of lateen vessel in its merchant fleet. In the fourteenth and fifteenth century, when it was not so necessary for the merchant galley *mudas* to provide this formation, Venice employed Dalmatian *marani* and *caravelles* [25] which were forbidden to leave the Adriatic. When the *viazi* disappeared from the scene, the problem became more acute but during the three centuries of its existence the Republic always kept a very diversified fleet. Alongside the *nef* with its overlapping square sails attached to at least three masts and its staysails, Venice adopted other square-rigged cargo vessels: the *chechia* and the *polacca*. The *polacca* however also carried lateen sails at the front and at the back. The family of lateen vessels was represented by the *tartane* which, with its triangular sails on two or three masts, resembled two other types of vessel, the *pinco* and the *sciabecco* [26].

5. There was one last crucial factor: the length of voyages. No experienced merchant would have ever hired a vessel of large tonnage for a short journey, for example from Istria or Northern Dalmatia to Venice, nor a small vessel for a journey from Crete to Cyprus [27]. Tonnage was in some way proportional to the distance which had to be covered for reasons of profitability. This point, which has already been amply demonstrated in relation to the salt trade [28], has also been confirmed in the case of the maritime corn trade [29]. The report by the Podestat of Chioggia Ermalao Barbaro observed in 1612:

«The sea trade carried on by *chiozotti*... never goes beyond the Otantro headland leeward and Dalmatia windward since, as the boats

[25] K. Nehlsen-von Stryk, *Die venezianische Seeversicherung im 15. Jahrhundert*, Abhandlungen zur rechtswissenschaftlichen Grundlagenforschung, Münchener Universitätsschriften - Juristische Fakultät, Bd 64 Ebelsbach am Main 1986; Italian translation *L'assicurazione marittima a Venezia nel XV secolo*, Il Veltro editrice, Rome 1988, has had two merits: discovering numerous marine insurance policies in Venice, some of which cover the risks ran by caravelles (Cf. pp. 500 and 517).

[26] Hocquet, *Storia di Venezia*, vol XII, *Il mare*, *cit.*, pp. 331-3.

[27] A. Tagliaferri ed., *Relazioni dei rettori veneti nel Dogado. Podestaria di Chioggia* (introduction by B. Polese), Milan 1982, p. 44.

[28] Hocquet, *Voiliers et commerce en Méditerranée*, *cit.*, pp. 127-142.

[29] M. Aymard, *Venise, Raguse et le commerce du blé pendant la seconde moitié du XVIe siècle*, Paris 1966.

have a small carrying capacity, the costs would outrun the earnings on long journeys [30]».

To end this brief survey, we ought to say something about the organisation of Venetian naval construction. It is customary to confront two contrasting sectors when discussing this subject: the private artisan's ship-yard which built round vessels of varying tonnage, and the government sector — the Arsenal — which employed modern and rational building methods and specialised in building galleys and other rowing boats [31]. In the Arsenal towards the end of the Middle Ages, the prices of galleys rose each year. The fact that the Arsenal was able to assemble in a very short time a hundred galleys in times of necessity only serves to show the existence of an integrated enterprise in which boats with interchangeable parts were produced on a kind of assembly line. At first the Arsenal grouped together different artisanal units, each constructing its own galley. When the galley returned to be laid up, only its accessories were dismantled, each piece being numbered and ready for being assembled at the next alert; meanwhile the galley was kept under cover. In other words, there were so many workshops and work crews that various galleys were assembled simultaneously. In this respect, the Arsenal reproduced the technical conditions which prevailed in the many private shipyards spread out along the main canals reached by wooden rafts (*zattere*) from which the ships were launched. Thus sails, oars, ropes, artillery, sabres, etc. — « all that which belonged to the outfit of the same galley in numbered *monti*, each galley having its own Roman numeral [32]» — were re-ordered and stored in various warehouses.

The Arsenal's *ordine mirabile* consisted above all in keeping in perfect order the parts which were made to measure for each galley. Each galley was a unique model that was produced according to the personal craftsmanship of the master in charge of the work crew who

[30] Tagliaferri, *Relazioni dei rettori veneti*, *cit.*, p. 44.
[31] F. C. Lane, *Navires et constructeurs à Venise pendant la Renaissance*, Paris 1965.
[32] Concina, «Venezia:arsenale...», *cit.*, pp. 18-19.

had given each galley its own distinct physiognomy, while following very general rules which aimed to standardise the size, burden and displacement of the galleys. The extreme rationalisation with which the industry was conducted can be seen in the way the authorities, given the great scarcity of marine wood since the middle of the sixteenth century, pursued a policy of reafforestation and of producing wood which had to be sufficiently pliable for the purposes of shipbuilding [33]. One could hardly ask more of nature in the name of industrial standardisation.

Every twenty or thirty years men invented or adapted a new type of boat, more often than not by developing a feature already existing on an old ship. Sailing ships were divided into two broad groups, those with square-rigging and those with lateen sails, without counting the improvements which made it possible to juxtapose the two types of sail on the ship's five masts, thereby enabling the ship to sail in all winds. However, in these ships with mixed sails, the square sails did the carrying. They signalled the arrival of larger carriers, *nefs,* barges, galleons and *marcilianes.*

In the fifteenth century, ships took to sea in all seasons and on all the Mediterranean routes. The winter season no longer caused long delays, although ships continued to be laid up in the winter in the thirteenth century. There were departures all year round, seasonal variations responding more to the needs of the market: in autumn, ships had to provide the urban entrepots with the grain collected in Greece and Sicily, while in spring they replenished the stocks which had dwindled as a result of winter consumption [34].

In these cases traffic was entrusted to small tonnage vessels, *barques, legni, marani* and *marcilianes,* later *saettes,* which had the task of keeping the granaries full during the difficult months. The need to supply the towns with food provisions meant that it was no longer

[33] *Boschi della Serenissima, utilizzo e tutela*, Exhibition 1987, Archivio di Stato di Venezia, catalogue by M.F. Tiepolo.

[34] M. Balard, J.C. Hocquet, J. Hadziiossif, H. Bresc, «Le transport des denrées alimentaires en Méditerranée à la fin du Moyen Age», 91-175, in: Kl. Friedland et al., *Maritime Food Transport,* Böhlau Verlag 1994, 583 p. Cf pp. 123-4.

possible to have winter stoppages. When ships did take a rest this was not due to factors related to nautical technology but to the laws of the capital market. The key factor of change in the composition of fleets through modification of the type of vessel employed every twenty or thirty years is the search to improve the productivity of sea transport, which, as a result of technological developments that have greatly improved the nautical qualities of vessels, has kept on growing.