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Can We Trace and Estimate the Technical Progress in Shipping Industry by Using the Cobb-Douglas Production Function?

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Abstract

This paper had an ambition: to estimate the impact of Technical Progress embodied in vessels. Given that technical progress is estimated in physical terms, we went a step further to estimate it also in $ terms, and this found equal to 8.2% p.a. The monetary technical progress is more meaningful to managers. First, we found the existence of economies of scale in tankers using the generalized Cobb-Douglas production function: $P_t = A_t C_t^{\beta} L_t^{\alpha}$, where $\alpha + \beta$set > 1; the parameter α set equal to 0.15 and the parameter β set equal to 0.94, based on actual data. The paper presented a historical account of the events since 1945, which we held responsible for the diffusion of a subsequent technical progress. Technical progress in ships-most of it is called to solve technical problems. Ships were regressing round 10,000 dwt, at relatively low speeds, after the 2nd World War, and they consumed *a lot of fuel oil*, but who cared (?) as oil was very cheap. Sea trade did not stay at low levels, but increased by leaps and bounds after the 2nd World War. Ships soon multiplied their size by 6 times initially and then by more than 10 times. Tank(ers), suitable to reap economies of scale, increased by 10 times, and eventually held the titles: VLCC & ULCC, passing over various adventures! During 1945-1973, all maritime variables were **increasing**, and even Onassis, an empirical shipowner and uneducated, understood well the arithmetic of scale economies, even before the 2nd World War by building the 1st super-tanker (1938)! Then, suddenly, and unexpectedly, Suez Canal closed (1956). Ships had to travel a lot more sea miles… as a result they became even bigger than proper for the future trade. Ships fell into the trap, however, believing that Suez Canal will open after a very long time—even Onassis believed this. Shipowners run to build giant ships! And all were going well till end-1973, for 16 years. Onassis and other tanker shipowners became rich during this time. OPEC, however, decided to change history (in end-1973) and to put an end in the story that oil is very cheap. The "trap" worked, as ships had become already bigger, faster, and covered longer distances, **before** fuel oil price increased about 10 times reaching \$200 per ton from \$20! Ships broadcast an SOS to… technical progress "telling" please: find a "cheaper oil and newer engines consuming less"! Technical progress responded… Today, a lot of discussion is going-on not for a cheaper fuel-oil, or a better main engine, but for a fuel oil… which will respect environment, e.g., LNG or hydrogen or else? Will shipping technical progress take revenge, in 2022 and thereafter on OPEC, on behalf of shipowners, by making ships **free from oil**? A new history for shipping is going to be written again…but this time will be a **revolution**, after Pandemic is over after 2022.

Keywords

Cobb-Douglas Production Function, Estimation of **Increasing** Scale Economies in Shipping, Estimation of Technical Progress in Ship Production, and in \$ Terms, History of Events and Technical Progress in Shipping, 1945-2021

1. Introduction

One of the most researched subjects in economics, we believe, is "technical progress"—TP, which played a basic role in economic growth models, in 1928, and especially between 1939 and 1967, starting with Ramsey's article on "optimal growth" in Economic Journal (Ramsey, 1928).

Is, however, **technical progress**—**TP** a product of…business magic? Because, how one company, using technical progress, can achieve a *higher* production with *unchanged quantities* of Capital and Labor? Should we accept the idea that TP is something falling from Heaven, like a manna? Or is something man-made? This type of technical progress is called disembodied.

Certain great economists, namely Hicks, Harrod and Solow embarked in determining the so-called **neutral** TP (**Table 1**). Neutral technical progress is defined as the one, which in its initial effects, leaves unchanged the ratio of marginal product of Capital over that of Labor. Solow found out that about 80% of the growth in USA output per worker was due to technical progress. Solow

Table 1. The neutral technical progress, 1948-1963.

Author-Year	Assumption of constancy of	Remarks
Hicks, 1963	Capital/Labor ratio	Neutral technical progress
Harrod, 1948	Capital/Output ratio	Neutral technical progress
Solow, 1959	Labor/Output ratio	Neutral technical progress

Source: author.

eventually allowed in his models—as we did—the capital embodied in machinery to have different ages (vintages). Important was that the more recent vintages had more technical progress. Eventually economists—as we did—found that capital is more important for growth.

Hicks (1963) compared points in the growth process, during which the ratio of the *marginal product* of Capital and Labor is *constant*. Hick's model assumes, in 2 cases, labor and capital **savings**. Solow's **neutral** technical progress, allows capital to increase. Harrod (1948) defined neutral advances those that leave the distribution of the total national product between labor and capital unchanged (at a constant rate of interest).

In shipping, shipbuilding **has to** achieve **less** labor quantity on board and inevitably **more** capital quantity. If both can be reduced, it would be perfect, but by reducing the quantity of capital, we do not want to part from scale economies! In shipping, the Ct/Lt and Lt/Qt ratios are *apparently* constant… because the size of the vessel (productive capacity-quantity of capital) is **fixed** and the number of crew is theoretically also **fixed**, after ship's **construction**. **Production**, however, is **not fixed**, depending mainly: on demand, on distance involved, and on vessel's speed!

We have to say from the start: *Speed in shipping*, *is an important factor*, *because it transfers ship's production from origin to destination*, *adding utility to cargo*, *or in other words*, *speed performs the* ***delivery stage*** *of the cargo transported by sea*. *In addition*, *speed is a coefficient demonstrating also* ***prevailing technology***! *The unfortunate fact is that* ***higher speed*** *needs* ***more fuel***, *and fuel has become an expensive commodity*, *since end*-1973, *with the exception of the Pandemic period*, 2019-2022!

2. Literature Review

Cobb and Douglas (1928) were not preoccupied so much with "technical progress", we believe. Their main concern was, using a production function $P = bC^{1-\alpha}L^{\alpha}$ (1), to prove the existence of *constant returns to scale*, *where b indicates technology*, *C*, *the Capital quantity*, *L*, *the labor quantity and P*, *the production*.

They wanted primarily to prove, using data, that $\alpha + (1-\alpha) = 1$ (2) (Douglas, 1934). The implication of (2) is great for distribution theory. If (2) holds, then each factor of production gets the *value of its marginal product* (*Henderson & Quandt*, 1958: p. 64)[1]. Accordingly, the total value of production is "given" to these two factors, *and* ***there is no monopoly profit***[2]**!** The above is also known as "Euler's theorem[3] (Chiang & Wainwright, 2005: p. 387).

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[1] Proof: let $Q_t = AL^{\alpha}C^{1-\alpha}$ (3); and $Q_t = L\left(\alpha AL^{\alpha-1}C^{1-\alpha}\right) + C(1-\alpha)AL^{\alpha}C^{-\alpha}$ (4) $Q_t = \alpha AL^{\alpha}C^{1-\alpha} + (1-\alpha)AL^{\alpha}C^{1-\alpha}$ (5) and $Q_t = \alpha Q_t + (1-\alpha)Q_t$ (6). The **long run total outlay equals the long-run total revenue!** But no matter **product price!**

[2] Meaning nothing is gained **above** normal profits.

[3] Given that $Q_t = \mathrm{d}Q_t/\mathrm{d}C_t * C_t + \mathrm{d}Q_t/\mathrm{d}L_t * L_t$ (7), or if $Q_t = MP_c * C_t + MP_l * L_t$ (8) holds, the production function **is homogeneous of degree one**.

Douglas (1976) re-visited "the 1928 Cobb-Douglas production function", mentioning its history, its testing and giving certain new empirical values. The Cobb & Douglas (1928) found[4] α = 0.6, and till 1938 = 0.65. Further, they estimated the results for fixed capital and physical production. In 1937, function (1) changed to: $P = bL^k C^j$ (9). Again, k found 0.65 and $j = 0.33$, using time series. Then the Cobb-Douglas research used the cross-section method, and applied it to individual industries (1904-1919, on discrete years), k found to vary from 0.65 to 0.66, and j from 0.31 to 0.32, over 1,450 observations.

Research resumed in 1956-1968, (the years were not continuous), over 160 industries and 1123 observations, and k found within 0.54 to 0.61. The two coefficients together were equal to 1 only in 1967. We have but to admire Cobb and Douglas, and especially Douglas, for his persistence in research for proving the *constant economies of scale* for a period of over 50 years!

As argued by certain economists (Hahn & Matthews, 1964: p. 379) technical progress is embodied in *new* machinery, and bear the technology of their date of construction or **machines have a birth date or *vintage*** (Goulielmos, 2021a). The new machinery consists a separate family with own production function! The *manna*, in the form of technical progress, falls only together with new machines. This is called "new approach" (and it had to be distinguished from the "orthodox" one).

One may ask: **how** a capital equipment, like a vessel, of unchanged size, and the same quantity of crew, upon delivery, can produce more? The answer is **mainly** by a **newly** built *larger* ship, with an **increased speed,** installing a more powerful **main engine,** due to *technical progress*…

In shipping, finance, i.e., the monetary capital is the one, which is transformed into fixed capital, which is a **necessary**, and also a **dominant** condition to make business, and thus the shipowner has the right to get lion's share, or 50% of the annual cost, as he/she is the one to find a loan, either from commercial banks or from Stock exchanges.

Alderton (1999) argued that between 1950 and 1970, a typical dry cargo vessel, run between Europe and Australia, increased her size from 13,066 dwt to 15,473 (18.4%), her speed from 13 knots to 15 (15.4%) and… her daily consumption from 20 to 24 tons, but her voyage time reduced from 217 days to 213…

3. Aim and Structure of the Paper

This paper has 4 main aims: 1) To estimate the coefficient b in the Cobb-Douglas production function: $P = bC^{1-\alpha} L^{\alpha}$ (where b, $1-\alpha$ and α are constants > 0); 2) to provide a historical account of the technological progress in shipping, after 1945; 3) to determine the production of the: a) vessel, b) shipping company and c) maritime industry, relating it to its technical progress, and 4) to estimate the physical value of shipping technical progress, but also the $-value of it. This last one makes more sense for managers and is a unique contribution of this work.

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[4] They calculated an index of the number of manual workers in 1927 USA manufacturing, covering 1899-1922.

The paper is made up by parts, after literature review and methodology. Part I deals with the history of the technical progress in shipping, 1945-2021; Part II deals with determining the framework of *production* in shipping industry; Part III deals with the production of tankers, 1963-2005, and Part IV deals with estimating technical progress in shipping in physical and monetary terms. Finally, we conclude.

4. Methodology

Equation[5] (1) will be used **generalized**, i.e., putting $1-\alpha=\beta$ (10). Also, $b=A_t$ (11). So, Equation (1) now becomes: $P_t=A_tC_t^{\beta}L_t^{\alpha}$ (12), where P_t is current production, A_t is a coefficient, which may increase current production due to changes in factors, other than Capital quantity, C_t, and Labor quantity, L_t, i.e., due to technical progress.

The above equation allows also to find-out all 3 cases of **returns to scale**: constant, increasing or decreasing. If $f(\lambda C,\lambda L)=\lambda^n f(C,L)$ (13) and if $n > 1$, there are *increasing returns to scale* (Jacques, 2018: p. 168), meaning that by increasing capital and labor by λ, production increases by $\lambda^n>1$. Of exclusive importance for this paper will be coefficient A_t, *indicating the state of technical progress* in production, at time *t*, showing the **efficiency** derived from **technology**!

This can be shown: let $C_{t+1}=C_t=1$ (14) and $L_{t+1}=L_t=1$ (15), meaning constant quantities of Capital and Labor in production, then by Replacing (1) becomes $P_{t+1}=P_t*b*1*1$ (16). This further means that by keeping C_t and L_t constant, we can **increase** production by b (=A_t)! A miracle? If managers knew this miracle, they would appreciate more the role of TP!

5. Part I: The History of Technical Progress in Shipping, 1945-2021

5.1. The Events, 1945-2021

All businesses take place within the historical time, and not in a vacuum. The events that occurred in the years after 2nd World War, are only shown (drawn on Beenstock & Vergottis, 1993; Hughes, 1996; Alderton, 1999; Buckley, 2008; Stopford, 2009) (**Table 2**).

For the time being, and from all the above main important technological advances, we may say that the **increase in oil prices** in end-1973 was the **decisive** factor for shipping, not only because increased the cost of fuel consumed by ships, but also because it **diminished** the consumption of oil worldwide, and many countries tried to find their own sources of energy! In addition, the *cost of living* increased, because all economies were, and are, oil-dependent and electricity-dependent which even this is produced by diesel.

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[5] Closer to shipping, where "land" does not get involved, and sea is free with the exception of crossing canals and calling at ports.

Table 2. Events after 1945, and technological advances till 2021.

Event, the	Event, the	Technical developments	Technical developments
Korean War 1950-51	Gulf War, 1990	Anti-fouling paints	Bigger ships by 1995 >**100,000** dwt; Capes >100,000 dwt
1st Suez Canal closure-1956-1957	Iraq invasion, 2003	More efficient **diesel** engines-more efficient engines[6] in general	Specialized vessels; 1975 emerged
2nd Suez closure 1967-1975	Global financial crisis end-2008-2018	Improved hatch covers[7]	Improved on-board technology
Yom Kippur War 1973-1st oil crisis	Pandemic 2019-2022	Unmanned engine room, early 1960 (*)	Satellite navigation
2nd oil crisis, 1979		Better organizing→ computerization; digitalization	(*) Automation in machinery spaces
Economies of scale recognized, 1955-	Air pollution control-scrubbers, 2011-2021	New ship-designs	Reduced manning cost due to 1981-1987 depression
Energy conservation measures: 1974-	Use of alternative fuels more friendly to environment than oil & coal	A Diesel engine design appeared	

Source: inspired from Stopford (2009), p. 119 & after; Hughes (1996), chap. 12.

5.2. Technical Progress as a Tool to Solve Shipping Problems

We believe that, in shipping, **technical progress** was called to **solve** major problems of the industry (Graph 1).

As shown, the major problems that had to be solved were that ships had to become larger; the ship engines had to be more economical by consuming less fuel; ships had to be more suitable to cover larger distances, and more recently ships had to reduce air pollution caused by ships' engines.

Shipowners, and Onassis, understood well the benefits of scale economies, especially after Suez Canal closures, and distances' lengthening. In addition, shipowners had to face a *very expensive fuel oil*, and this could be done only by new engines, and/or by a cheaper fuel! The scrubber is a rather recent invention, quite expensive[8], emerged when ships found to pollute air.

As shown, the 7 challenges were specific and provided a chain reaction so to

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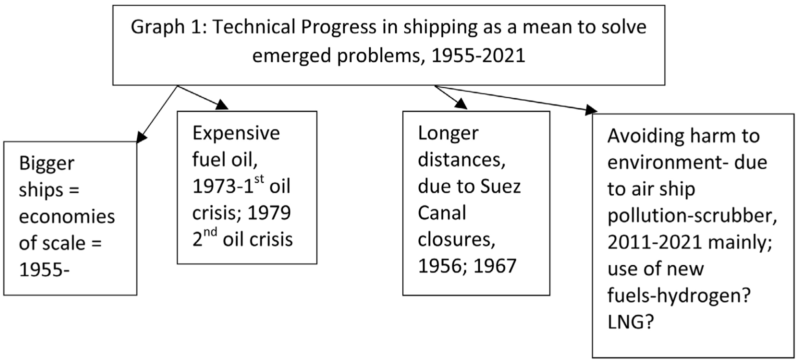
[6] The propulsive *performance* of a modern vessel, during mid-1971-mid 1996 (25 years), reached a high level. In mid-1996 the "***derated** main engine*" (*) emerged, but it was expensive. During this period, a quite remarkable improvement occurred in the performance of the so-called ***conventional*** propulsion systems. (*) Method used to increase the "thermal efficiency of a main diesel engine" by maintaining the maximum combustion pressure (by design).

[7] A major technical innovation was that used to **close** ship's hatchway water tightly. There are available 6 types (Brodie, 1991). Their operation is hydraulically.

[8] Perhaps $1m.



Graph 1. Technical progress in shipping as a mean to solve emerged problems, 1955-2021. Source: author.

say: economies of scale required by the greater volumes of sea trade, meant bigger ships, which required more powerful engines-capable also for an increased speed. The increased speed required also by the emerged longer distances. To the above expected normal changes, the severe challenge of a very expensive fuel emerged! The fuel used by ships received a double increase in price! Old ship engines were designed with an internal cheap fuel in mind, which after 1973 and 1979 was not the case, till this day. Normal were also the changes as far as new designs of ships with reduced friction of the hull in the sea etc. are concerned.

The history of technical innovations that have occurred in shipping is remarkable as well fascinating, with an always focus on "fuel" as to how to move the vessel: first was the wind, then steam and then diesel, where the target was always to reduce crossing time. Time is money they say! Today, engineers regretted because they have adopted fuel oil at the end of 2nd World War as fuel-as being the main polluting substance…causing the climatic collapse… The Revenge of fuel oil has been accomplished!

Technical progress in **ships** more frequently than not, and during recent years, par excellence, **focused** also on the **type** of **fuel oil** likely to be used, which would be more **friendly** to air environment! People today see the most tragic way the impact of the climatic destruction with fires (USA), and floods in Europe (Germany, Belgium, the Netherlands etc.). The revenge of the rivers is also realized!

Next, we will present above issues following the order of Graph 2.

5.3. Economies of Scale-The Size of Ships

The standard vessel[9], after 2nd World War, was the 10,000-dwt dry cargo (bulker, with **tween decks**[10]), named: Freedom[11], Liberty[12], Fort, Empire and Victory[13];

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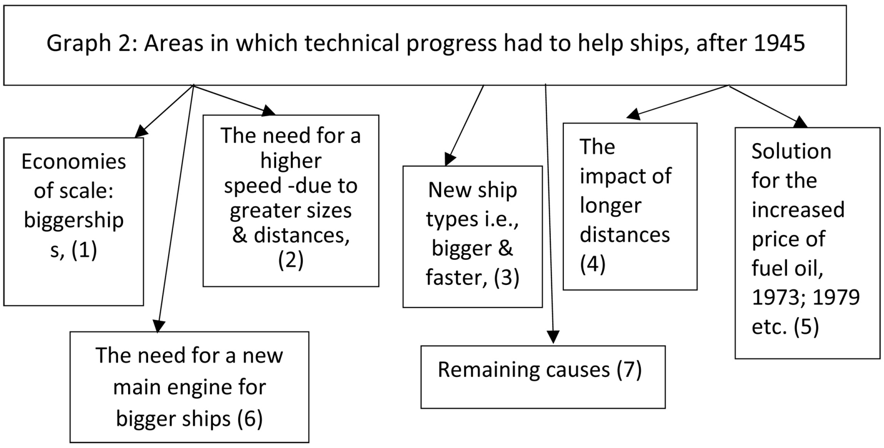
[9] These ships had a "steam reciprocating engine" with "oil fired boilers", with a loaded speed of about 10 knots, and a high (35 tons) fuel oil consumption!

[10] Popular type of general cargo vessel with holds divided horizontally by 1 or more decks. They increased in size by 1991 to 18,000 dwt, 15.9 service speed, 4 holds, and 3 cranes of 25t each.

[11] The "freedom" ships ranged from 14,800 to 15,600 dwt at 13.5 and 14.5 knots speed.

[12] With water tube boilers.

[13] "Turbine driven" for a somewhat larger dwt and/or a higher speed.



Graph 2. Areas in which technical progress had to help ships, after 1945. Source: author.

the T-2 tankers were slightly larger[14], with turbo-electric machinery; their main engine drove the propeller, when in sea, and the cargo pumps while in port!

The year 1955 marked the beginning of the rather massive shipping **economies of scale** (Goulielmos, 2021b) in both tankers[15] and bulk carriers[16]. The size of the tankers stabilized at around 540,000 dwt in 1970-1980. Bulk carriers stabilized too, and theirmid-1996 maximum dwt was 350,000 (Very large bulk carriers), carrying iron ore from S. America to Japan.

Then, the 400,000 dwt bulk carriers were built, called the "Vale" bulk carriers aimed at carrying iron-ore to China (**Scan 1**). We all are aware today of the tankers called VLCCs (very large crude carriers) and ULCCs (ultra large crude carriers), varying from 100,000 dwt to 350,000 dwt and from 350,000 dwt to 550,000 dwt respectively!

5.4. A Higher Speed?

As understood so far, the solution for larger ships and longer distances was speed! As shown (**Figure 1**), in order to increase ship's speed from 10.2 knots to 12 (18%), a shipowner needs to increase the "*break horse power*" by 50%, and the daily *consumption* from 9 tons to 18!

As shown, going from 12 knots to 14, the oil consumed approached almost a double figure. The fuel cost is the new headache for shipowners and they may cover 47% of the voyage cost as between 1970 and 1985 fuel prices increased by 950%. In 1985 this increased to 34%. The rises continued in 2000 and thereafter. A Panamax bulk carrier at 14 knots consumes 30t/d. A 27% of the energy is used to cool the engine; 30% is in the exhaust emission; 10% by the propeller; 10% by hull friction and only 23% is used to move the ship! The above analysis gives 3 targets: main engine, hull and propeller. Between 1979 and 1985, with slow

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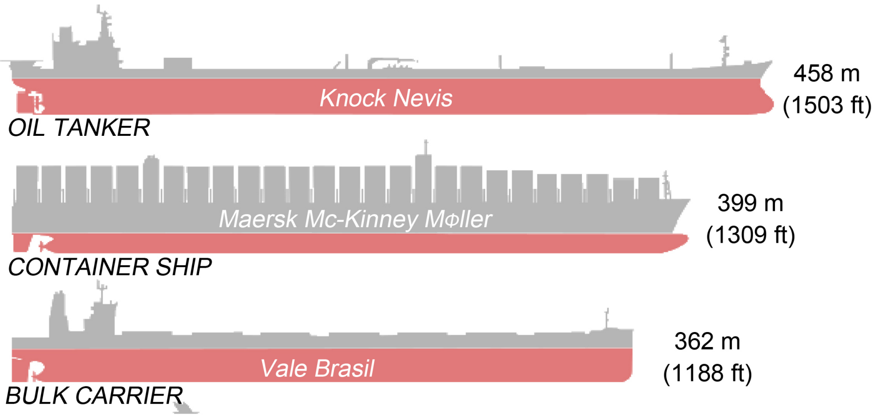
[14] With no enclosed dock systems & specific dimensions. 16,750 dwt at 14.5 knots.

[15] In 1979 C.Y. Tung built the giant 569,783 dwt tanker (Hong Kong); 13 knots.

[16] The SD 14 vessel, became popular (emerged 1968); shelter-decker, 15,250 dwt, at speed 14 - 15 k., 5 holds, 5 hatches and lifting gear. A 5-cylinder diesel consuming 25.5 t heavy oil/day, loved by Greeks.



Scan 1. The largest ships among bulk carriers, tankers and containerships, 2012. Source: Wikipedia.

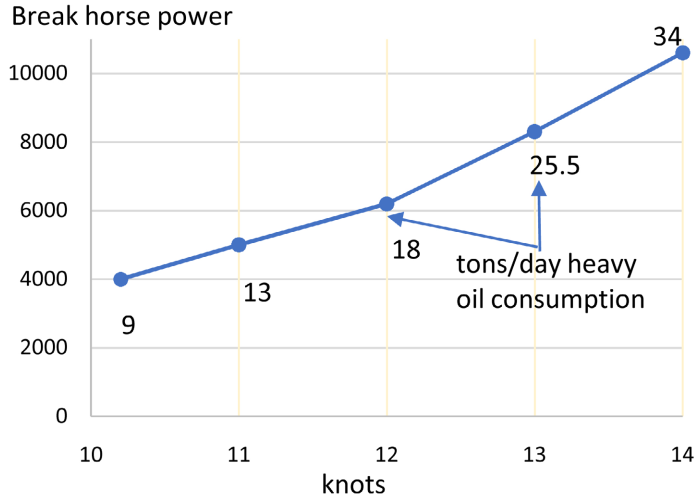


Figure 1. The speed of a loaded Panamax ship, built in 1995, at 15% sea margin. Source: author; data from Hughes[17] (1996) (p. 88).

speed engines (less 100 rpm), we had 23 grams per break horse per hour and propellers of larger diameters. The results were spectacular!

5.5. New Types of Ships: The Combination Carrier; The New Bulk Carrier

A new type of drycargo ship emerged called "combination carrier". This was an experiment in ship *flexibility, because she was* designed to carry oil/bulk/ore, i.e., 3 cargoes in one (ship)! These were successful in 1950-1970 as new oil and dry cargo trades appeared. Their designs were two: 1) the "combi" carrier carrying oil and ore, which emerged in 1950-1960. 2) the oil/bulk/ore (OBO), which emerged in mid-1960-1970. Leading Greek shipowners ordered OBOs, certain of them perhaps prematurely (Colocotronis Bros).

The above experiment was profitable, albeit only during tanker booms: 1967,

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[17] Sea margin is the % (usually 15% - 20%) difference between speed achieved during sea trials and that in actual service conditions, which are less favorable.

1970 and 1973 (Stopford, 2009: p. 601-603). In 1975, the fleet of this type of ships reached 49 m dwt, but by 2007 **fell down** to **only** 8 m.

The above idea was technological clever, but was not brilliant *market-wise. The secret in the above ships is to find a return cargo, which did not always appear. Perhaps digitalization may solve this problem by registering cargoes anywhere in the sea world for the knowledge of shipowners. The ballast time is a quite expensive part of maritime business and waste of resources and technological progress which already exists in computer systems may help quite a deal in this area. Greeks too sold their combi ships after* 1973. *Carrying* 3 *types of cargoes, this vessel, could select the one paying most, and this was a further advantage*! *The combination carrier demonstrated the problem that vessels have, spending time in ballast, especially tankers… We revisit this issue below.*

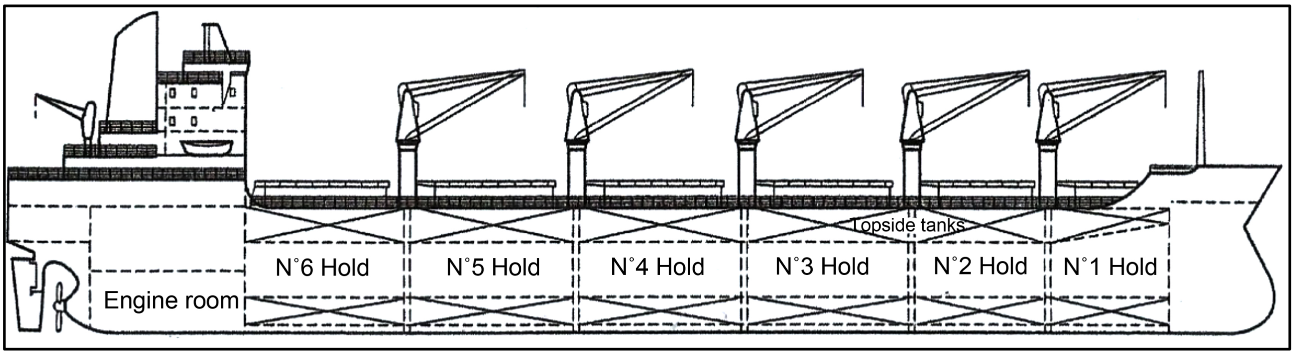
The 1960-1970 period was important, as a shipping technological innovation took place: "the new bulk carrier" (**Picture 1**). This was a single deck, *larger* by *six times* (~60,000 dwt) vessel. Her design provided scale *economies* from both operations and building costs and she provided a better return on price.

The ship, as shown, has 6 holds, 5 cranes, 12 top- and bottom-side tanks for ballast water and her engine room at stern; she has also "weather deck hatches". Her design economized on cargo spaces giving the most space to cargo, as it should.

5.6. The Longer Distances

One event which **marked** the 1st decade of shipping after 2nd WW, was the short 12 months 1st Suez Canal closure in 1956-1957 (Beenstock & Vergottis, 1993: p. 26-29). Despite its short duration, the closure **influenced** technical progress (!). This because it caused a *rise in ship sizes* and a *considerable expansion of the order book* (*new production*)! New ships, as mentioned, only bring new technical progress…

Many shipowners, and Onassis, but Gratsos C, (Goulielmos, 2021c), believed that the closure would be long, **but it was not**. This bad estimation, led shipowners to **order** ships suitable for almost a double distance (**Figure 2** & **Figure 3**). So, the **first cause** of **technical progress** was the**1st Suez Canal closure** in 1956**!**



Picture 1. The 1960-1970 bulk carrier. Source: Modified from that in Branch & Robarts.

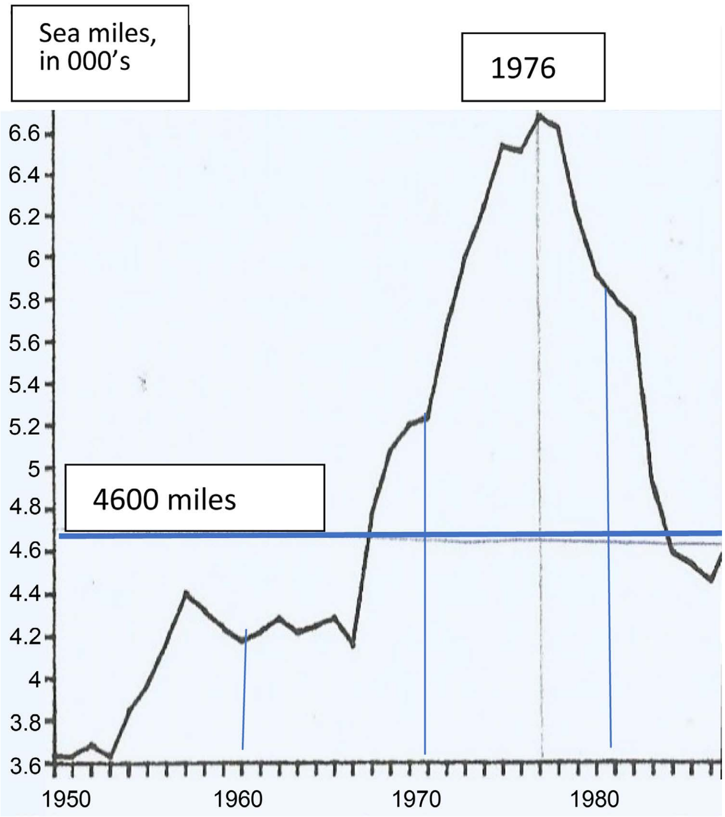


Figure 2. Average haul-length of oil shipments, 1950-1986. Source: author.

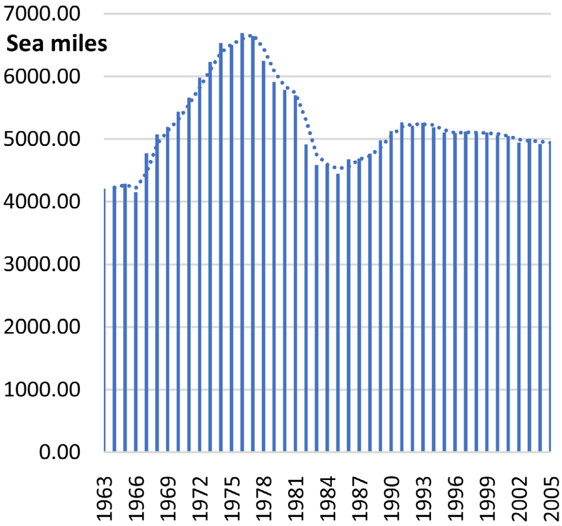


Figure 3. The Distances covered by tankers, on average, 1963-2005. Source: author.

As shown, between 1950, and 1953, distances for oil shipments were close to 3650 sea miles. Starting 1954, and **especially** in **1956-1957**, *when Suez Canal closed for the* 1*st* *time*, distances **reached 4400** (+20.5%; 1955-1966) sea miles, and stabilized at **4200** by 1966. Then came the 2nd Suez Canal closure in 1967, which was really long, lasting 8 years!

Canal closures followed the rule[18]: "the *longer* the *distance*, the *larger* the vessel"! As shown, after 1966, distances exploded from 4200 to 6700 (**+59.5%**), and in 1976-1977, tanker distances topped-up to 6695 sea miles! Then stabilized down to 5000 sea miles (2005).

Worth noting is that "distances" triggered an *important technical progress in the form of, not only of* ***bigger ships****, but also of* ***faster ones***! Albeit, while the longer distances **favored** the ship economies of scale, and technical progress, **oil prices** took the **revenge** on behalf of Arabs, because fuel became a very dear commodity in end-1973!

5.7. The Price of Fuel Oil

The characteristic of the 1st Oil crisis, (1973), was that the bunker prices increased 4 times[19], (from $20 per ton) to $80, and to $200 (10 times) in early 1980-1990! The above means that the *fuel cost* increased from $1800/day to $3600 for the $200 per ton[20] price.

Unfortunate was the fact that due to Suez Canal closure, ships became bigger, **before** *fuel becoming expensive*! They gained also an extra speed of 1.8 knots/day, which **increased** their **revenue**! Arabs (OPEC, est. 1960), however, terminated the myth of the cheap, available to all, and abundant, fuel oil, and **cancelled** the total technical progress of ships obtained **before 1973**!

The maritime business environment turned to a new unwritten page, and a new history started to be written! Should shipowners expect such a revolutionary change? Should those who invented the private car imagine such a development at the start of the 1900 century? Should business men be proactive than reactive? Surely there was and other fuel available in 1900s. Oil was selected and proved to be detrimental to the world economy and unfortunately to global climate as well! Are business-men blind?

The cost of fuel (**Figure 4**) became a **powerful** factor, and since then (end-1973) **prevented** technical progress, as new bigger ships **stopped** to be ordered, and **invited** it, in another time, for a *lesser fuel consumption* or even for an *alternative cheaper fuel*! This meant to "demand" from "ship engine manufacturers" to design an engine consuming **either less** quantity of fuel or a **cheaper** one and at higher speed!! A difficult puzzle!

As shown, in 1979, the oil fuel price more than *doubled*, till 1985, due to "Yom Kippur war", the "Iranian revolution" and the "netback pricing[21]". OPEC, a cartel of governments, caused the rises in oil price. Between 1986 and

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[18] We believe that there is a chain relationship between distance, ship's size, speed and price of fuel, not always all to the same direction. In certain ships, the *value of cargo* determines also vessel's speed (e.g., in containerships). The *longer* distances imply *fewer port calls*, and thus a lesser port cost, given that the port cost depends on ship's **dwt** (or rather on GRT/NRT) i.e., on size!

[19] The "heavy fuel oil" emerged in **1950-1960**.

[20] The "heavy fuel oil" in Rotterdam reached the mark of $200 per ton in **end 1980-mid-1981;** and greater than $150, from end 1979 till mid-1985.

[21] The price of oil after 1973 included all costs from extraction to buyer.

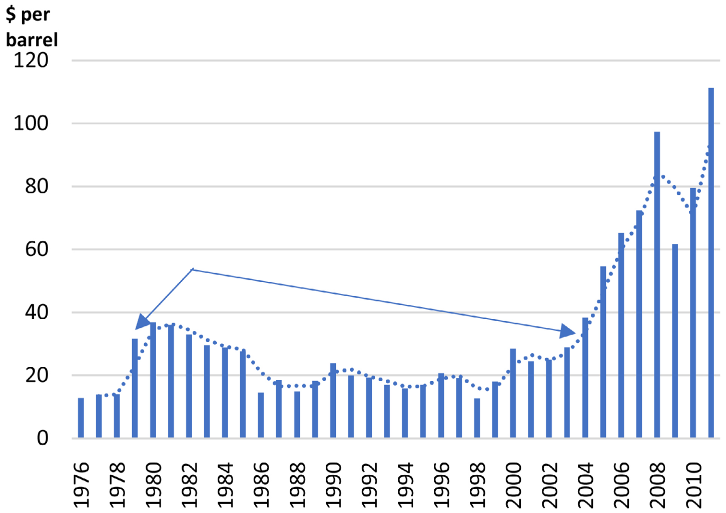

Figure 4. Spot crude oil prices in Brent, 1976-2011. Source: author; data from BP statistical Review, June 2012. (*) 1976-1983 forties; 1984-2011 Brent dated.

1999-with the exception of 1990: the oil prices fell near $20. In 2000, however, an upward trend took place again for the oil price to reach $111 by 2011! Pandemic in 2019 led oil price down to about $40.

The reasons for seeking for a "better" fuel oil, are not the same each time. Recently everybody realized, we believe, and par excellence EU, as well USA after Trump administration, that environment is **vital**; and for us is the **fourth** factor of production, and we have to include it into production function, and pay the cost to preserve it (Goulielmos, 2020a, 2020b). Climate will revenge the un-clever man, who believed that he is more powerful than mother-Nature! Germany's 150 dead have proved this in July 2021.

When the fuel oil is expensive, the substitution law of economics holds, pointing to the use of even coal; and natural gas, methanol, hydrogen, schist, etc. Moreover, the **expensive fuel oil** triggered the so-called "energy reservation measures" for the first time! Nations embarked in finding their own sources of oil (North Sea; Alaska; Aegean etc.) and other sources more friendly to the environment. But the effort was not uniform and was in grave delay.

5.8. Technical Progress in Main Ship Engines

In 1945, the choice of a shipowner was among: 1) a reciprocating *steam* engine, 2) a geared turbine, with high-pressure steam, and 3) a moderately-powered *diesel* engine. Forty-five years later (1990), the choice was broader, among steam, diesel, and gas turbines; and among medium—or slow-speed engines—single or multiple engine systems, direct geared or with diesel-electric drive! The output derived, n 1990, was greater from 30,000 to 90,000 HP. Engine manufacturers faced successfully the challenges of the very dear fuel oil… we believe.

The problem of the doubled distances in one night, in 1956, was solved within 2 - 3 years, by building **bigger** and faster vessels. But the problem of "better" main engines was more difficult, and this required a **longer time (1973-)**.

First, a cheaper fuel oil was used! D*iesel engines* replaced the steam ones, but they **could not cope** with the **bigger** ships! One technical progress[22] (diesel engines) prevented by another (economies of scale)[23,24]. T**echnical progress** embodied thereafter in a small % of ships fitted with ***diesel*** **engines[25]**, with 12 tons only of diesel oil consumption! This was a great economy. This caused, however, the **death** of the **steam** turbine engines (Hughes, 1996: Chap. 12).

The reason for the above was that when oil prices are high, ship's speed is a very expensive factor, and the horse-power is lower; also, the "thermal efficiency[26] issue" emerged with diesel engines (then at 40%). **Steam engines** were popular in tankers among USA and UK shipowners, but not among Norwegians.

The diesel engines[27] had a *high revolution* propeller system compared with the steam engines (100 - 110 against 70 RPM, in a VLCC), and they were *inefficient* in propulsion. So, they were candidates for replacement!

A diesel-engine in a VLCC—built in 1976—covered 5.4 sea miles/ton of fuel oil, while one built round 1995, performed 7.7 miles (an increase of ~43%). This improved performance is considered as something **typical** (Hughes, 1996: p. 185) for most types of ships in mid-1996. This had an impact on total ship performance, given that fuel oil cost was 30% of total annual cost (Buckley, 2008: p. 369) in 1980!

5.9. Remaining Inventions

Another invention at the time was the *self-trimming*[28] bulk carrier, important in the carriage of grain. The automation of machinery spaces, started in early 1960s, and led to the **unmanned engine room**. The 1981-1987 deep dry cargo shipping crisis revealed, as an **expensive** factor, ***labor on board for the first time***! This caused flagging-out and the birth of the "European dual registries" (Goulielmos, 2020a, 2020b). Less labor quantity was in the target of ship designers all along, where in old times (1860) sailing ships had about 55 persons on board! Artificial Intelligence may present also the unmanned ship!

Technical progress in ships depends on technical progress in advanced indu-

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[22] The low-speed diesel engines designed with a view to make the gearbox capable of reducing the propeller *revolutions*, especially with the medium-speed engines.

[23] The operation is on a 2 stroke (cycle) principle with crossheads & guides transferring reciprocating piston movement via connecting rods into saft revolutions. Larger cylinder bores were as low as 260 mm.

[24] The "crosshead" engines are distinguished from the "trunk piston ones".

[25] Steam engines were **replaced** by **diesel** engines made by Doxford, Harland & Wolff, Sulzer B&W and Gotarverken.

[26] "Derating" is a method to increase "thermal efficiency" of a main diesel engine. Here engine's reduced output is combined with maintaining the maximum combustion pressure (PMax). The "fully rated engine" had a lower unit cost vis-à-vis the "derated" one (i.e., $/horsepower).

[27] The 2 stroke turbo-charging in early 1950s improved, by increasing the degree of turbo-charging, leading to a higher cyclic pressures and temperatures… and higher **efficiency** by 13% (40% + 13% = 53%), but *expensive* power turbines had to be provided. A "fully rated" engine can achieve 55% efficiency by increasing cyclical pressures.

[28] A ship whose holds are shaped in such a way so that a bulk cargo loaded into her will level itself.

strialized countries, having also strong shipbuilding industries (e.g., USA; Japan; and others), and their customers, having expensive *national* crews, demand *reductions* in crew complement! So far, *automation* mainly in *engine room*, reduced labor on board worldwide.

Research into alternative fuels for marine propulsion is going-on today, including coal[29], hydrogen, methanol, natural gas, and… plutonium in the past. Some have also used wind power as an additional push. This is the area were technical progress faces its largest challenge of the whole its history! A cheaper and more friendly to the air environment fuel for ships larger and faster? This will be the invention of all centuries!

5.10. "Sea Time" Is the King, but "Port Time" Is the Queen in Shipping!

If we want to select only one factor for ship's technical progress this is s**ea time**, which depends mainly on **speed**. Another factor, of equal importance, if not higher, is **port time**, which depends on ports' (Table 3) technical progress.

As shown, an oil tanker gets a **partial** and **lower**, (39% in $ terms), benefit from her production, despite that her speed increased by ~7% (rounded), and her sea time reduced by 2.78 days per voyage. However, the fuel consumed increased up to 5271 tons-at a price of $101/ton, and over the same distance of 15,000 sea

Table 3. Time spent by ships at sea, in ports and in crossing canals depending on speed and port/Canal efficiency; on fuel quantity consumed, depending on speed; unchanged distances, 2008.

Case 1: distance 15,000 sea miles (tanker: 75,000 dwt)	Case 2: distance the same (tanker: 225,000 dwt)	Remarks
Speed: 14.5 k/day; **sea time** → 43.1 days	Speed: 15.5; **sea time** → 40.32 days	Saving 2.78 days; ~7%
Port time: 4 days; port cost: $90,000	Port time 8 days; port cost $360,000	4 additional days; $270,000 more cost!
Canal transit time: 2.25 days (Panama 1 day; Suez 1.25 days) (*)		
Fuel quantity at sea: 55 mt/day plus 5 mt/day at port plus 100 mt for other use, total = **3300 mt**	Fuel at sea etc. 5271 tons; fuel cost at the same price: $532,371; % on total cost: 36.2%	2471 tons fuel oil extra; plus $249,571 extra!
Fuel price: $101/ton = $282,800; 30% on total cost		
Total income $938,000	Total income $1,472,211	$534,211 extra income or 57%

Source: data from Buckley (2008), pp. 167-170, based on "Worldscale" calculations. (*) The Panama Canal charged to a ship, in 1992, of 60,000 dwt, $68,000; the Suez Canal charged in 1992 to a 250,000-dwt vessel, $295,000 (ballast); and in a vessel 60,000 dwt loaded charged $135,000 (Alderton, 1999: p. 224)!

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[29] The coal is mentioned in relation to a "coal fired steam turbine", or even a "steam reciprocating engine propulsion". Coal can be turned into oil.

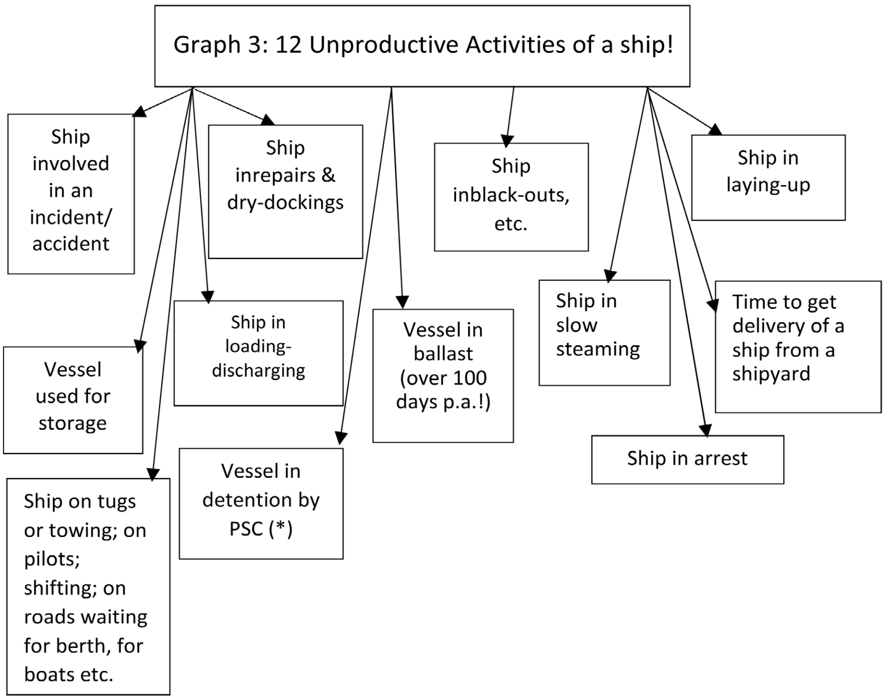
miles. The time spent in ports was longer—8 days against 4 and the cost of it was $360,000!

6. Part II: Determining the Framework of Production in Shipping Industry

What type of technical progress shipowners wish? TP in shipping is the one bringing *inventions* that make ship's production **faster** with **bigger** ships! We put this in two words: larger and faster! Worth-noting is that the contribution of Capital to production is dominant, in both, quantity and value, as mentioned. The complementary contribution of the Labor quantity, is comparatively smaller, as labor cost does not exceed 10% - 15% of the total annual cost of the vessel.

The vessel produces only 95% of her dwt, if she is fully loaded. But even so, the vessel does not **produce always**, as shown in Graph 3, because there is: the "ship's time lost in off-hire operations"! We believe that the most efficient shipping manager is the one managing the time of ships in a rather perfect way! But do managers/Captains pay the attention that **time** deserves in ship operations? We doubt.

The ship's carrying-productive capacity is determined also by the weight of bunkers, water, stores, crew, etc., which **restrict**[30] her 100% carrying capacity by



Graph 3. 12 Unproductive Activities of a ship! Source: Author; Stopford. (*) IMO Port state control.

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[30] Efficient Captains will optimize all items that reduce ship's carrying capacity so that these to be at a minimum possible. Captains may accept extra cargoes and gain an extra income for their company. The 5% of ship's dwt we assumed above is not **fixed**, and 2% of it may be saved, meaning a further income of $800 per day in a freight rate of $40,000, or $277,400 p.a. for 346.75 days p.a. We may call this: the effort to optimize ship's cargo spaces.

about 5% on dwt on average… Stopford (2009: p. 155), presented a number of ship's activities, which provide **zero** production. We added to his list a few factors missed by him (**Graph 3**).

As shown, there are 12 causes that **prevent** a vessel to produce fully! An efficient management has to *eliminate this time*. This is a serious waste of resources both for the company, but also for the economy.

Stopford (2009: p. 155) calculated the time for 4 of the above factors (namely: incidents, repairs, laid-up & storage), for a VLCC, in 1991, and found it equal to 21% or 73.5 days p.a. (on a 350-days year)! But, taking into account the loading/unloading and ballast time, the **productive time** of a VLCC is **restricted** to 140 days p.a. out of 350 (only 40%)! We understand that a VLCC is difficult to find a **return** cargo, but these figures are terrifying for any **efficient** management.

The production of a vessel is determined by the *distance* she has to cross and of course by the **speed** applied by her Captain[31]. **Distances** cannot be influenced by shipowners[32]. The actual production of a vessel per unit period, will be affected also by the time required to *cross canals* (Suez; Panama; etc.). Many exogenous variables act in shipping, which have to be controlled…

Moreover, the port time affects also the present, but also the future ship production! The port time depends on the *technical progress* **adopted by** ***ports***. This is true for gearless ships, i.e., those loaded/unloaded by port means. Port congestion is rather rare today, unlike 1975[33], and Canals' blockades are also sporadic and we will ignore them, though we had an incident in March-July 2021 concerning Suez Canal with the giant containership "Ever Given" to block Canal's traffic for 3 months! *An interesting question is who is going to pay Canal's forgone transit fees*?

Vessel's speed, however, remains the key-factor for ship's production for 3 main reasons (**Graph 4**). Managers have to decide about ship's speed[34] after a careful **study**.

It is worth noting that shipping industry re-introduced *time* in economics (Goulielmos, 2018). One knot (1855.2 m) of additional speed makes a voyage faster by 2.78 days for a tanker of 225,000 dwt (Goulielmos, 2021b) for a 15,000 sea miles round trip. This time-saving per voyage, for one-year, amounts to 83.4 days, for 30 voyages per year, providing a serious additional production and revenue!

However, the port time increases also by 120 days (30 voyages × 4 extra days) due to the higher quantity of crude oil to be loaded/unloaded! Apparently, tankers **failed** to ***increase the power of their loading pumps***! So, benefits from a

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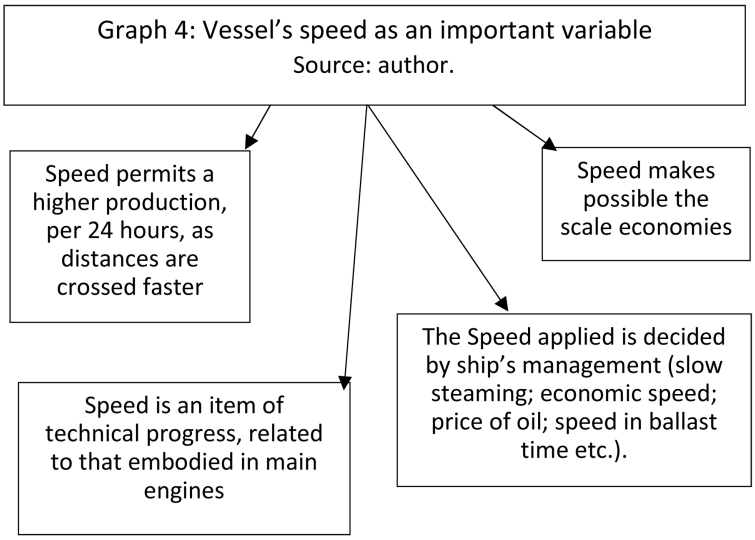
[31] There are influences from weather, sea currents, swells, terrorism, piracy, etc.

[32] There is a program indicating the 2nd best route, i.e., the most secure one. "Ship routing" services at a fee are provided with up-to-date weather predictions, avoiding storms, fogs, ices, etc.

[33] The Nigeria case of Lagos port waiting 3 months to discharge cement!

[34] The increase in ships' speed is more impressing, if we get long historical time. In 1870 a ship 2970 dwt had a speed of 7 knots; another, 5 times larger, had a speed of 15 k., 100 years latter!



Graph 4. Vessel's speed as an important variable. Source: author.

higher size and an increased speed, can be **cancelled** by a longer port time!

Given that the cost of transport is paid by consumers, Governments had to push their **ports** towards additional technical innovation in reducing the time spent by ships across their production line, *including receiving and discharging cargo and oil*!

This paper has **contributed** by underlining this important target, we believe! The importance of time in shipping is further shown in Graph 5.

As shown, **time** is a very important technical, as well economic, factor in shipping business, which has not received the attention it deserved… But "latter is better than never". Ports should not hide under their carpet or behind their state or municipal nature, providing to them a monopoly[35], but they have to adopt technical progress in advance of ships that my call… Otherwise the technical progress embodied in ships is done in vain… as we showed!

7. Part III: The Production of Tankers, 1963-2005

Idle productive capacity is another waste of resources in shipping. Figure 5 indicates the idle capacity, that crude oil tankers **could** put to production, for the recent 43 years, **if demand** supported them, and supply was more rational.

The above bad situation continued and after 1979, with the exception of 1980, and in 1981-1987. The sacrifice involved amounted in 1963 to 1.7 m dwt, but increased after 12 years, to 27.9 m dwt (1975), and increased more thereafter, between 1976 and 1979. In a tanker crisis, tankers are used for *storage*. They are also used to carry grain, after be *cleaned*. Unfortunately, tankers become also laid-up, when demand falls, like in 1975. In 1983 this idle capacity approached 70 m dwt!

As shown, the tanker sector was depressed in 1975, when oil seaborne trade

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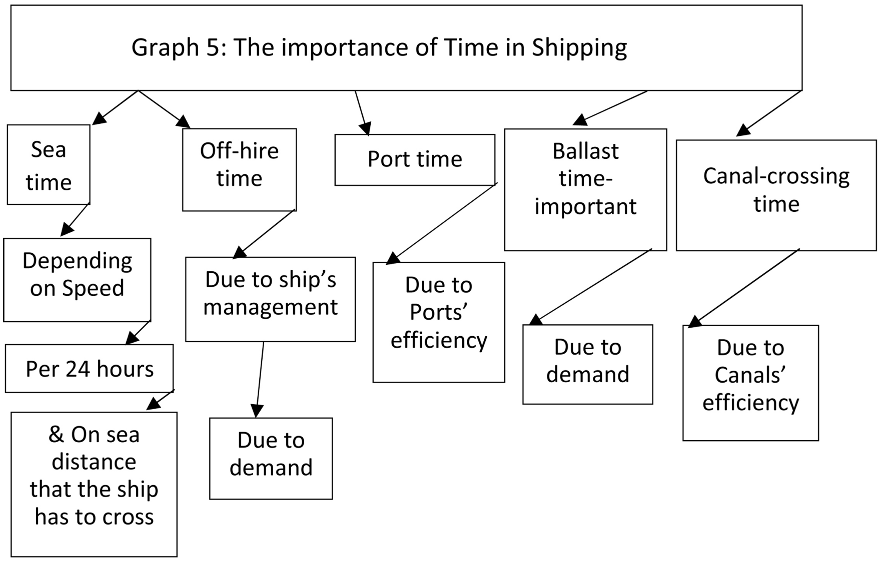
[35] Alderton (1999: p. 225) wrote that for the **same ship** in 1988 Finland ports charged $150,000, while Lisbon only $12,500!!! How is this possible??



Graph 5. The importance of time in shipping. Source: author.

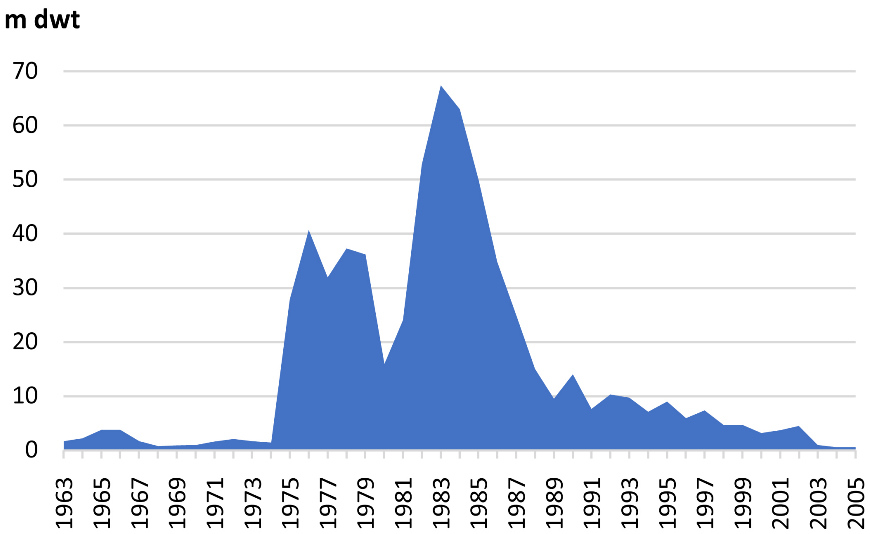


Figure 5. Tankers laid-up, in storage and in carrying grain, 1963-2005. Source: author; data from Stopford (2009: p. 748).

for the **first** time fell. This depression lasted till 1988 (12 years), while in 1980, it had a retreat. The relationship between demand for tankers and supply for them is shown in Figure 6.

As shown, the tanker demand had a cyclical behavior with a low in 1985 (blue line), while its decadence started in 1979. A *part* of the active tanker fleet (red line) served oil trade. The fleet responded to a higher trade between 1970 and 1980.

The Productivity of Tankers

More important of all is Figure 7, dealing with the tanker fleet, showing its **productivity** and **Capital's marginal product!** Unbelievable!

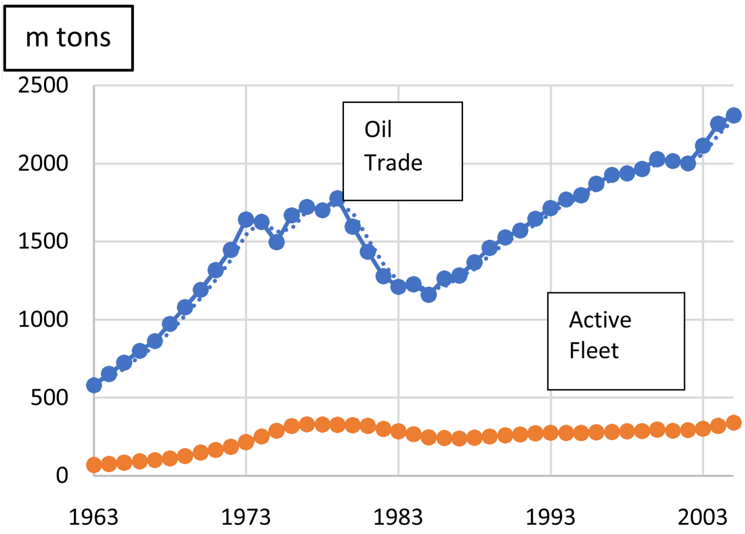


Figure 6. Supply and Demand for Tankers, 1963-2005. Source: Author; data from Stopford.

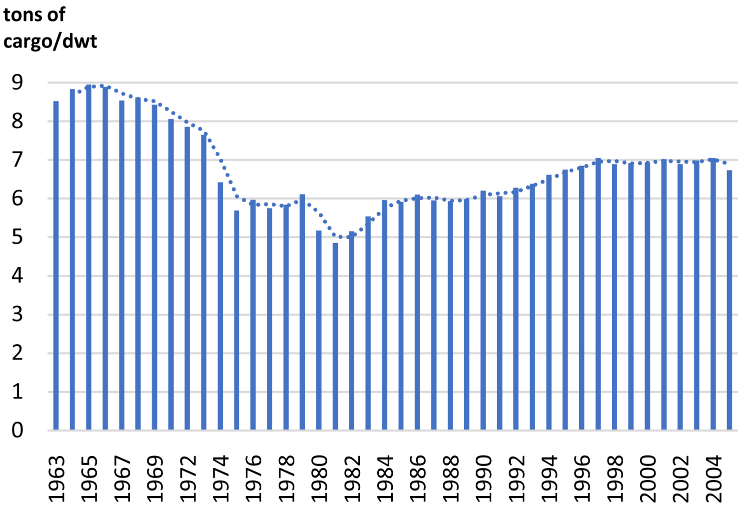


Figure 7. Tanker fleet productivity, tons per dwt p.a., 1963-2005. Source: author; data from Stopford.

Capital's marginal product—MP_c—can be defined as: the increase in capital quantity by 1 ton (dwt), and the increase in tankers' production. This was 8.95 tons (1965 top) of cargo carried, assuming a constant crew quantity. This MP_c fell in 1967 to 8.54 **tons**, and to about 7, in 1997-2004. One may ask here: if technical progress increased tanker production, *why fleet's productivity fell*…?

Stopford informed us (p. 243) that ship's productivity depends on the: 1) average operating *speed* (per hour; and over 24 hours); 2) *loaded days* at sea p.a., and 3) dwt % *utilization*.

The crisis in tankers, 1979-1987, reduced the loaded days at sea, and the % utilization of ships. It is important to mention here that the role of demand, in the *diffusion of technical progress*, which comes from new buildings, is a **key-factor**. Thus, shipping depressions, ***discourage*** *the* ***order*** *of* ***new ships*** *and* *thus the* ***coming*** *of* ***technical progress, if it*** *exists in shipbuilding. We wrote elsewhere that a research and development department is quite necessary in shipping companies, but we see it nowhere!*

Ship productivity fell further from 6.11 to 5.95 tons (1979-1987). Technical progress pushed-productivity -up slightly between 1988 (5.93) and 1991 (6.06), where a heavy ordering of 55 m dwt took place; also, in 1995, the shipbuilding output over doubled from 15 m to 33 m dwt, proving our argument.

In ship's production *distances*, however, cannot be ignored (**Figure 8**). Above (in **Figure 7**), we calculated productivity **free** from the impact of distances.

As shown, distances increased in 1967, due to 2nd Suez Canal closure (in May), for 8 years (till June 1975)! This had as a result **bigger** ships to be built, as distances increased by 2543 sea miles between 1966 and 1977. Thus, the **major technological… invention,** which took place, was to **face** the **increase** in **distances** by a **subsequent increase** in **sizes** of **ships,** and **their speed!** The importance of distances made us to present them twice.

Important for shipping is the cost of the raw material that is used to build ships, i.e., the **steel**. Shipping depends on so many other industries that they have to adopt technical progress too. The steel industry also passed through a series of technical developments (Besanko et al., 2013: p. 51). The steel industry initially produced high-volume products, suitable also for shipbuilding, where in early 1950s the *lighter*[36] steel products emerged.

It has been used the so-called "basic oxygen furnace" (1950), the continuous

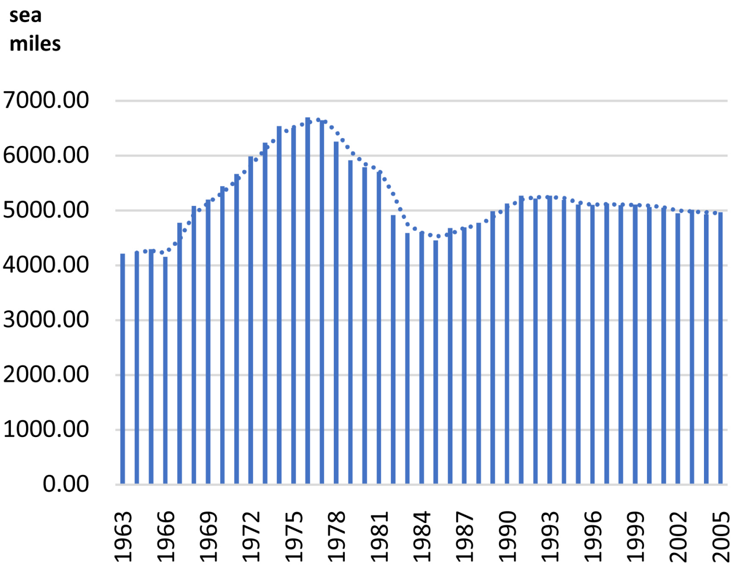


Figure 8. Distances covered by tankers on average, 1963-2005. Source: author, data from Stopford (2009: p. 748).

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[36] The weight of the vessel is a serious factor in order to make ships faster and larger! Initially ships were made by iron. Moreover, iron plates were nailed one on the other and nailed down with iron-rivets—additional weight. Ships, latter, were made of steel—a great TP—using electro-soldering-another great TP, and steel plates' soldering made one next to other without overlapping. Latter steel produced lighter—another technical progress.

casting process (1960s) and the scrap metal processing, using the “electric arc furnace”. In 1970 the scrap steel (due to discarded **cars**) introduced, followed by “mini-mills” (small producers) which converted scrap metal into finished steel products. In 1988, 93% of all Japanese firms adopted the “continuous casting process”. Modern societies produce millions of discarded cars, not taking into account useless ships. We are not sure if new material will be used in the construction of ships, but if this is lighter, cheaper and stronger, it will be of a technical advance.

Delivery of newly-built ships is the *agents* of *technical progress*, and as shown (**Figure 9**) in 1967, 1971 and 1977, this occurred. But deliveries *did not exceed* the 10% of existing fleet. Orders, at the same period, reached 23% maximum of the existing fleet, in 1957 (20.5%), 1970-1971 (23%) and 1975 (20.5%). We see that deliveries are about 50% of orders, and there is a construction time between ordering and delivering.

In the 1st semester of 2021, almost 11m “compensated gross tons” of ships ordered in e.g., the S. Korean yards, the bigger since 2008! Cgtis equal to A* gt^b, where A expresses the influence from the ship type. E.g., an oil tanker, with double hull, has A = 48, while a car carrier has 15; b states the influence from size and gt is the gross tonnage. For tankers this was, in 2005, 0.57 (Stopford, 2009: p. 752-754).

Our feeling is that shipping will expand enormously in 2021 and thereafter, trying to rectify the low growth rates since end-2008-2021.

To make our analysis complete, *scrapping* is also a positive agent of technical progress (**Figure 10**), because *it removes old technology* from market in a permanent way, unlike laying-up, which is a temporary withdrawal!

As shown, scrapping peaked in 1986 with 29% of the existing vessels of an age of over 15 years. We see that scrapping is almost 3 times higher than deliveries, meaning a reduction in fleets. In July 2021, the price of scrap steel reached $600 per ton indicating an excess demand, perhaps due to the inactive period of the Pandemic!

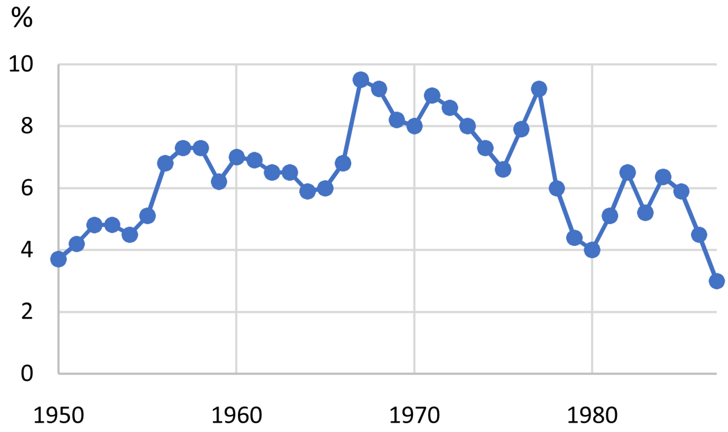

Figure 9. Deliveries of dry cargo ships as a % of total fleet, 1950-1987. Source: author; data from Beenstock & Vergottis (1993), p. 35.

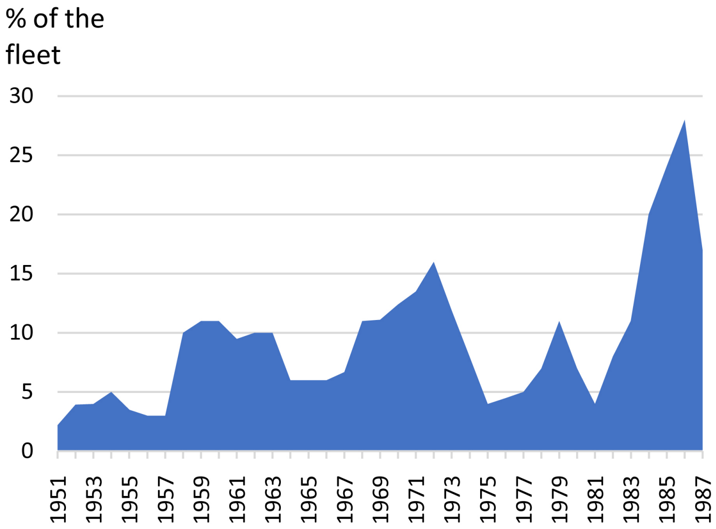

Figure 10. Scrapping, dry cargo, 1951-1987, ships of 15 years and over. Source: author; data from Beenstock & Vergottis, 1993, p. 35.

8. Part IV: Estimating Technical Progress in Shipping

Now, we will try to perform two estimations: 1) shipping technical progress in physical (production) terms, i.e., in tons, and 2) shipping technical progress in $ terms.

1) Let us take a newly-built tanker having a Capital quantity of 30,0oo dwt with a labor quantity of 26 persons, (data from Buckley, 2008: p. 369). She produces 28,200 tons per voyage. Her production function, in Cobb-Douglas form, therefore can be: $28{,}200t = A_t 30{,}000^{\beta} 26^{\alpha}$. Assuming $\alpha = 0.15$ and $\beta = 0.94$, then $A_t = 7.04\%$. Given that $\alpha + \beta = 1.09 > 1$, there are also *economies of scale in tanker shipping*.

The constant α put equal to 0.15, given that this is the share of labor to total voyage cost; constant β put equal to 0.94 as this is the share of capital to total voyage production. *This means that with constant Capital and Labor, in shipping, a shipowner can produce about* 7% *more production due to existing and embodied technical progress*!

Cobb & Douglas (1928) found $A_t = 1\%$. Goulielmos (2021b) found[37] $A_t = 7\%$ for tanker shipping, where $t = 2008$, due to a higher speed by 1 knot. Moreover, increasing capital quantity by 3 times, the tanker production increased by 5.5%, (rounded), i.e., beyond the 3-time increases in Capital, on data from Buckley, 2008: p. 165-170), due to the bigger size of a 225,000-dwt tanker (**Table 4**).

2) Now, we will estimate the contribution of technical progress to shipping industry by finding-out the reduction in sea transport cost (freight rate) that achieved over the whole post 2nd World War (61 years), using a *deflated* **freight rate** index found in Stopford (2009: p. 757-758). The signs of technical progress in shipping, as shown (**Table 5**), are four.

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[37] This based on the increase of ship's speed by 1 knot. This meant a rise in average speed of a tanker from 14.5 knots to 15.5 knots or +7%.

Table 4. Estimating technical progress in tanker chartering, 2008.

Change in Capital's quantity by:	Change in Labor's quantity:	Change in Production	Change in speed	Technical progress
+150,000 dwt	Assumed constant	147,329 dwt (219,029 - 71,700) due to bigger size; 15,102 dwt due to higher speed	+1 knot; benefit 2.78 days per voyage	5.5% more production due to size; 15,102 more production due to speed or 10.25% on next production; total 15.73% benefit

Source: author; data from Table 3.

Table 5. Signs of main shipping technical developments, after 1945.

Signs	Sign	Sign
Bigger bulker ships > 100,000 dwt (1995); Capes emerged > 100,000 dwt	More efficient engines	Specialized ships (1975): a continuous & pervasive trend
Improved on-board technology, which led to unmanned engine room	Result→	→Reduction of the cost of sea transport by about 2/3

Source: Inspired by Stopford.

The technical progress is **encouraged** by the existence of an **adequate demand** for the services produced! We did not fail to stress this reality… The post 2nd war sea trade rose more than 6 times (from 500 m tons to 3.2 billion tons, 1950-1973). Shipping companies improved also their familiarity with computers, and especially with PCs. Recently adopted also digitalization (Goulielmos, 2020a, 2020b). Before we proceed, we need to prove the next question.

Are Shipping Markets Perfectly Competitive?

For the argument that technical progress led to a lower transport cost per ton for charterers, we have to prove first that shipping industry is ***competitive***, because then price rests down on *minimum* average cost. We can say that shipping markets of dry and liquid cargoes are *competitive*, meaning that there are a very large number of small charterers and shipowners, acting independently, and no one can influence freight rate (price).

We know that in shipping exist, on average, about 10,000 shipping companies small, medium and large. About 70 large shipping companies are in the first 10 top maritime nations (=700) (Goulielmos, 2017), which can **influence** supply for orders of a few million dwt and over! In charterers, too, exist large influential companies like the 7 oil majors in the past. capable of influencing supply. We will assume that shipping markets are purely competitive, *but not perfect*.

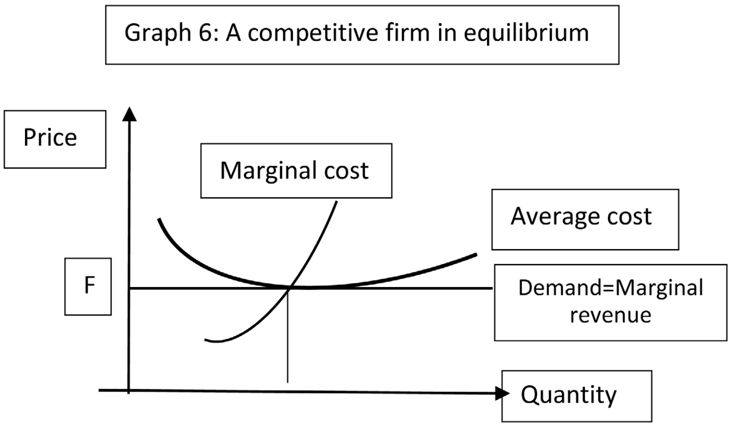
Perfect competition is surely *rare* in real life, and it demands: 1) identical services[38], called homogeneous, with *perfect information*; 2) free entry[39]; this is more massive if profits are *above* normal; the **free entry** in shipping is important-and there is also a well-organized 2nd hand ship market as when profits are above normal, new shipping companies **enter**, and normal profits are eliminated (**Graph 6**).

As shown, average cost equals freight rate in the long-run. As it is known, in the average cost, also normal profits are included. This is why people prefer perfect competition, as they pay the minimum possible, vis-a-cis imperfect markets! However, the average cost here **is not** only of the most *efficient shipowner*, **but also** of that of the "**marginal**" shipowner, who has the higher cost of all others!

So, competition provides the elimination of super (monopoly) profits, but not the *elimination of high-cost firms*, ***needed** to **satisfy demand***! This means that new ships may be required to enter, but as shown elsewhere (Goulielmos, 2021a), is not guaranteed that the ***new ships*** have the lower *total average cost* (in the long run)!Worth noting is that competitive are not the newly-built ships, as most great economists, but Keynes, assumed for new machines! To be so, the newly-built ships have to have **prices** below the prices of the vintages before them! Then are more competitive. Greek shipowners know this…

Given our assumption that technical progress reduces the long run average freight rate (or cost of transport), using faster and bigger ships, and achieving shorter sea times, this, however, has to be confirmed by data (**Figure 11**) (Stopford, 2009).

As shown, the **real** (free of inflation) cost of sea transport, after reaching a top high in 1950-51, and in 1956, due to Korean War and the 1st Suez Canal closure in 1956 fell down to **400** units, till 1972 (−60% for 14 years). There was an interval between 1973 and 1974, due to the 1st oil crisis in 1973, when shipping was



Graph 6. A competitive firm in equilibrium. Source: author.

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[38] "Perfect information" does not exist. Are all shipping companies complying equally with ISM Code (an ISO maritime standard)? Are all vintages of ships equally safe?

[39] This assumes a rather low capital cost or low shipbuilding prices and low 2nd hand ones and an easy access to shipping finance. The availability of finance and its level determines also the size of the vessel and her vintage! As ships get bigger, the sum to build or buy them gets higher and apart from risk, it becomes more difficult for medium and small companies to find it.

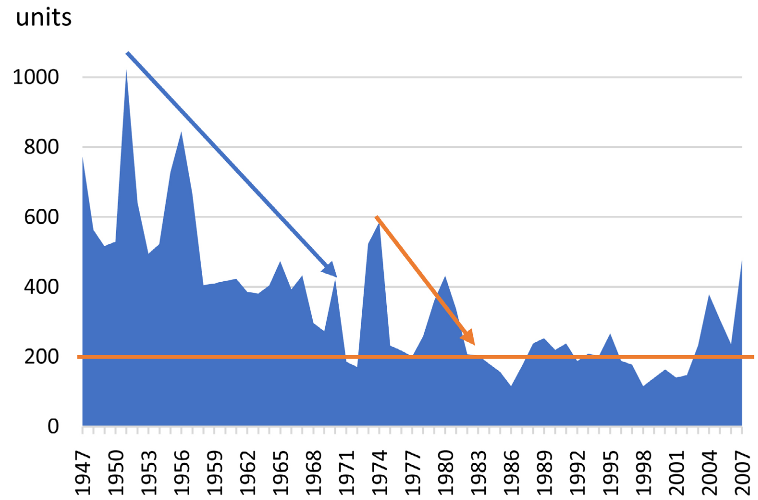

Figure 11. Maritime economics index 1947-2007, deflated by 2000 prices; 1947 = 772. Source: data from Stopford (2009: p. 757-758).

producing at a higher sea cost, and then returned to **400** units' mark, continuously falling till 2006.

Given that a *typical* low sea cost is **200** units of the index, then technical progress reduced sea cost by 2.6 times in 1947-1970, and from 1971, with the exception of 1972-1974, due to the 2nd oil crisis in 1979 to 2007, by 2.4 times, a total of 5 times. So, A_t = 8.2% per annum (500%/61 years) in money terms. Inflation excluded, but, 4 wars, 2 oil crises, longer distances, 2 Suez Canal closures, were taken into account! We wonder what the progress of shipping could be, if there was peace!

9. The Research Significance and the Main Contribution

All maritime economists have taken for granted that shipping industry is one of continuous technical achievements, but without providing proof for this in either physical or monetary nature. Apart from certain remarkable advances in ships' sizes, nothing has been discovered in the production function of the individual vessel despite the long existence of the celebrated Cobb-Douglas production function. First, we proved in a definite way that in shipping there increasing returns to scale, meaning that it pays to pursue economies of scale if demand exists. Further, we calculated the share of Capital and Labor in the production, with the lion's share to go to Capital, which is a right thing to see. The remarkable finding is that 8.2% per annum in $ terms technical progress passed on to charterers, and perhaps from them to consumers. In physical terms 15.73% additional production has been provided by the innovations applied in tankers.

10. Conclusion

Analysis covered the last 75 years of technical progress in shipping industry, since 1945. One definition, and target, of **technical progress**, was to improve **vessels' performance**, and finally to **reduce** sea cost! However, the price of shipping services is determined in the first step by **demand** and **supply**, and the cost of shipping adjusts to it in a second step, following the rules of a competitive industry. Sea cost rests there down on long run average cost, free from monopoly profits.

An all-embracing factor reflecting technical progress in shipping was **time** spent in production. The advances in shipping technology, we believe, were in the right direction all along, and tried to achieve **less** maintenance, **fewer** crew, and **lower** shipbuilding cost! The last one is the most important! Economists assumed wrongly that new machines are cheaper (they are not due to a higher depreciation and profit requirements on capital invested).

As shown, using physical data of shipping production, and also monetary data, technical progress for the period of the last 61 years achieved a money benefit to world economy of 8.2% **p.a.**, mainly aided by **faster** and **bigger** ships. In physical terms, production increased by 15.73%.

Technical progress in shipbuilding, reducing ship prices, is of **prime importance** for shipping. Of course, the shipbuilding cycle, following the shipping one, will reduce prices of ships, liking it or not! One step of course is to produce a still cheaper and lighter, **steel**, but equally strong; another step is to reduce the building time using digitalization; a third step is to economize on materials, on engines etc.; a fourth step is to use cheaper, but skilled, labor, perhaps using educated females.

This paper produced important policy implications for ports for which also we added an appendix. Ports have to adopt technical progress *at the pace* that ships embody it! Otherwise, they harm ships. Ports must realize that they provide services to ships, and these services must be produced at lower cost than hitherto.

Ports from monopoly firms must **become** competitive ones. Ports achieved reductions in costs, but was this for own benefit, or for the benefit of ships? The gross average speed of cargo-handling, per hatch, all right increased from 80 tons/day in 1950 to 100 in 1970, but there is a large room for further improvements. Are port pumps for tanker unloading[40] properly at 10,000 tons or so of petroleum per hour?

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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[40] "Louisiana offshore oil port" in 1981 processed more than **1 m** barrels of petroleum …per day! This copied by others, thanks God.

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Appendix: Certain Policy Implications for Ports & Fuel Oil Suppliers

Ports and Bunker Suppliers get lion's share out of ships (!): $892,271 out of $1,472,211 or 61%! So, the efforts of shipowners must be to reduce the time spent in ports and **demand** also a lower port cost, via INTERTANKO or INTERCARGO.

The port cost to be charged on the true carrying capacity of the ship, which is ship's *net dwt* (**less** stores, bunkers and water…). These 3 items are transported **free**, but they increase by almost 60%, going from a standard tanker of 75,000 dwt to a 225,000 dwt!

Captains have to optimize (minimize) the factors, which antagonize[41] dwt: stores etc. (200 tons), water (500) and fuel (5271), which were 5971 tons totally or 2.65%, on a total dwt for a 225,000-dwt tanker! These items cost $6.72 per mt or $40,125 per almost 50 days (plus 1 Suez Canal transit)! For a 7-voyage-year the above comes to $280,875! Of course, the **proper** amount of fuel cannot be reduced, and it had to be adequate for the ships to cross from point A to point B of bunker supply, plus to cope with weather conditions, and so on, but stores[42] and water **could be reduced**. Certain ships have desalination units to economize on water. My analysis has revealed as a by-product that ports, they should provide to ships the so called "external economies" by applying newer technological progress.

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[41] Captains may be in trouble to ascertain the true dwt of a ship, as after delivery any additional constructions may take place and a number of machines may be added on board and even fixed. This is more common in passenger ships! Whatever or whoever gets up on board reduces ship's dwt by its, his/her weight!

[42] This reminds me of certain of my theories inspired by the Japanese practice of "just in time". Japanese wanted to transform labor from a variable coefficient of production, into a fixed one, believing in "life employment" by conglomerate employers! Later this abandoned. To do that, they decided to minimize all kinds of stocks (spare parts in particular). This meant to maintain the minimum possible stock, say to one spare part, on the idea that a 2nd spare part can be delivered on next day (coupled with what is known as "door to door") upon request! In shipping, when helicopter transport will become cheaper and all larger ships will obtain a pad, transport of spare parts can be done in a **just in time** fashion. One may think a company with 30 ships having an average budget for spare parts, stores etc. and a stock of $100,000 p.a. for each vessel on average, kept at that level!