Maritime Economics & Logistics (MEL)

P2: Shipping Management:
(Optimum Speed and Size of Ships)

Port & Maritime Organization – I.R. Iran
Tehran, Iran, October 2016

Recommended Reading:

1. UNCTAD *Review of Maritime Transport* (various years); freely downloadable from www.UNCTAD.org
2. Haralambides: Determinants of Price and Price Stability in Liner Shipping
3. Haralambides: Structure and Operations in the Liner Shipping Industry
4. HE Haralambides: Special Handout
5. HE Haralambides: Works on http://eur.academia.edu/HerculesHaralambides
6. HE Haralambides: Works on https://www.researchgate.net/profile/Hercules_Haralambides

Supply of Tonnage

The supply of tonnage is distinguished in 'physical' supply (measured in dwt or any other measure of capacity, e.g. TEUs) and 'effective' supply (measured, same as demand, in dwt*miles, TEU*miles, etc.)

Physical supply simply expresses the amount of shipping capital (stock) at a point in time, and it is given by:

$S(p)_t = fleet_{t-1} + deliveries_{(t-1)t} – scrapping_{(t-1)t} – losses_{(t-1)t}$

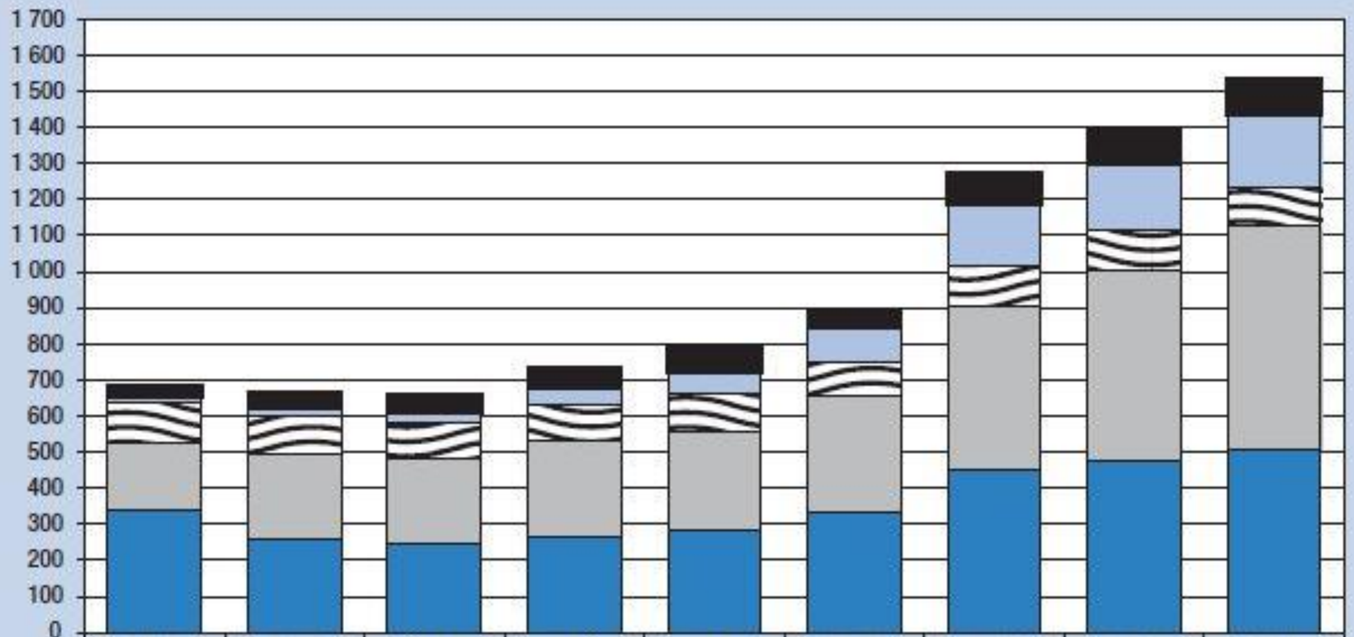
Effective supply gives us the amount of service provided by the fleet during a period of time (flow), taking into account 'fleet productivity'. Thus,

$S(e) = S(p) * dwt * miles / dwt$

In maritime economics, effective supply is the relevant variable

World fleet by principal vessel types

(selected years, beginning of year figures, millions dwt)



	1980	1985	1990	1995	2000	2005	2010	2011	2012
Other	31	45	49	58	75	49	92	96	100
Container	11	20	26	44	64	98	169	184	198
General cargo	116	106	103	104	101	92	108	109	106
Dry bulk	186	232	235	262	276	321	457	532	623
Oil Tanker	339	261	246	268	282	336	450	475	507

Source: Compiled by the UNCTAD secretariat, on the basis of data supplied by *IHS Fairplay*.

[a] Seagoing propelled merchant ships of 100 gross tonnage (GT) and above.

2012: 1.5 billion tons dwt

World fleet by principal vessel types 2011-2012
(beginning of year figures, 000 dwt, (%) in *italics*)

Principal types	2011	2012	Percentage change 2012/2011
Oil tankers	474 846	507 454	6.9
	34.0	*33.1*	*-0.9*
Bulk carriers	532 039	622 536	17.0
	38.1	*40.6*	*2.5*
General cargo ships	108 971	106 385	-2.4
	7.8	*6.9*	*-0.9*
Container ships	183 859	198 002	7.7
	13.2	*12.9*	*-0.3*
Other types of ships	96 028	99 642	3.8
	6.9	*6.5*	*-0.4*

Principal types	2011	2012	Percentage change 2012/2011
Liquefied gas carriers	43 339	44 622	3.0
	3.1	*2.9*	*-0.2*
Offshore supply	33 227	37 468	12.8
	2.4	*2.4*	*0.1*
Ferries and passenger ships	6 164	6 224	1.0
	0.4	*0.4*	*0.0*
Other/ n.a.	13 299	11 328	-14.8
	1.0	*0.7*	*-0.2*
World total	1 395 743	1 534 019	9.9
	100.0	*100.0*	

Source: Compiled by the UNCTAD secretariat, on the basis of data supplied by *IHS Fairplay*.
Seagoing propelled merchant ships of 100 GT and above. Percentage shares are shown in italics.

224 m.dwt of this, or 16% of world tonnage, is of Greek ownership. 70% of which, however, is registered under flags of convenience.

Cargo carried and ton-miles performed per dwt of the world fleet

Year	World fleet (million dwt)	Total cargo (million tons)	Total ton-miles performed (thousands of millions of ton-miles)	Tons carried per dwt	Thousands of ton-miles performed per dwt
1990	658	4 008	17 121	6.1	26.0
1995	735	4 651	20 262	6.3	27.6
2000	808	5 871	23 693	7.3	29.3
2004	896	6 846	27 574	7.6	30.8
2005	960	7 109	29 094	7.4	30.3
2006	1 042	7 416	30 686	7.1	29.4

Sources: World fleet: Lloyd's Register – Fairplay (dwt: mid-year data for 1990, year-end data for all other years shown); total cargo carried: UNCTAD secretariat; ton-miles: Fearnleys, *Review*, various issues. Data compiled by the UNCTAD secretariat.

NB: Tons/dwt = Number of roundtrips per year

Fleet Productivity

But what determines how many tons of cargo will be carried each year, or how many ton-miles will be performed, by the average ship of the world fleet?

Fleet Productivity

Fleet productivity tells us how many tons of cargo will be carried, or ton-miles performed, per year by the average dw ton of the world fleet. This can vary significantly, depending on:

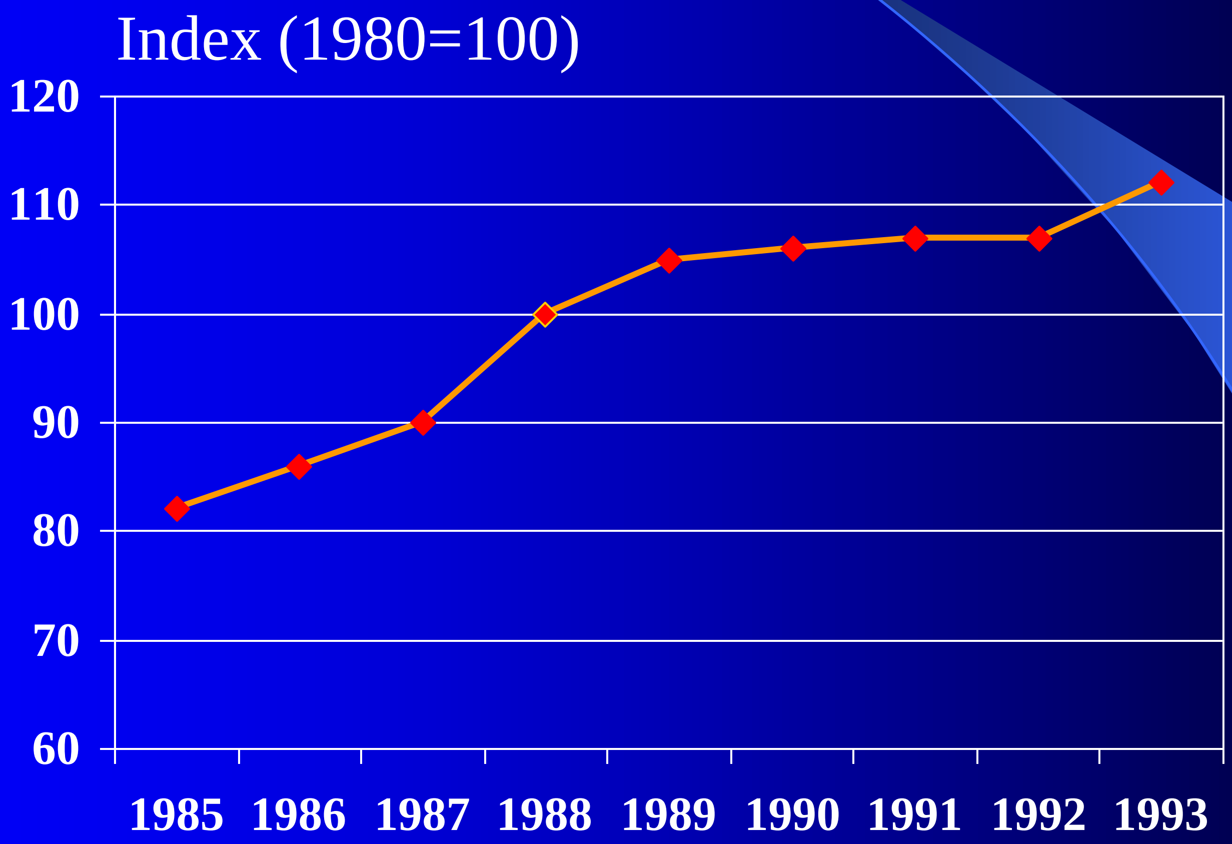
•Steaming speed of ships (function of the freight market)

•Cargo handling productivity in ports

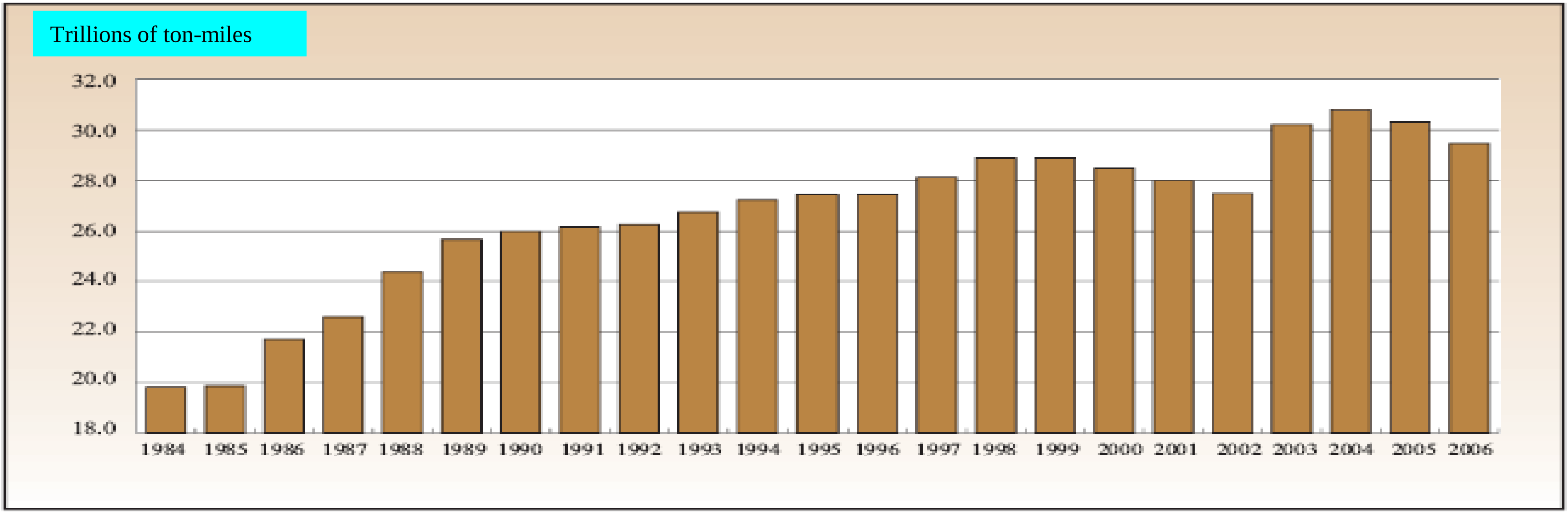
•Other factors

Fleet Productivity

(index of ton-miles performed per dwt of world fleet)



Ton-miles Performed per dwt of Total World Fleet 1984-2006



Source: UNCTAD calculations.

NB: decreases correspond to supply adjustments due to declining demand

The Four Stages of Supply Adjustment

...the more you wait for the bus to come, the more you keep on waiting just because you have waited so long already.. **Z. Zannetos** (*The Theory of Tankship Rates*)
[expectations are sticky (inelastic) but not in shipping; this precipitates shipping cycles]

- **STAGE I:** *Inelastic Supply* ⇩
  - Operators wait for firmer market indications (*it costs money to reactivate a laid up ship*)
- **STAGE II:** *Elastic Supply* ⇧
  - Decrease in lay-ups
  - Increase in speed
  - Postponement of maintenance
  - Avoidance of long-term contracts
  - Avoidance of long-distances
  - Avoidance of "poor" cargoes
- **STAGE III:** *Inelastic Supply* ⇩
  - Monopolistic power
  - High demand on shipyards
  - Inelastic supply of newbuildings
  - Long delivery times
- **STAGE IV:** *Long-run Supply Becomes Elastic* ⇧
  - New tonnage enters the market
  - New technology lowers costs and freight rates

Impact of Speed and Cargo Handling Rate on Effective Supply

(the basic formulas)

$$t = 2\left(\frac{d}{s} + \frac{2Q}{r}\right)$$

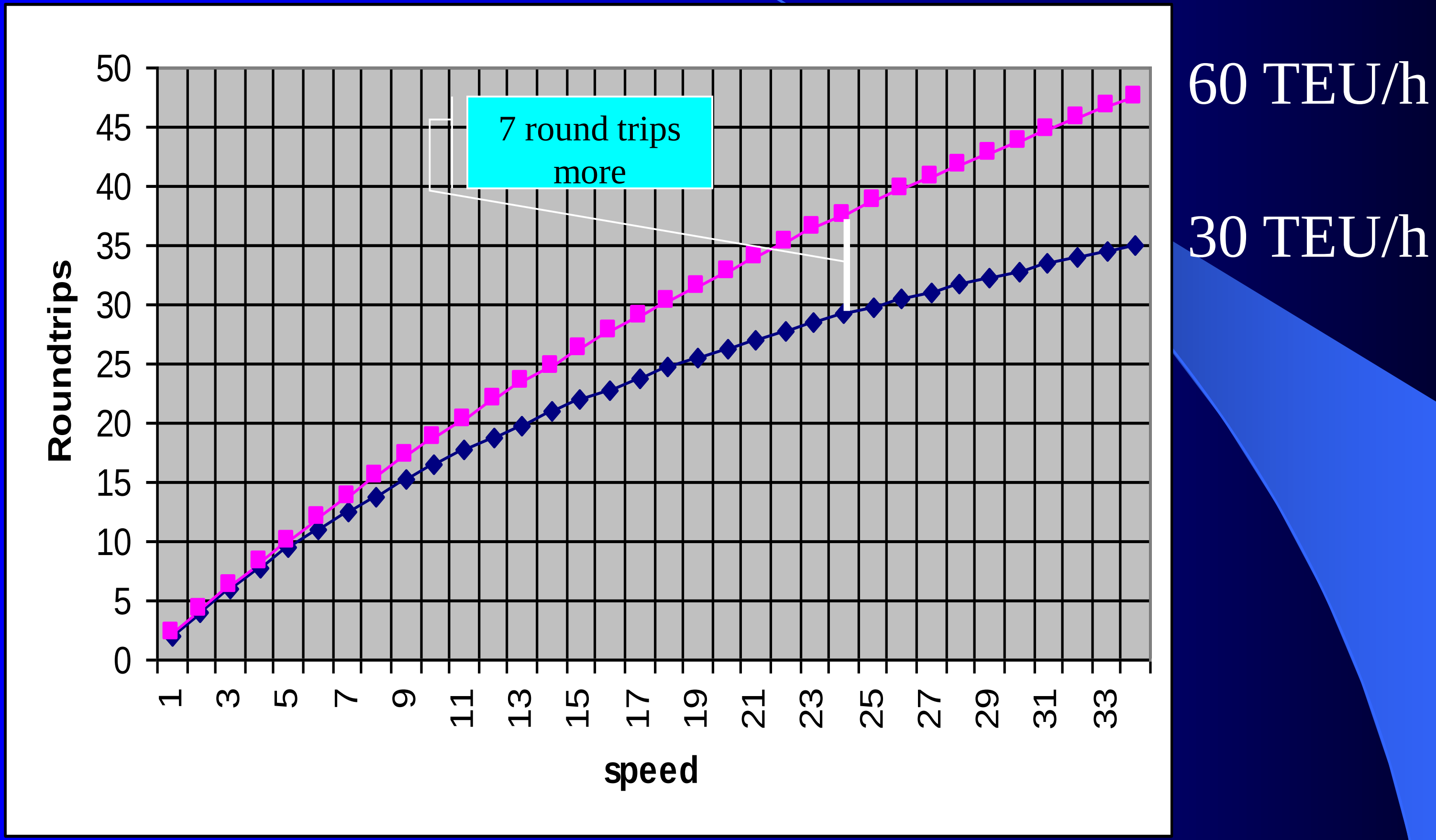
$$n = \frac{A}{t}$$

$$n = \frac{A}{2\left(\frac{d}{s} + \frac{2Q}{r}\right)}$$

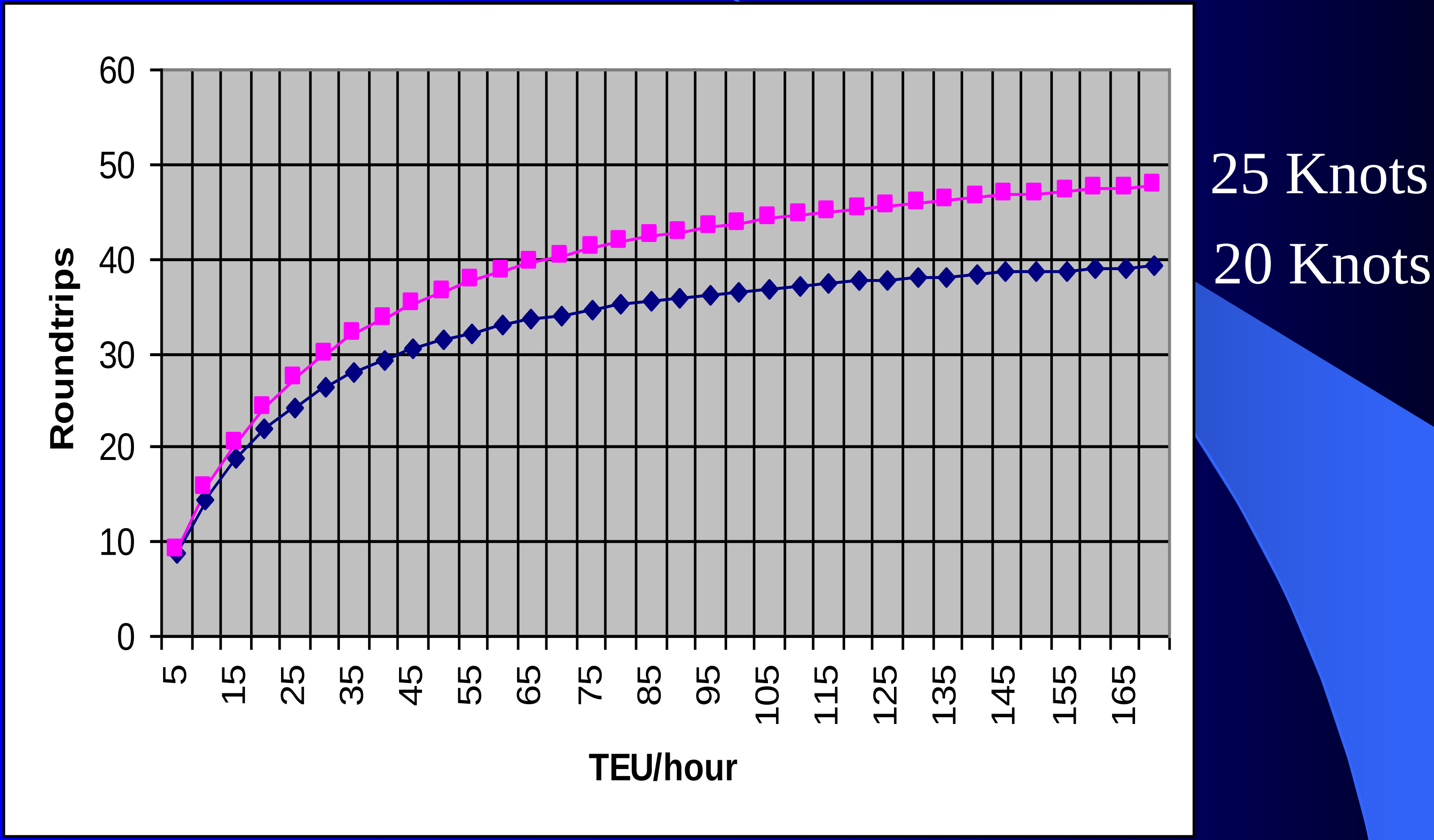
t=round trip time (hours)
d=distance between ports (nm)
s=speed (knots)
Q=capcity (DWT or TEU)
r=rate of cargo handling (TONS or TEU/hour)
n=number of round trips per year (frequency)
A=annual operating time (hours)

Productivity: Impact of Speed on Effective Supply

(round trips per year of a 1000 TEU feeder ship over a distance of 2000 nm)

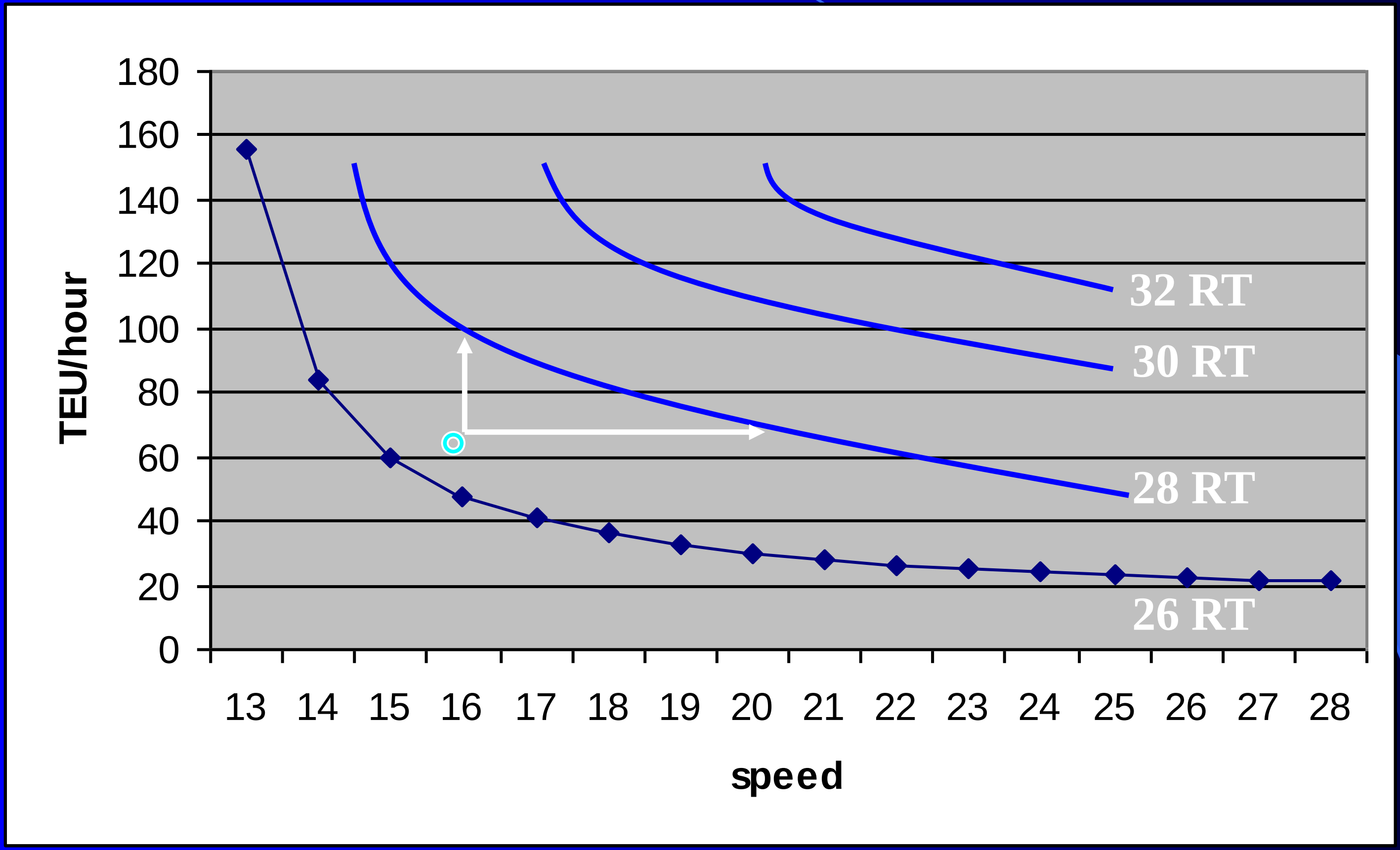


Impact of Cargo Handling Efficiency on Effective Supply



Trade off Between Speed and CH Efficiency

(Indifference Curves)



Optimum Speed

- What determines how fast or how slow a ship should sail?
- Fuel consumption increases exponentially with speed. Roughly, a 10% increase in speed would require a more than 20% increase in fuel consumption.
- What would therefore take for a ship to go faster?
- Apparently, well-paying freight rates to start with.

Optimum Speed 1

The fuel bill of a large liner shipping company amounts to billions of dollars every year. Hundreds of millions can thus be saved by selecting the optimum speed, particularly when fuel prices are high. Invariably, in the last 5 years, companies slow-steam to save on fuel. Savings are so high that easily allow carriers to introduce an extra ship in their rotations (9 instead of 8, Asia-Europe) to maintain sailing frequencies. This however increases pipeline inventory costs of shippers who dislike the practice.

Optimum Speed 2

Consider this:

An 8,000 TEU containership, at a speed of 24 knots, burns 240 tons/day. @ $400/ton, a round trip Asia-Europe (42 days at sea) would cost 240x42x400=(approx) $4 million in fuel only! The ship can make 6 (if not 7) such trips per year and a large company would have more than 300 ships!

Optimum Speed: The Variables

T	= Time period (constant) (days)
Q	= Ship Size (dwt)
n	= Number of roundtrips per year or per T/365 (if T different from one year)
Cs	= Fuel consumption (tons/day)
p	= Price of fuel ($/ton)
Speed	= Miles/hour (knots)
s	= speed (miles/day)
k	= Technical coefficient (ship design, engine efficiency, maintenance, etc.)
d	= Distance (miles) covered in period T, as a function of s
Ft	= Freight rate ($/ton)
f	= Freight rate ($/mile)
TC	= Total costs ($)
TFC	= Total fixed costs ($)
TVC	= Total variable costs ($)
MC	= Marginal cost ($)
CC	= Capital costs ($)
OC	= Operating costs ($)
VC	= Voyage costs ($)

N.B. cargo handling costs are not included in voyage costs

Optimum Speed: The Economic Relationships (1)

$$TC = TFC + TVC$$

$$TC = CC + OC + VC$$

$$CC + OC = \alpha$$

Optimum Speed: The Economic Relationships (2)

$$VC = fuel\,costs = p \cdot Cs \cdot T$$

$$Cs = k \cdot s^3$$

$$s = \frac{d}{T}$$

$$Cs = \left(k / T^3 \right) \cdot d^3$$

Optimum Speed: The Economic Relationships (3)

$$VC = \frac{p \cdot T \cdot k}{T^3} d^3 = \frac{p \cdot k}{T^2} d^3$$

$$TC = \alpha + \frac{p \cdot k}{T^2} d^3$$

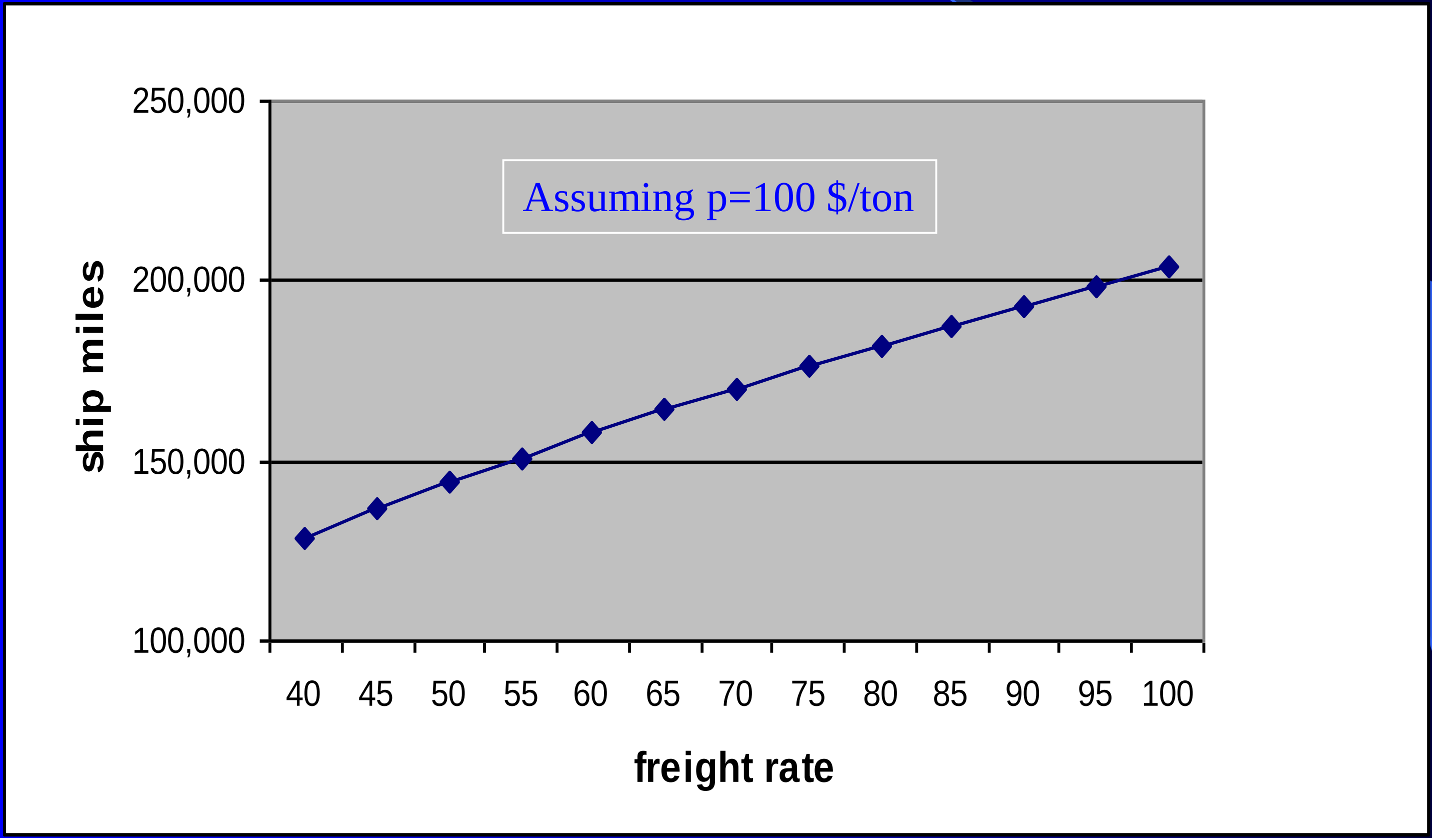
$$MC = \frac{\partial TC}{\partial d} = \frac{3pk}{T^2} d^2 = f$$

Optimum Speed: The Economic Relationships (4)

$$d = \sqrt{\frac{T^2 f}{3pk}} = T\sqrt{\frac{f}{3pk}} \quad \text{supply function} \quad *$$

$$\bar{S} = \frac{d}{T} = \sqrt{\frac{f}{3pk}} \quad \text{optimum speed}$$

Supply: Ship Productivity as a Function of Freight Rates ($/mile)



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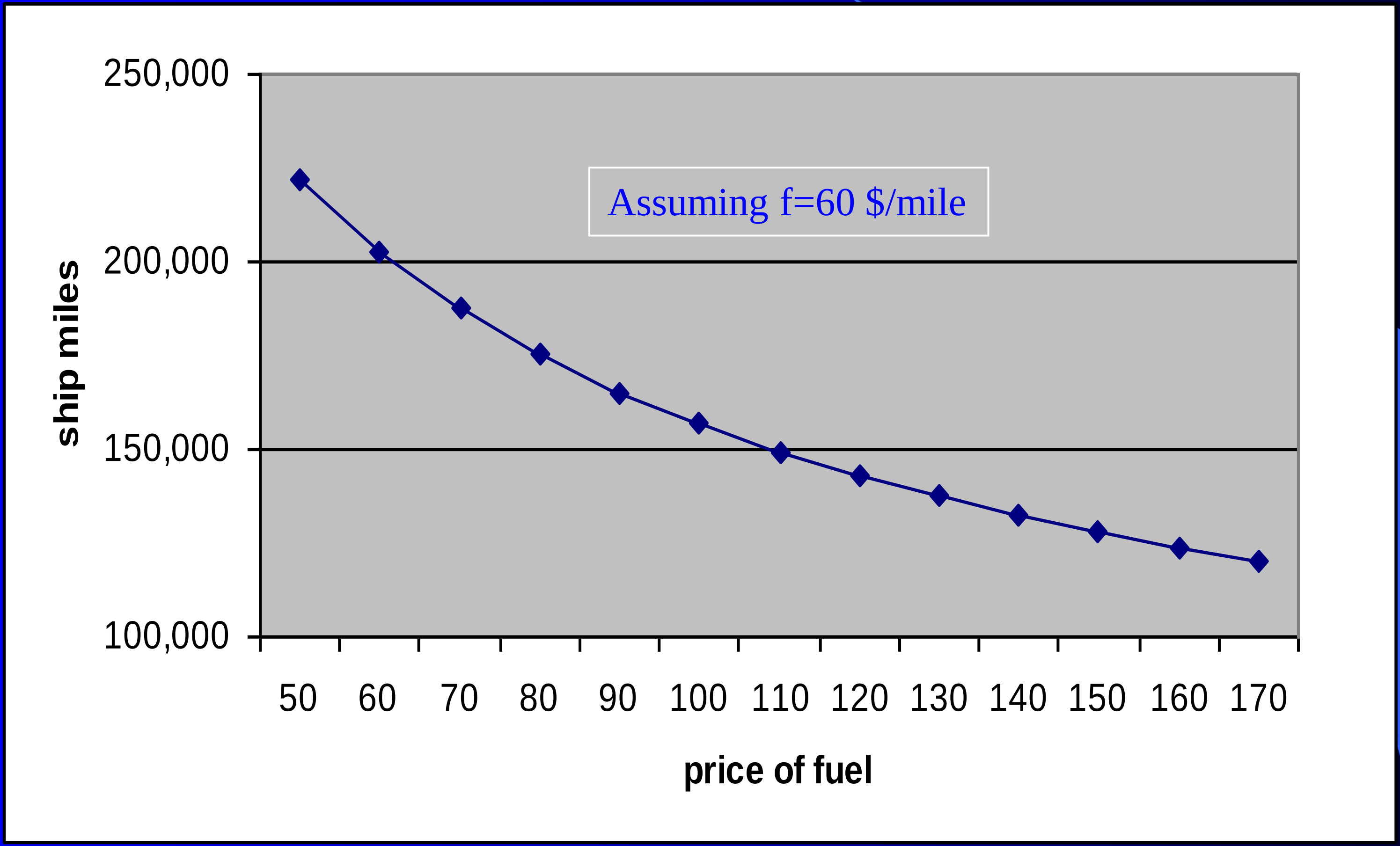
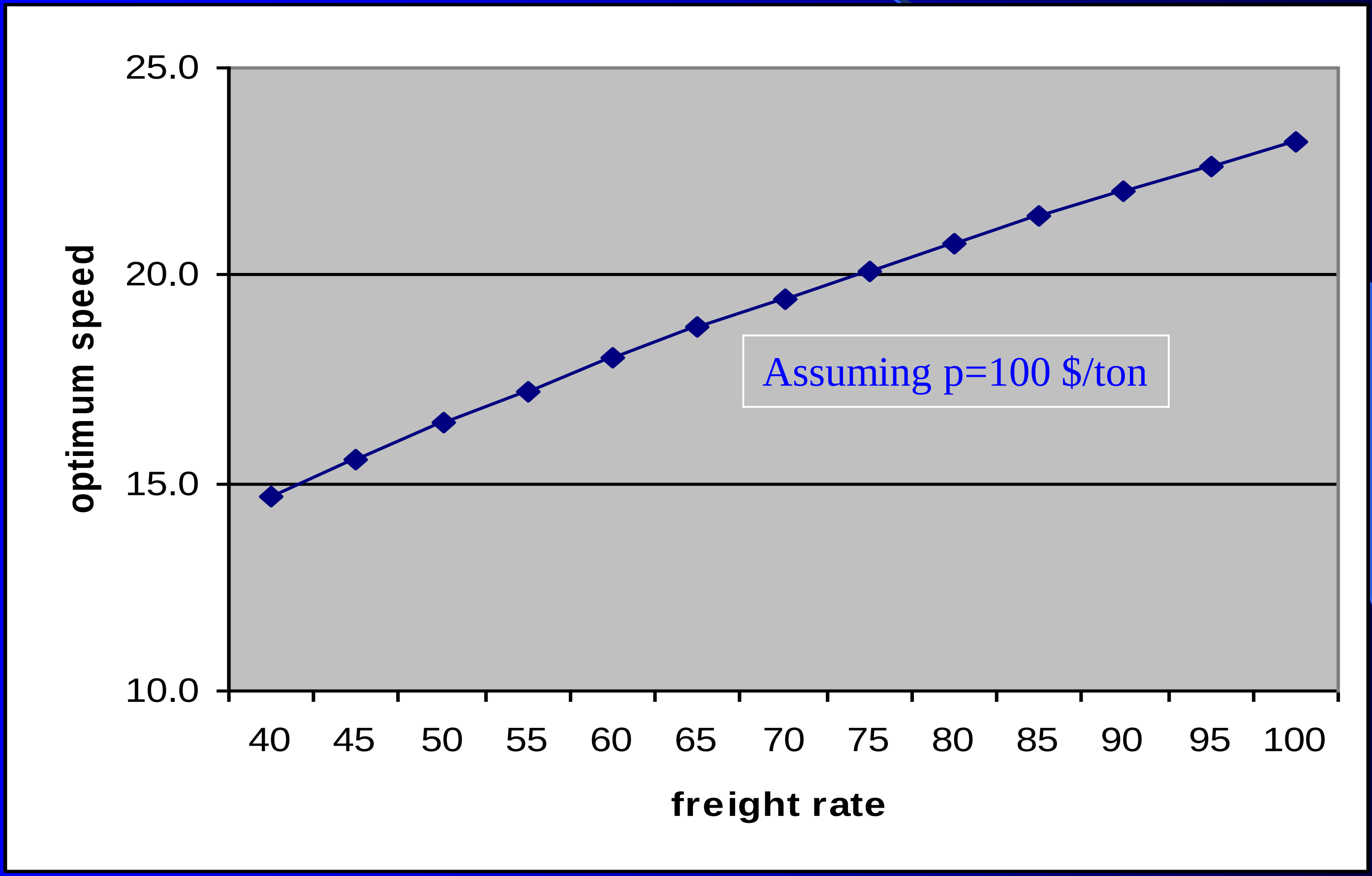
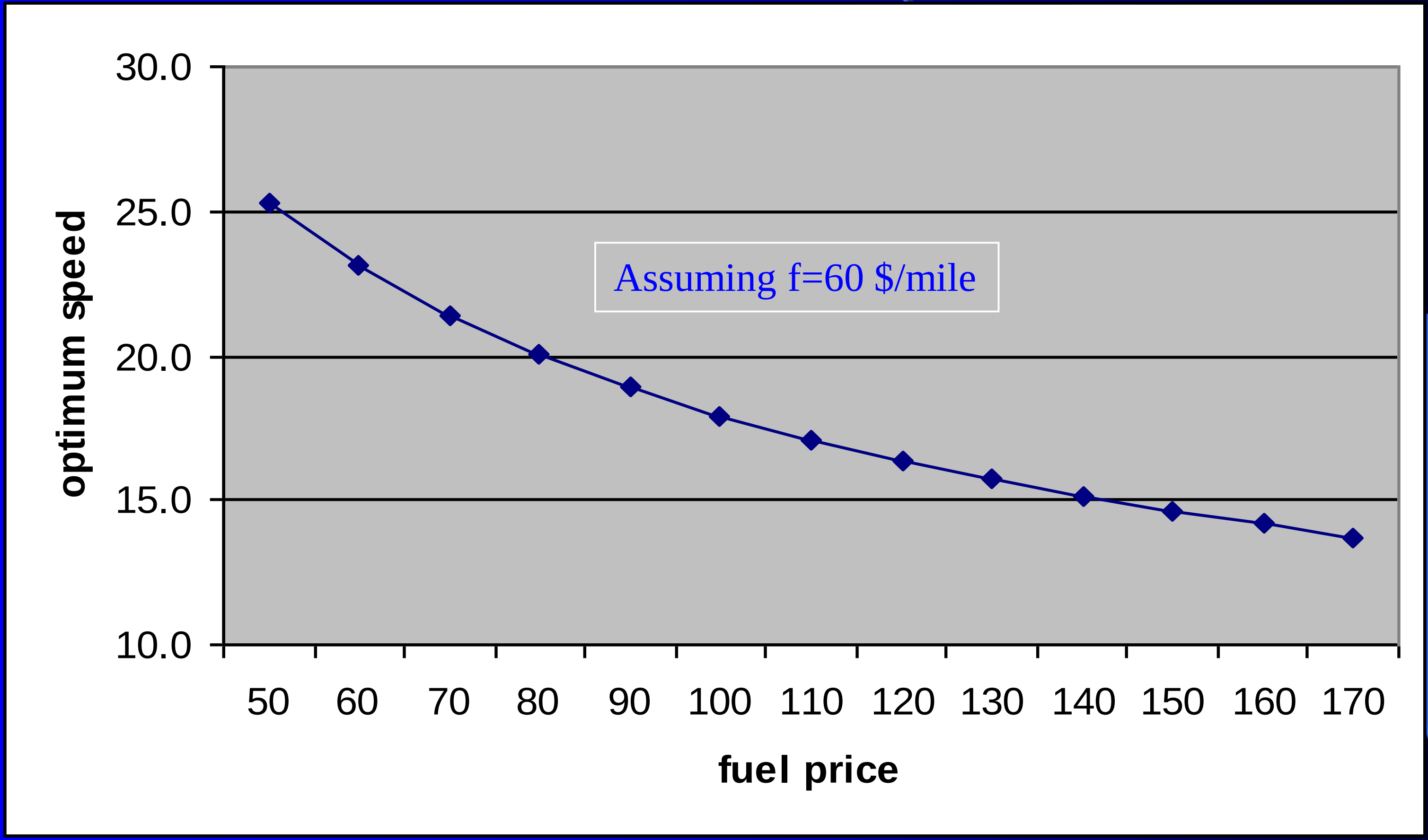


Slow Steaming: Optimum Speed as a Function of Freight Rate ($/mile)



Slow Steaming: Optimum Speed as a Function of Fuel Price ($/ton)



Economies of Scale in Shipping

Economies of Scale refer to the situation whereby unit costs (i.e. cost/dwt or cost/TEU –the relevant costs for pricing and competitiveness- are reduced as ship sizes increase. This reduction is more pronounced particularly in the case of shipbuilding costs, manning costs (Emma Maersk has a crew of 13!) and fuel costs.

However, there are also limits to the growth in ship sizes, depending on demand, port capacity and technology; land infrastructure; other logistical costs; and the attractiveness and future of the hub-and-spoke system in container transportation.

So, what are the factors affecting optimum ship size in a certain route (trade)?

Size Economies and Cost Competitiveness (secondhand prices for five-year-old vessels)

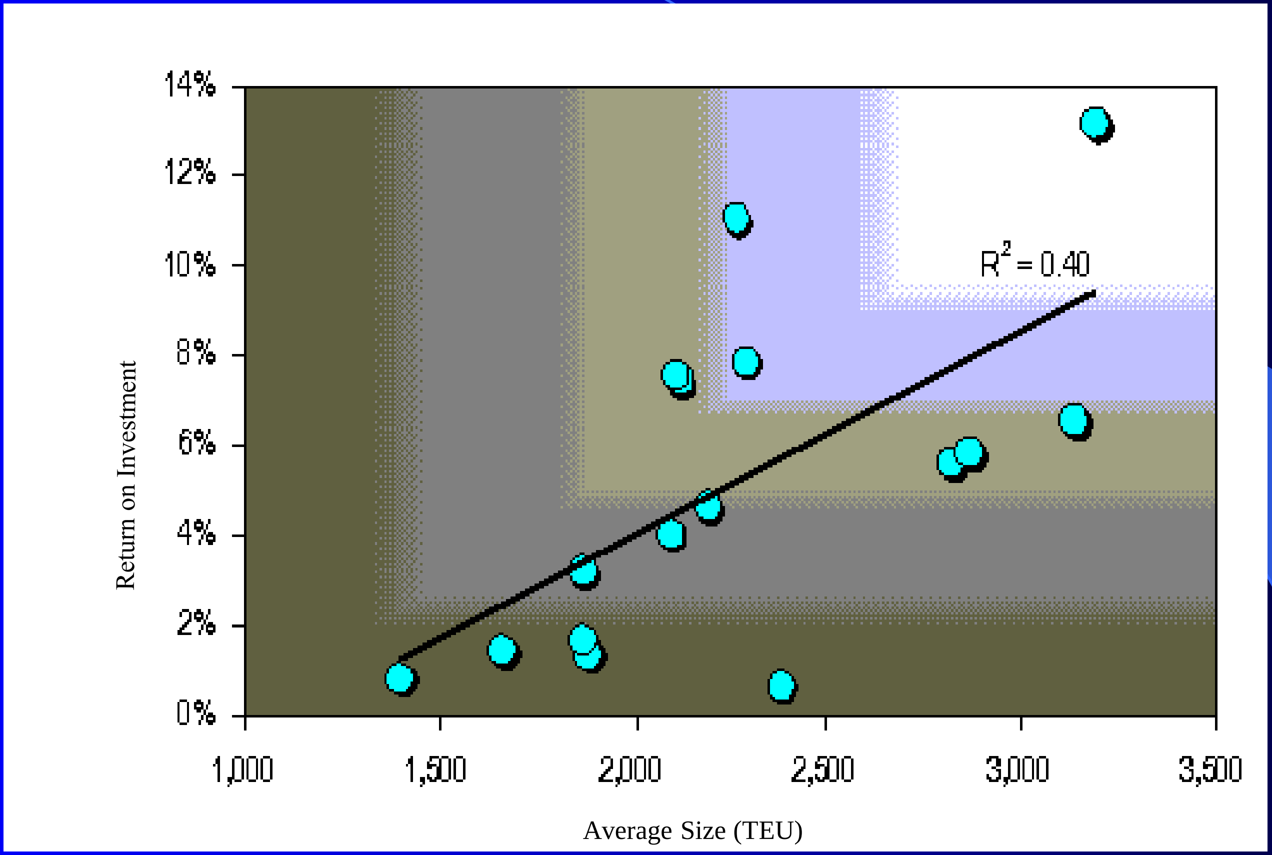
(as at end of year, in millions of dollars)

Vessel	1993	1994	1995	1996	1997	1998	1999	% change 1998/99
30,000 dwt tanker	18.0 (**600**)	18.0	20.0	22.0	23.0	16.0	16.0	-
80,000 dwt tanker	32.0 (**400**)	31.0	30.0	31.0	33.0	--	--	--
130,000 dwt tanker	34.5 (**265**)	34.0	35.5	40.0	41.5	--	--	--
45,000 dwt dry bulk carrier	18.5 (**411**)	20.7	22.0	18.5	18.0	13.0	15.5	19.2
70,000 dwt dry bulk carrier	19.5 (**279**)	21.0	23.0	20.5	21.0	14.5	17.0	17.2
150,000 dwt dry bulk carrier	33.0 (**220**)	32.0	28.0	26.5	30.0	23.5	27.5	17.0

Source: UNCTAD secretariat on the basis of data supplied by Fearnleys (Oslo), Review 1999

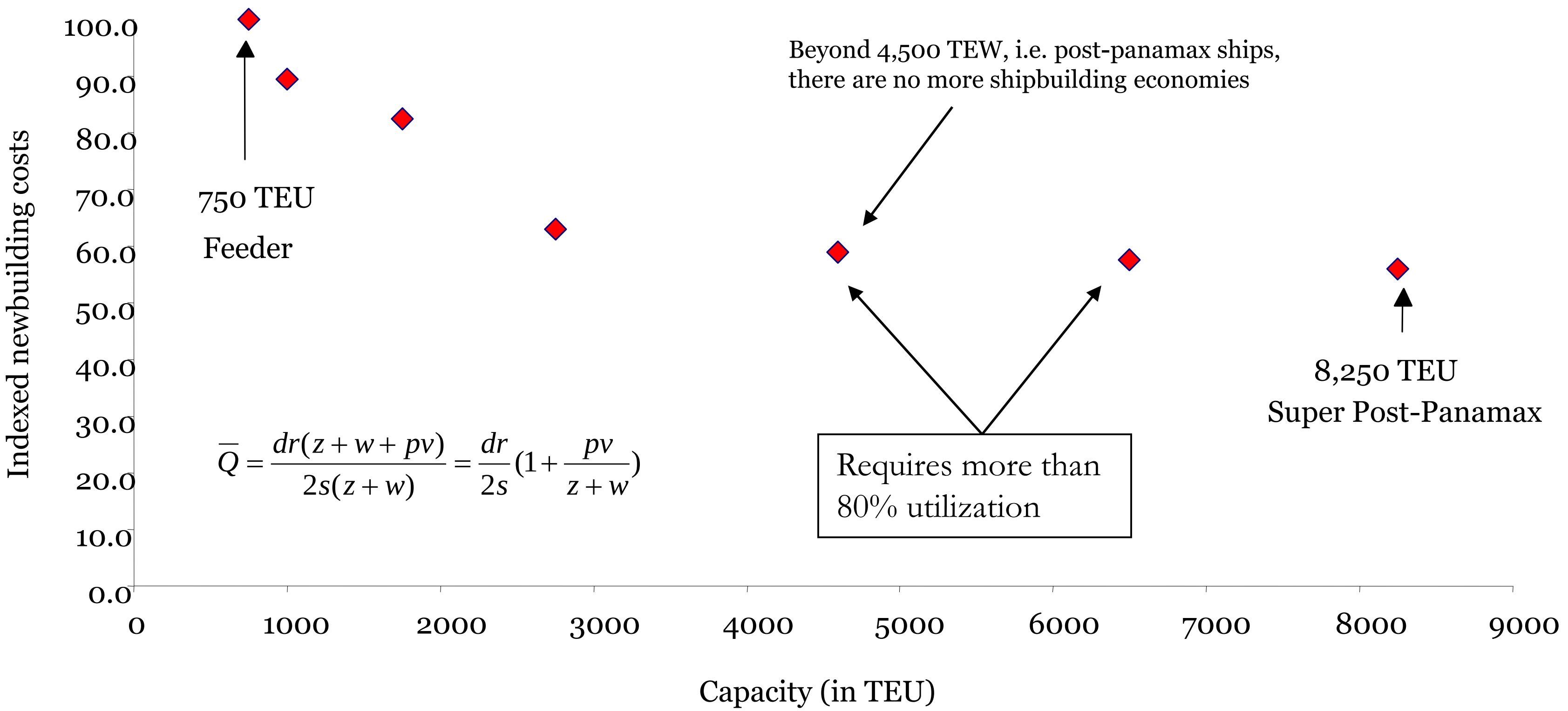
(**…**) $/dwt

Average Vessel Size (of company) and Return on Investment



Source: Hoffmann
UN-ECLAC: www.eclac.org
Good report on concentration still available on the eclac site

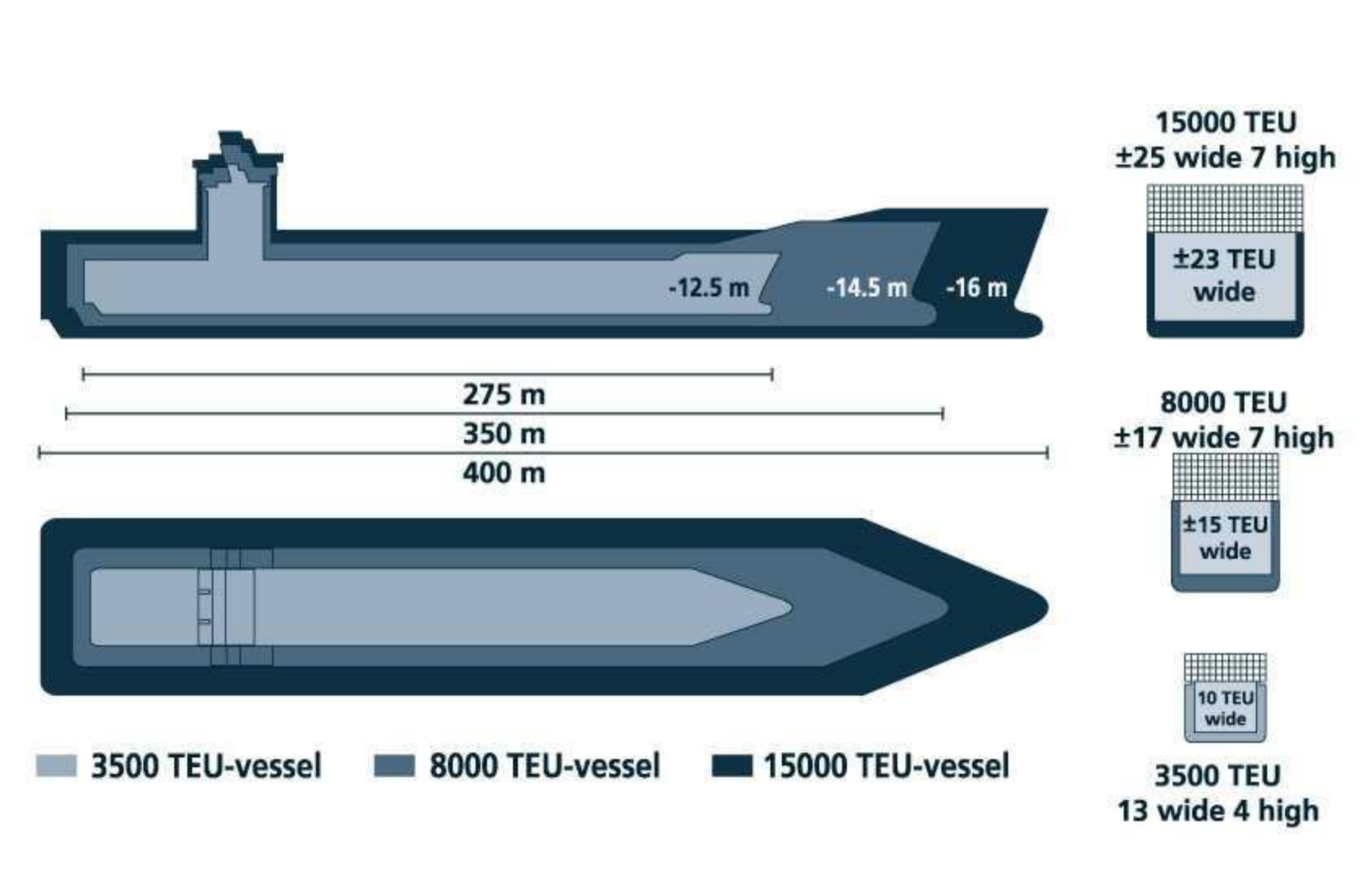
Economies of scale in shipping have led to cargo consolidation, storage and distribution; thus the emergence of regional hubs



$$\overline{Q} = \frac{dr(z+w+pv)}{2s(z+w)} = \frac{dr}{2s}(1+\frac{pv}{z+w})$$

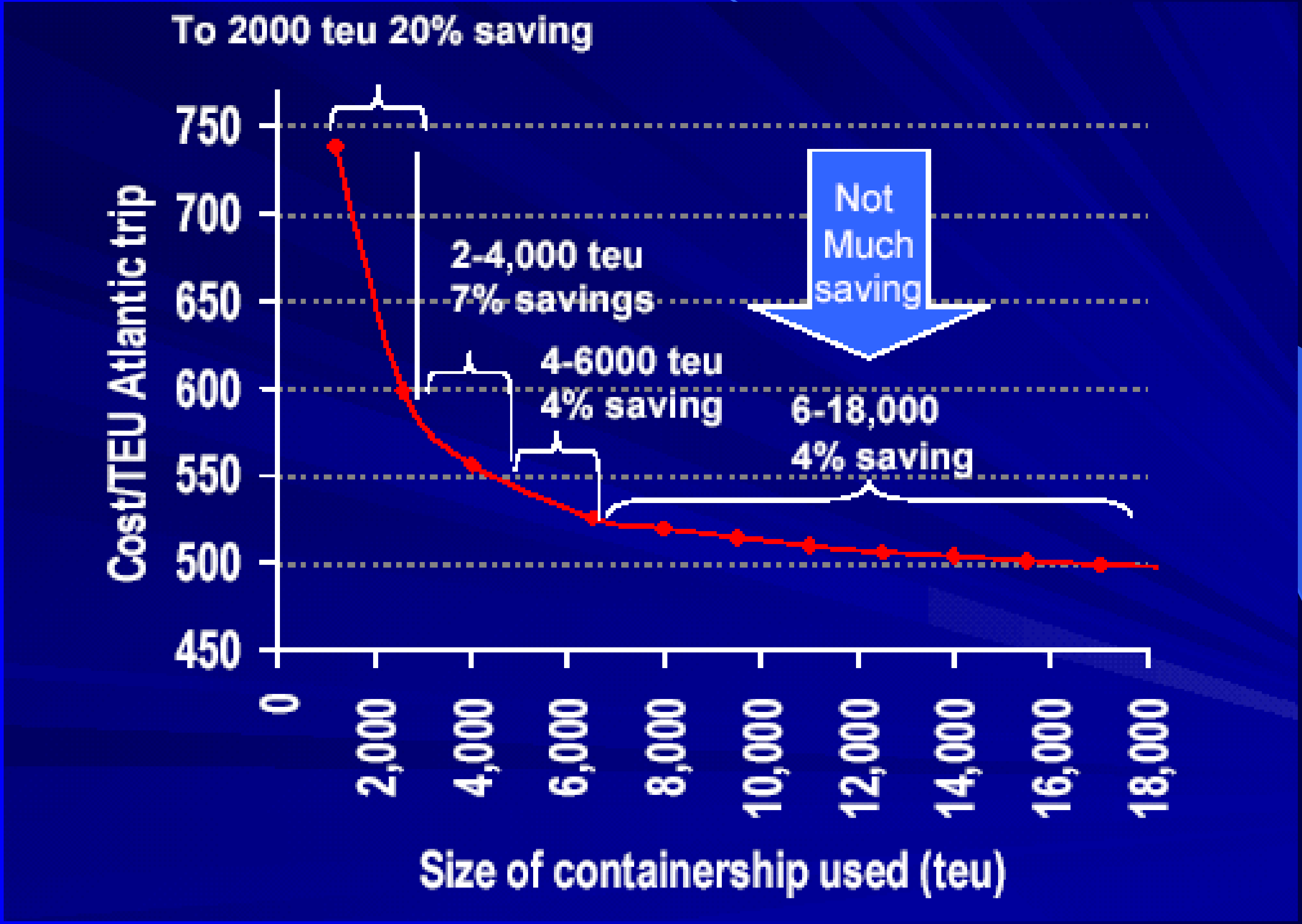
Source: MEL

Container vessels
(economies of scale in shipbuilding)



Scale economies in practice

(**TOTAL COST** / TEU in USD: Atlantic route)

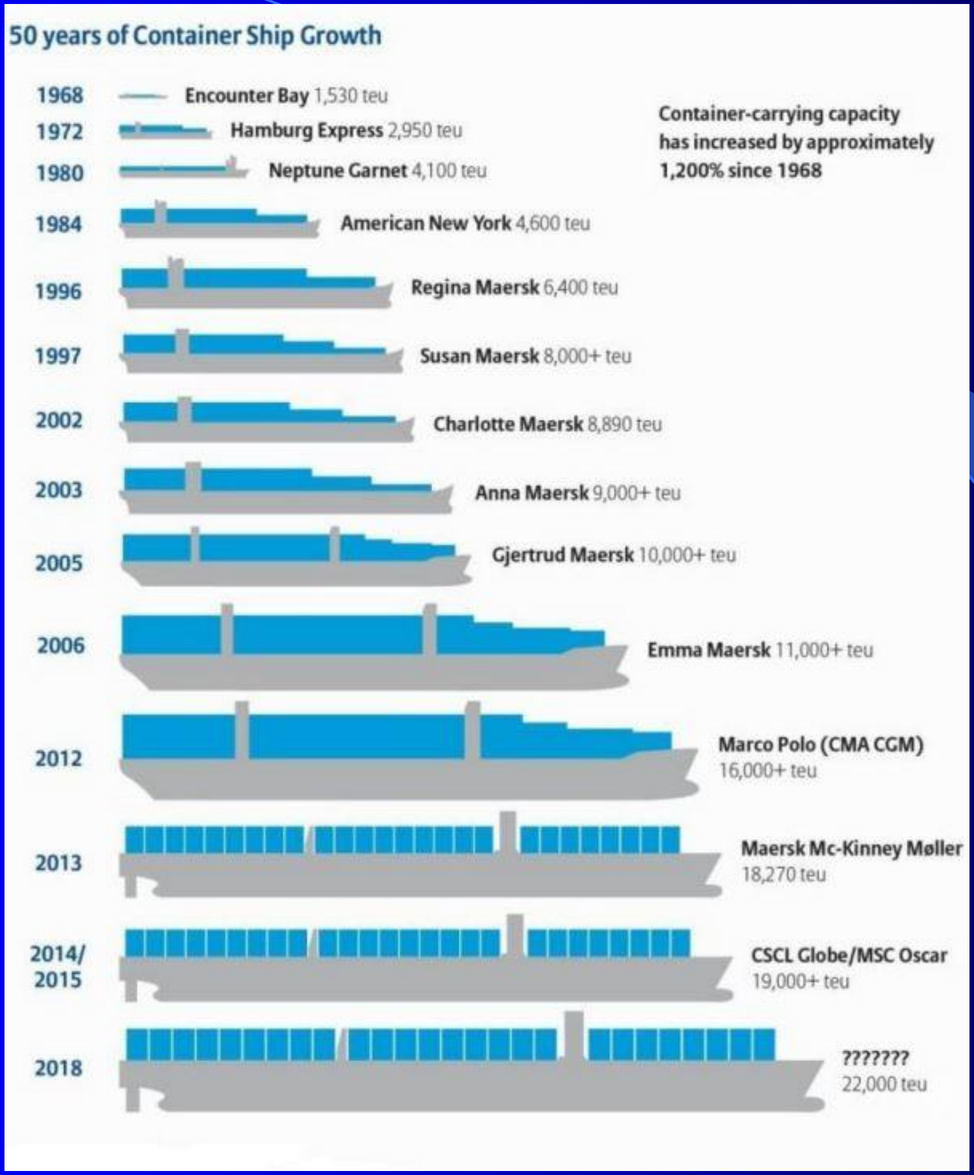


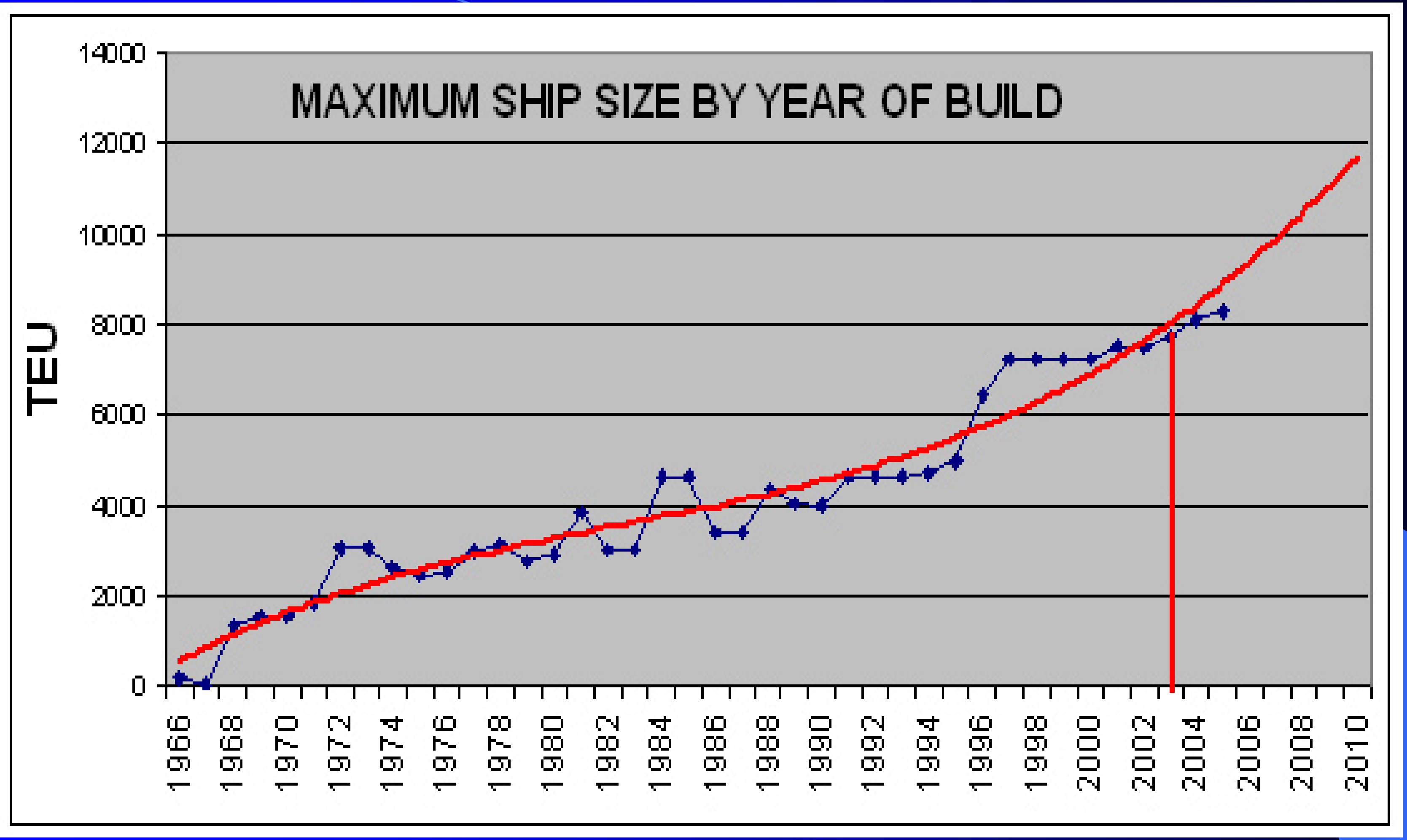
Source: Stopford

Economies of Scale in Practice

		Length	Draft	TEU
First (1956-1970)	Converted Cargo Vessel Converted Tanker	135 m 200 m	<9 m <30 ft	500 800
Second (1970-1980)	Cellular Containership	215 m	10 m 33 ft	1,000 – 2,500
Third (1980-1988)	Panamax Class	250 m 290 m	11-12 m 36-40 ft	3,000 4,000
Fourth (1988-2000)	Post Panamax	275 – 305 m	11-13 m 36-43 ft	4,000 – 5,000
Fifth (2000-2005)	Post Panamax Plus	335 m	13-14 m 43-46 ft	5,000 – 8,000
Sixth (2006-)	New Panamax	397 m	15.5 m 50 ft	11,000 – 14,500

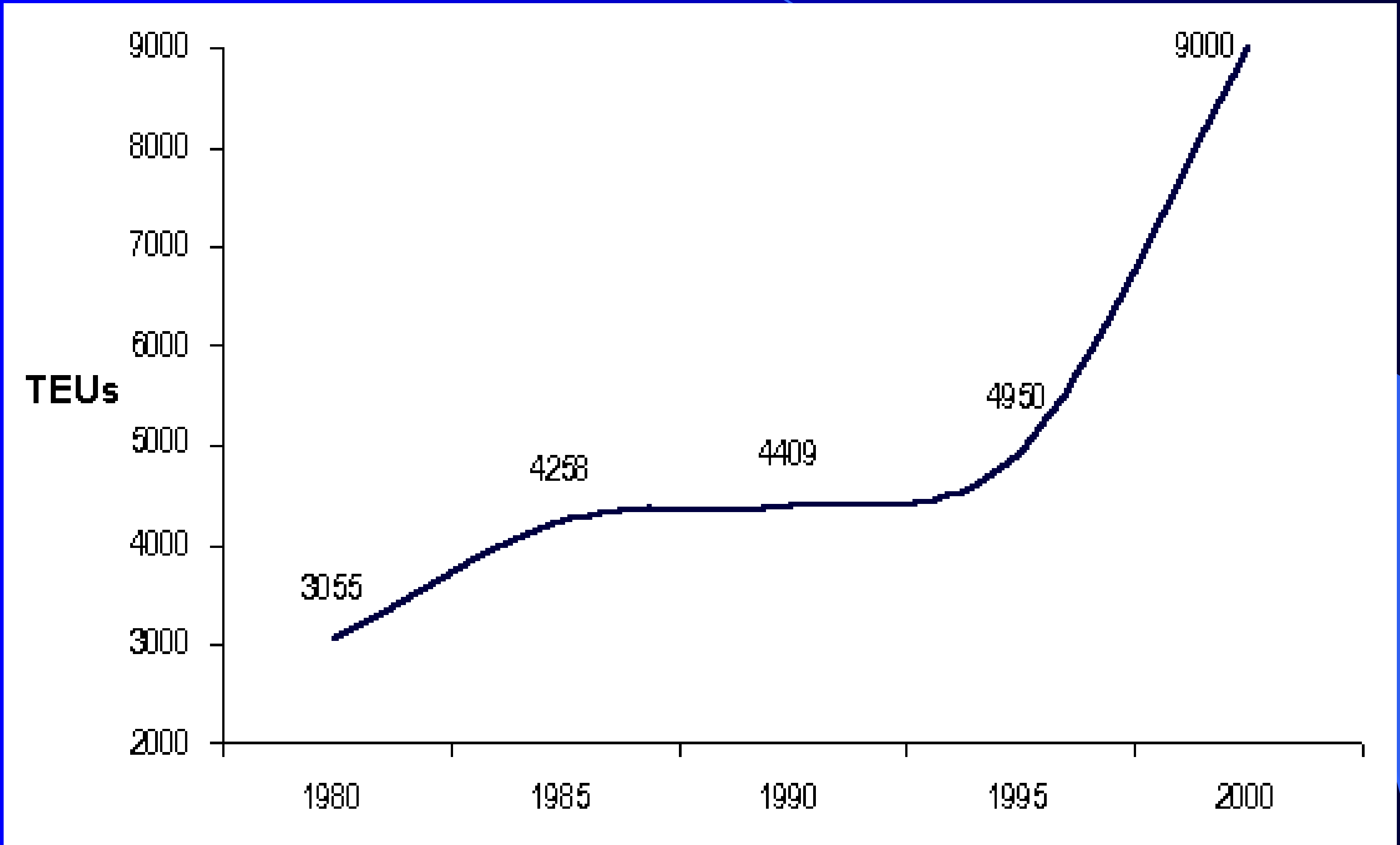
Source: Chen Tao


50 years of Container Ship Growth
1968
Encounter Bay 1,530 teu
1972
Hamburg Express 2,950 teu
1980
Neptune Garnet 4,100 teu
Container-carrying capacity has increased by approximately 1,200% since 1968
1984
American New York 4,600 teu
1996
Regina Maersk 6,400 teu
1997
Susan Maersk 8,000+ teu
2002
Charlotte Maersk 8,890 teu
2003
Anna Maersk 9,000+ teu
2005
Gjertrud Maersk 10,000+ teu
2006
Emma Maersk 11,000+ teu
2012
Marco Polo (CMA CGM) 16,000+ teu
2013
Maersk Mc-Kinney Møller 18,270 teu
2014/ 2015
CSCL Globe/MSC Oscar 19,000+ teu
2018
??????? 22,000 teu



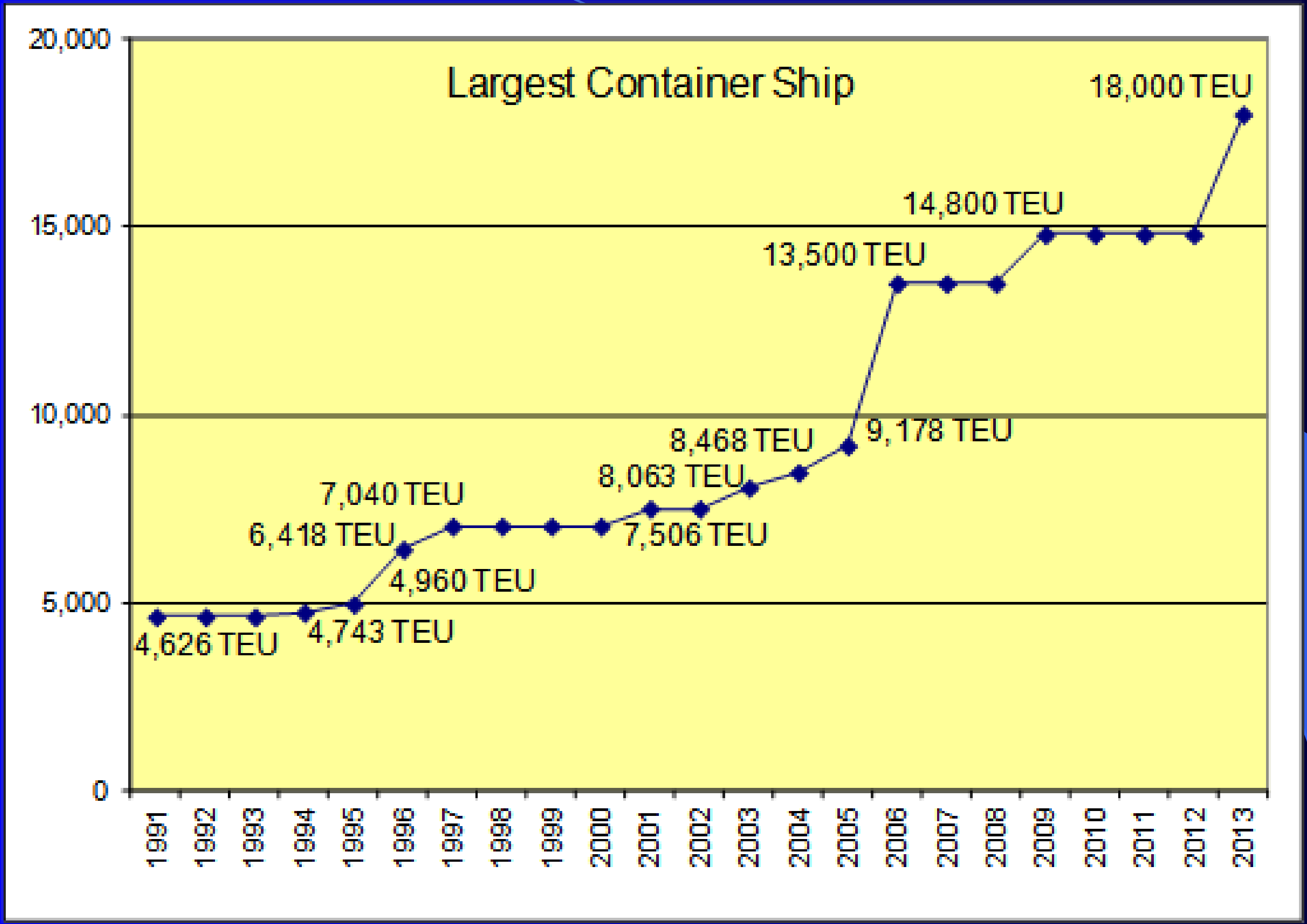
Apparently estimated by a naval architect! An economist would have estimated a second degree convex line or a straight line

Developments in Maximum Size of Containerships

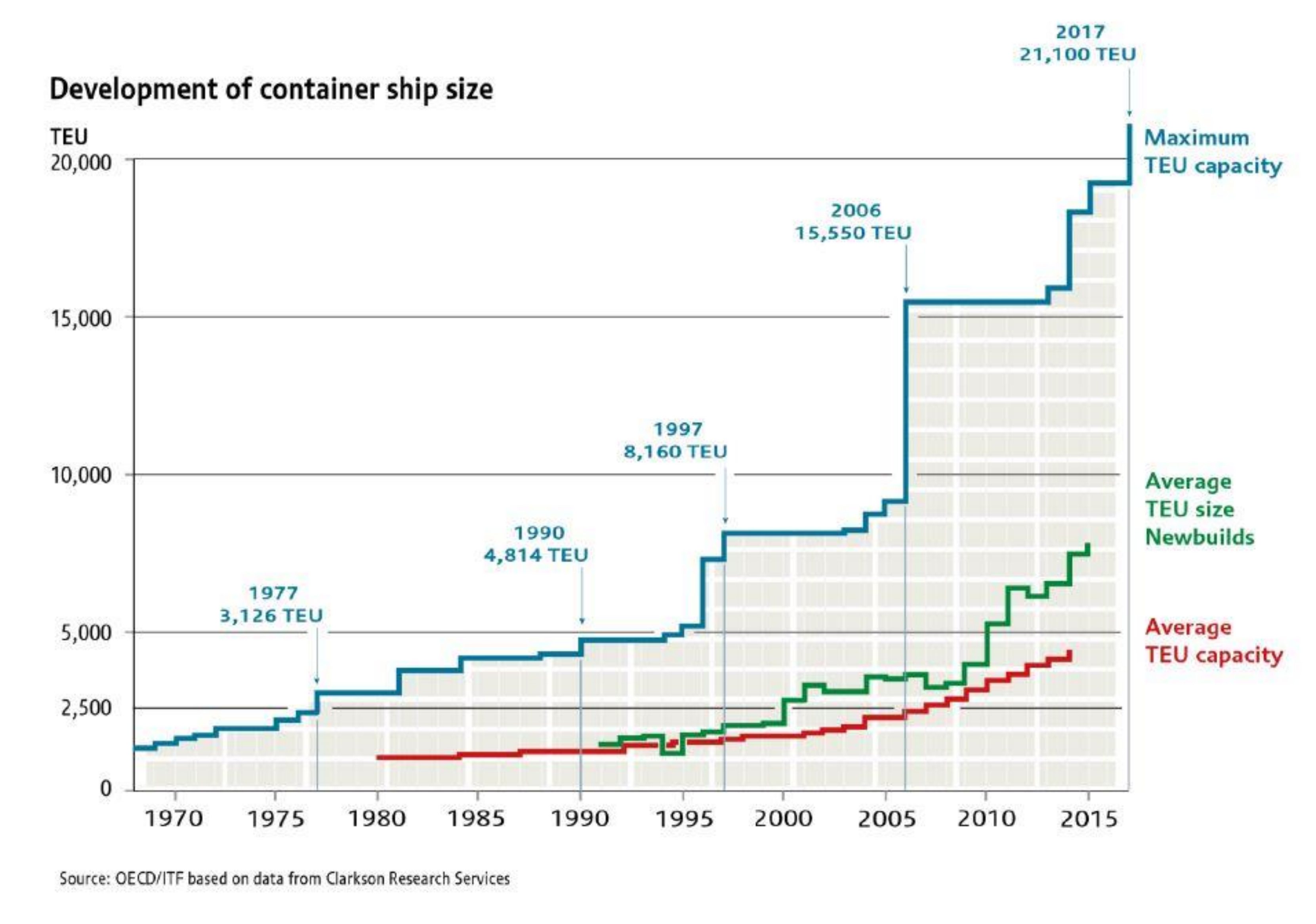


Source: Hoffmann

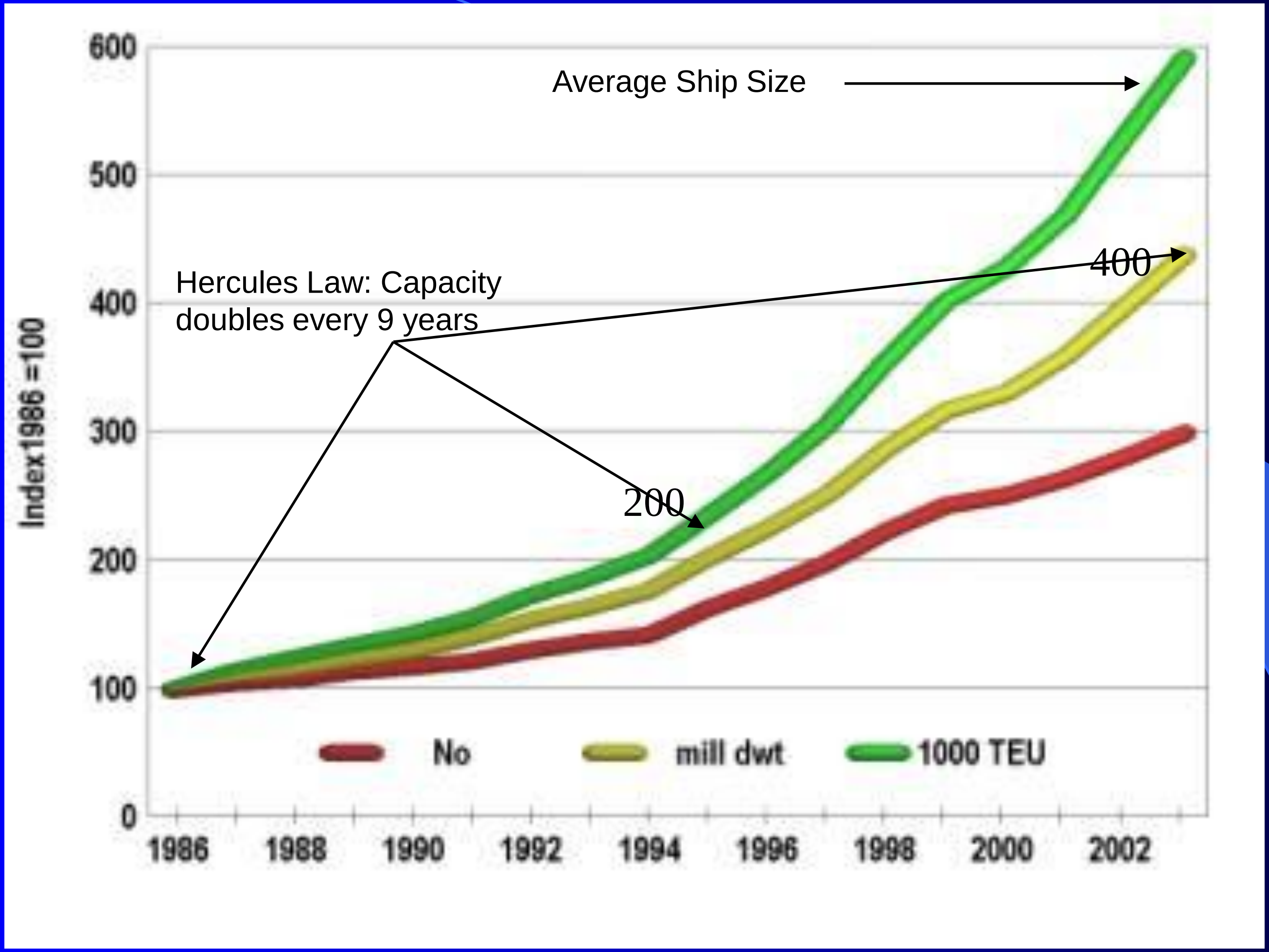
Developments in Maximum Size of Containerships



Source: Ocean Shipping Consultants; Drewry Shipping Consultants

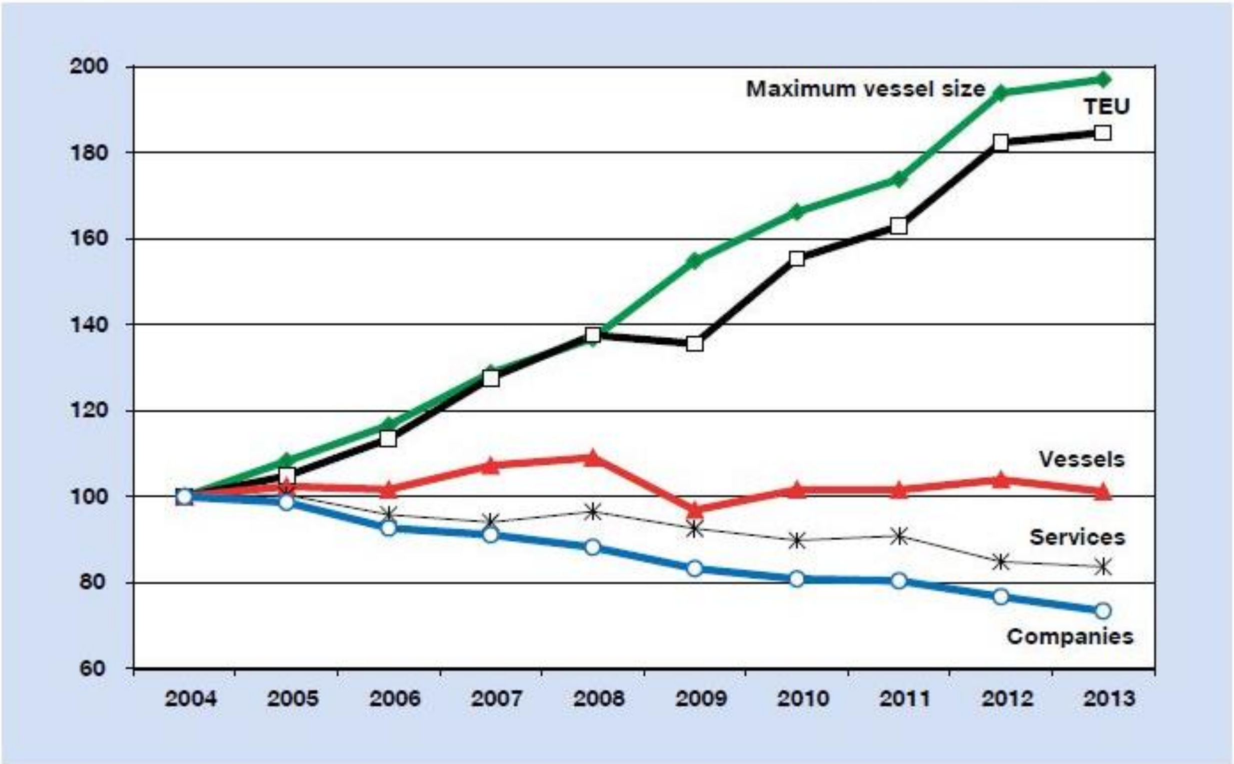

Development of container ship size
TEU
20,000
15,000
10,000
5,000
2,500
0
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2017
21,100 TEU
2006
15,550 TEU
1997
8,160 TEU
1990
4,814 TEU
1977
3,126 TEU
Maximum
TEU capacity
Average
TEU size
Newbuilds
Average
TEU capacity
Source: OECD/ITF based on data from Clarkson Research Services

Trends in containership development (1986-2013): Fig. 1



Source: ISL

Trends in containership development (1986-2013): Fig. 2



Source: UNCTAD, based on data provided by Lloyds List Intelligence.

While in the previous period (Fig. 1) both ships and tonnage had been increasing, here the number of ships has remained constant and the increase in demand has only been met by larger ships. However, larger ships call fewer ports (transhipment) and can be economically utilized only through shipping alliances. Thus, both the number of services (transhipment) and the number of companies serving each country (alliances) have been declining.

Economies of Scale & Optimum Size

The variables

Q	= Ship Size (dwt)
Cs	= Fuel consumption (tons/day)
P	= Price of fuel ($/ton)
Speed	= Miles/hour (knots)
s	= speed (miles/day)
V	= Technical coefficient (propulsion)
Z	= Technical coefficient (construction)
W	= Technical coefficient (operations)
D	= Distance (miles) (**constant**) (round voyage)
r	= Cargo handling rate (tons per day)
VC	= Voyage costs ($)
PC	= Port costs ($)
SC	= Sea costs ($)
DCC	= Daily capital costs ($)
DOC	= Daily operating costs ($)

Economies of Scale & Optimum Ship Size:

Numerical Example (2)

Technical coefficients

$$construction: \quad DCC = zQ^{1/2}$$

$$(22.89 * Q^{0.70})$$

$$operations \quad : \quad DOC = wQ^{1/2}$$

$$(267 * Q^{0.40})$$

$$propulsion \quad : \quad C_s = vQ^{1/2}$$

$$(1.21 * Q^{0.51})$$

Numerical formulas from: Tran, N.K and Haasis, H.D. (2015). An empirical study of fleet expansion and growth of ship size in container liner shipping. *International Journal of Production Economics*, 159, 241-253.

Economies of Scale & Optimum Size

Economic relationships

$$Time\ in\ Port = \frac{2Q}{r}$$

$$Cost\ of\ time\ in\ Port = \frac{2Q}{r}(DCC + DOC)$$

$$= \frac{2Q}{r}(zQ^{1/2} + wQ^{1/2})$$

$$= \frac{2(z+w)}{r}Q^{3/2}$$

Economies of Scale & Optimum Size

Economic relationships (cont..)

$$
\begin{aligned}
&\textit{cost of time at sea} \\
&= \frac{d}{s}(DCC + DOC) + \frac{d}{s}\,pCs \\
&= \frac{d}{s}(zQ^{\frac{1}{2}} + wQ^{\frac{1}{2}}) + \frac{d}{s}\,pvQ^{\frac{1}{2}} \\
&= \frac{d}{s}(z + w + pv)Q^{\frac{1}{2}}
\end{aligned}
$$

Speed, s, has already been optimized

Economies of Scale & Optimum Size

Economic relationships (cont..)

$$Total\,Voyage\,Costs$$

$$VC = \frac{2(z+w)}{r} Q^{3/2} + \frac{d}{s}(z+w+pv)Q^{1/2}$$

$$Voyage\,Costs\ per\ Ton$$

$$\overline{VC} = \frac{2(z+w)}{r} Q^{1/2} + \frac{d}{s}(z+w+pv)Q^{-1/2}$$

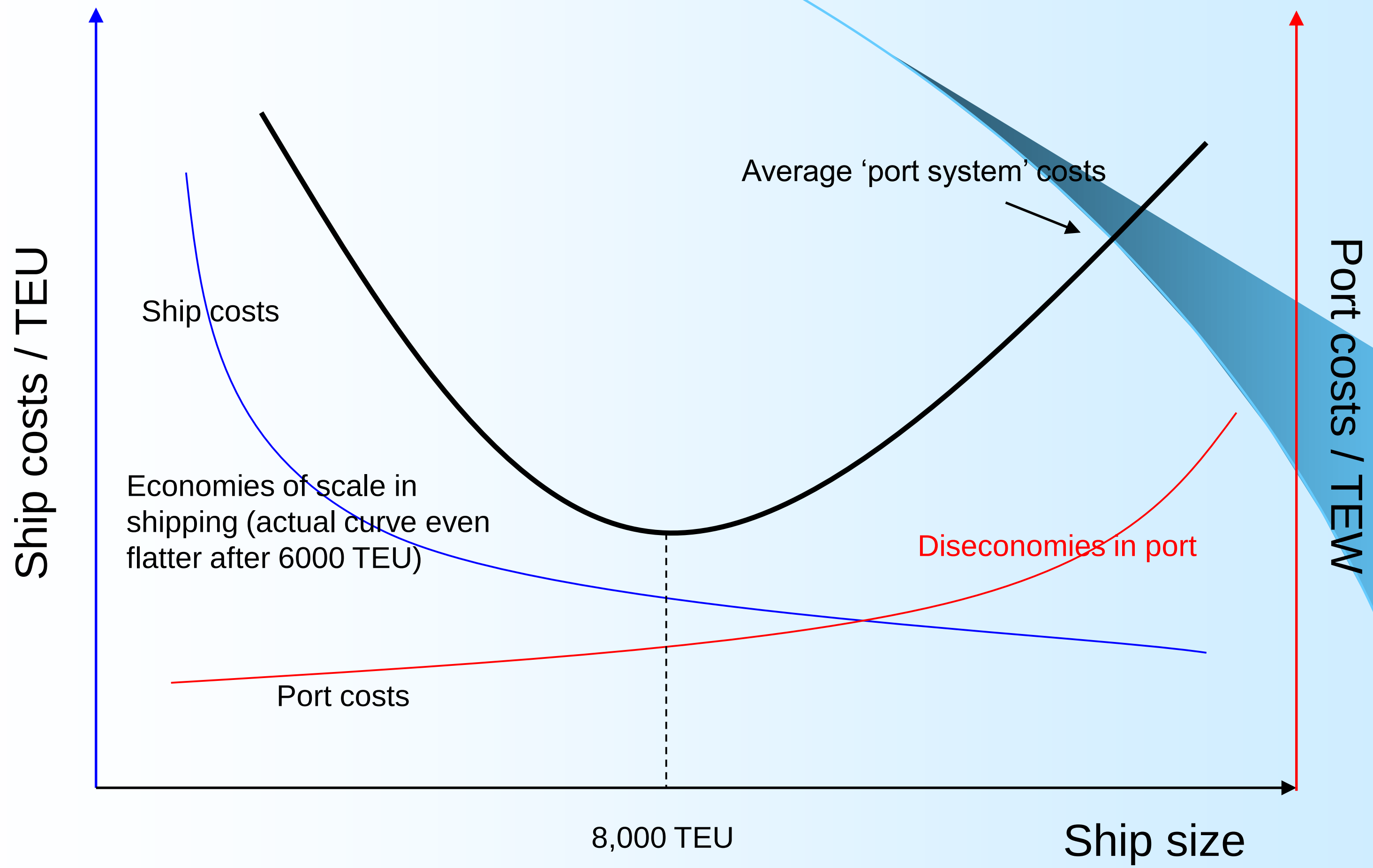
$$\frac{\partial(\overline{VC})}{\partial Q} = \frac{z+w}{r} Q^{-1/2} - \frac{d}{2s}(z+w+pv)Q^{-3/2} = 0$$

$$\frac{z+w}{r} = \frac{d}{2s}(z+w+pv)Q^{-1}$$

$$\overline{Q} = \frac{dr(z+w+pv)}{2s(z+w)} = \boxed{\frac{dr}{2s}(1+\frac{pv}{z+w})}$$

Optimum Containership Size and Diseconomies at Ports

(the need for joint optimization)



Kendall, UNCTAD, OECD and MEL have calculated that the average container, arriving on a larger ship, takes more to handle and store. In other words, port time per TEU is an increasing function of ship size.

Mega Containerships and diseconomies at ports. Why? (1)

Assumptions

To understand this complex issue, one needs to start from two fundamental assumptions:

1. In spite of increasing ship sizes, the port needs to keep ship turnaround time constant (approx. 48 hours).
2. General macroeconomic trends apart, the port faces a fairly constant and predictable traffic demand (in the short- to medium term)

Mega Containerships and diseconomies at ports. Why? (2)

1. **Constant turnaround time**

- As crane productivity cannot be stretched much beyond 30 moves/hour (it actually declines after a certain crane density), the only way to serve a larger ship at the same time (48 hours) is by adding more and bigger (air draft; outreach) cranes.

- Increasing the number of cranes, i.e. 'crane density' (number of cranes per 300 meters of quay length) reduces crane productivity, nullifying the advantages of the bigger ship hatches.

Mega Containerships and diseconomies at ports. Why? (3)

2. **Constant traffic demand**

- If bigger ships are to serve a certain traffic demand, in a certain period of time, the number of port calls will have to be less. As a result, berth and crane utilization decline and this impacts on the capital costs of the port and of the terminal operator.
- Moreover, a fixed-length quay can naturally accommodate fewer (bigger) ships simultaneously, and this also affects negatively berth productivity.
- Similar observations can be made for yard operations, productivity and costs.

Diseconomies of Scale
(The 6 Trends of the Second Scenario)

Trends Leading to an Expected Increase in the Market Share of Smaller Ships Targeting more Immediate Hinterlands

- World wide port development
- Regionalisation of trade
- Infrastructure development
- Road pricing
- Future of liner shipping alliances
- Information technology