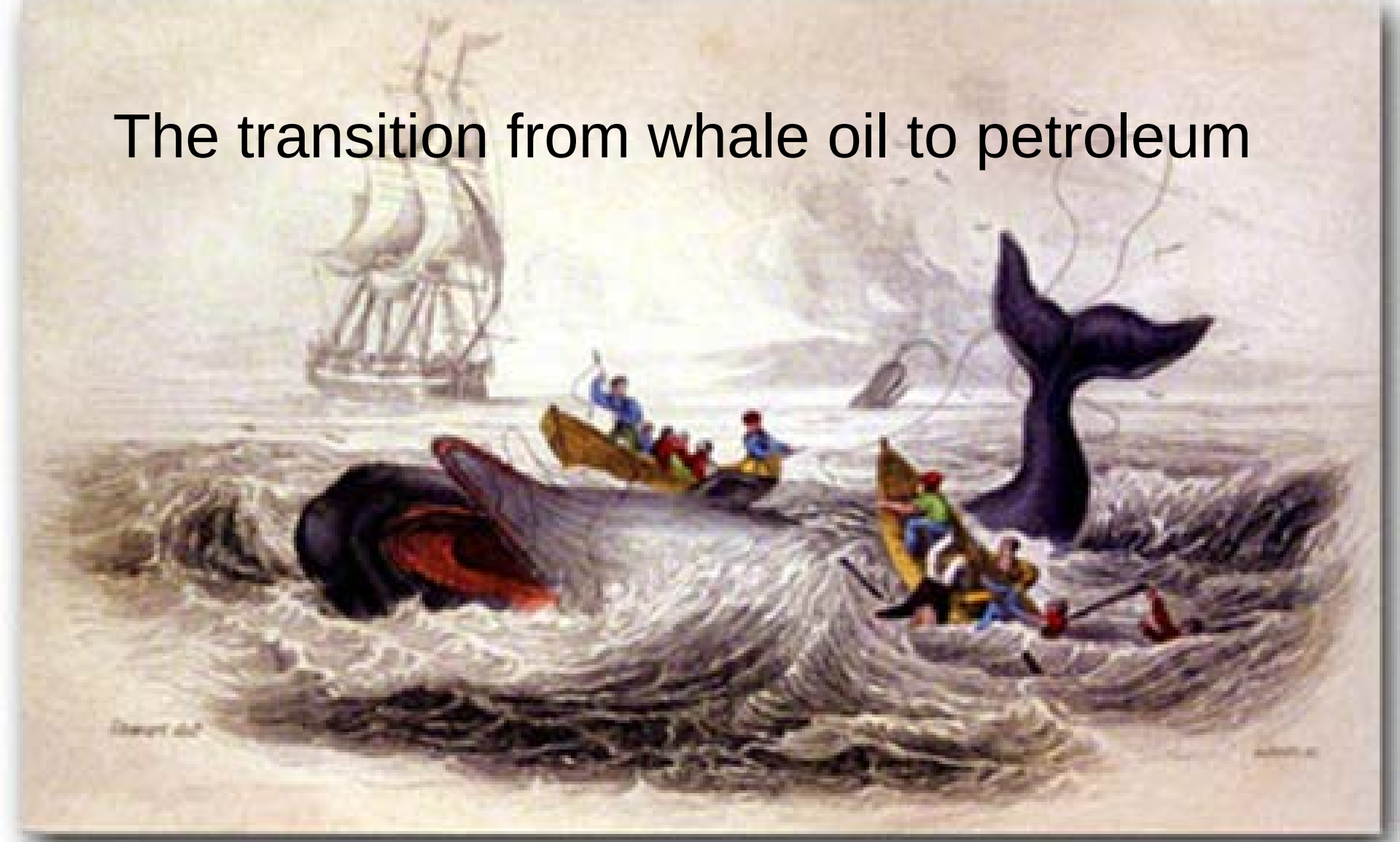
The transition from whale oil to petroleum



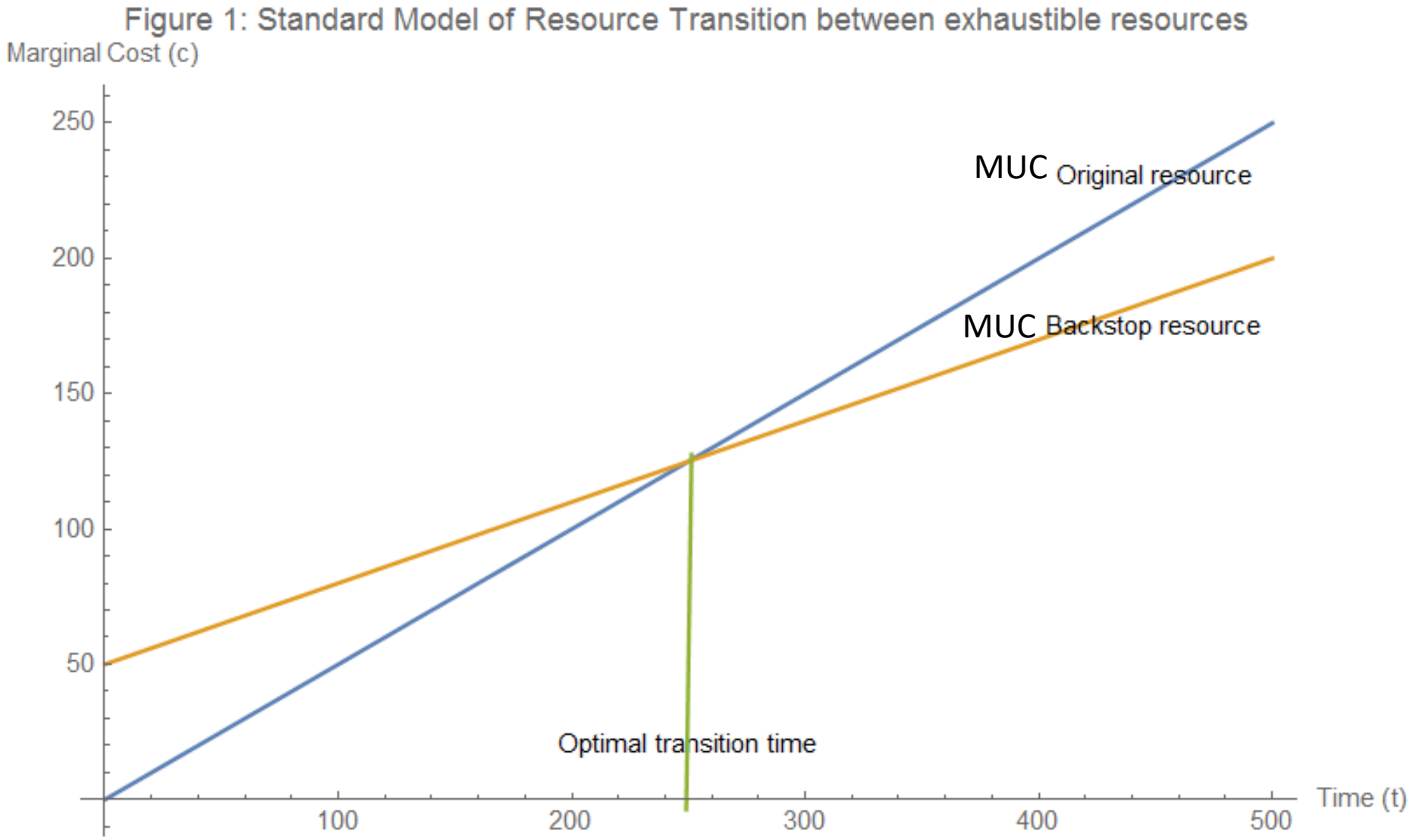
"The Spermaceti Whale"
by J. Stewart, 1837
New Bedford Whaling Museum

Brooks A. Kaiser
University of Southern Denmark
University of Hawaii, Manoa

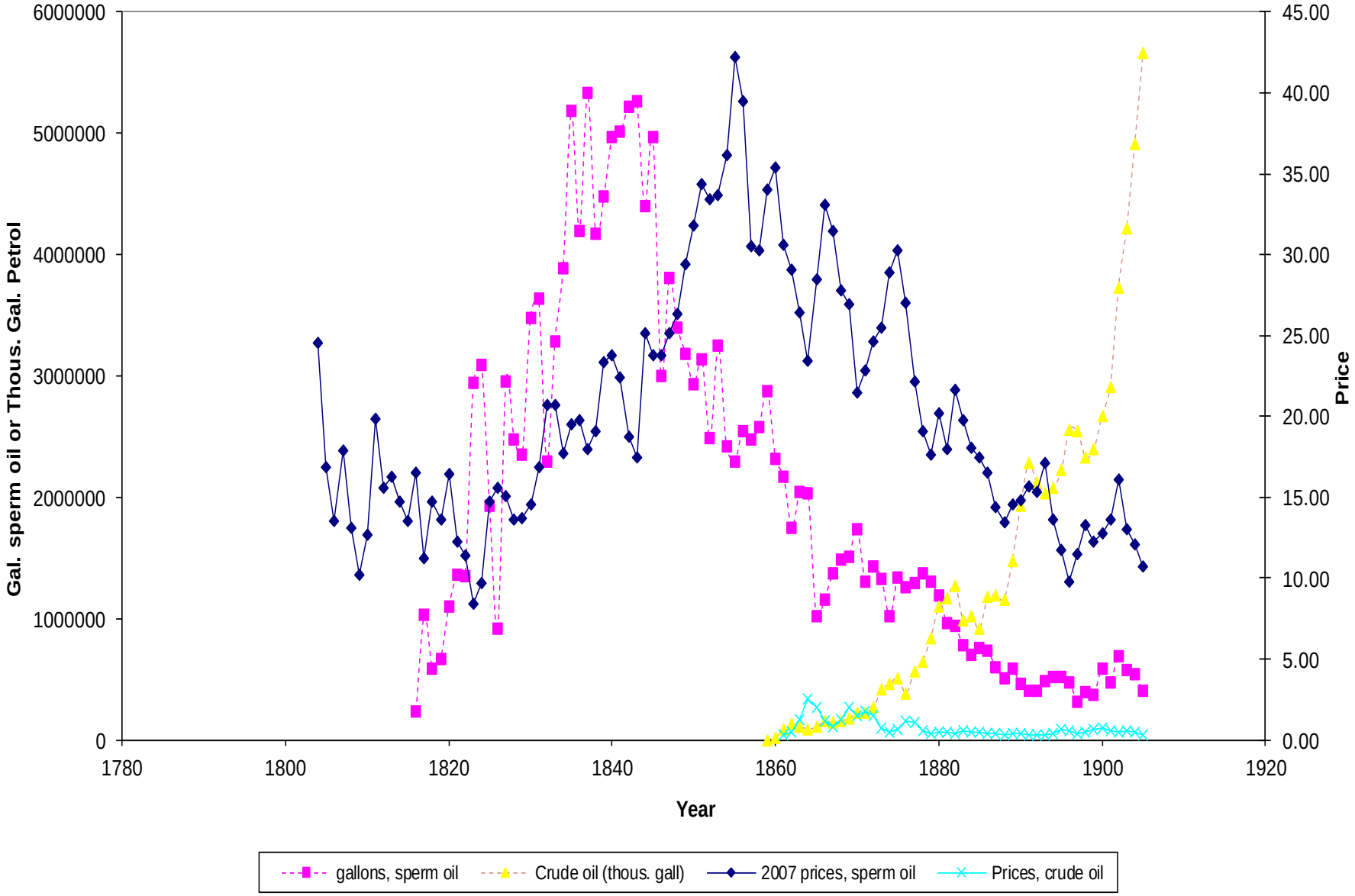
Main question (many asides possible)

- How well does the transition from whale oil to petroleum that occurred in the mid - 19th century fit a deterministic model of dynamic efficiency of natural resource use?
  - In other words: just how ‘lucky’ was the discovery of petroleum, and what can be said about resource transitions when new resources/technology are uncertain

A standard transition between two known resources

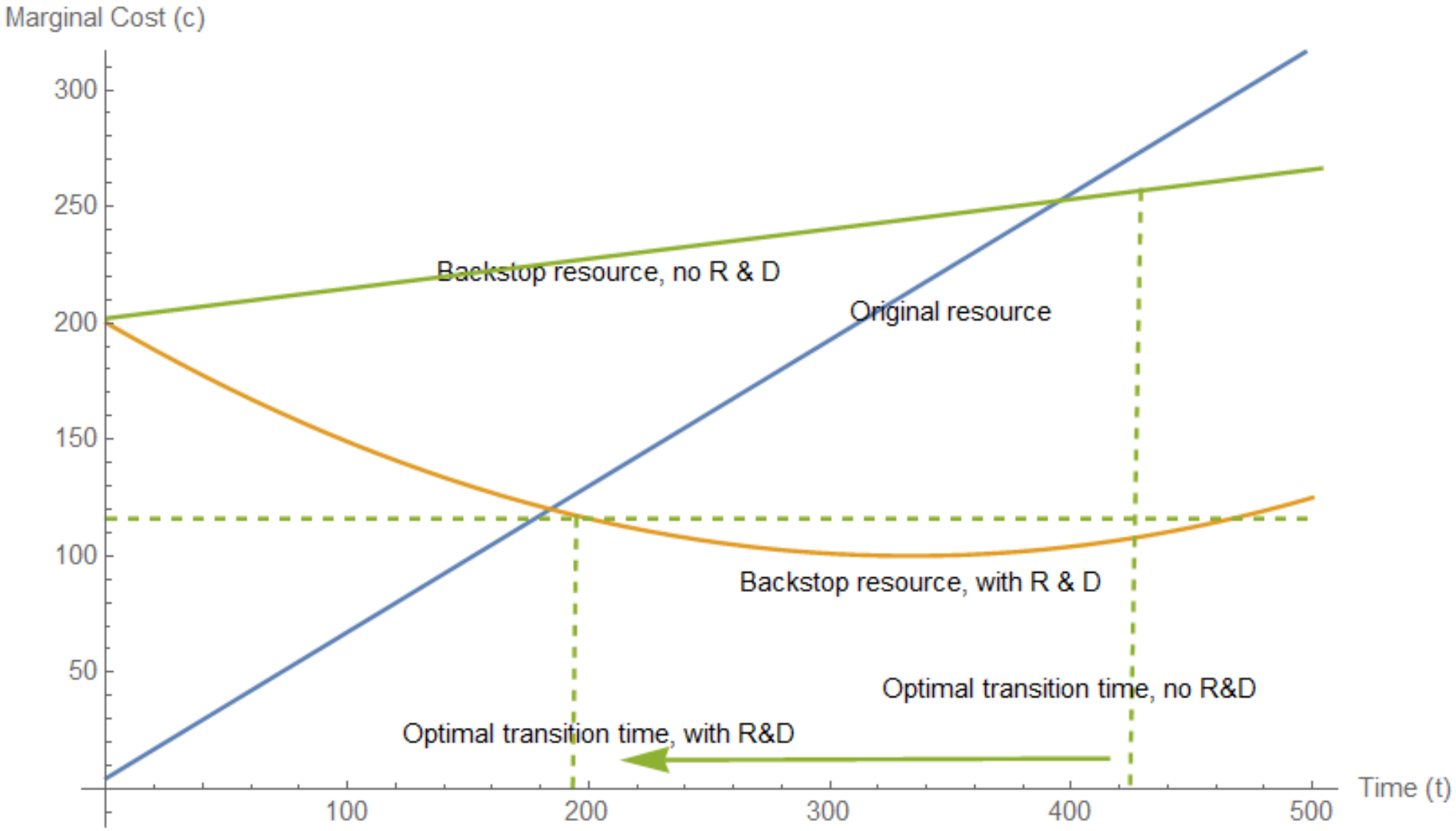


Illuminating Oils Price and Quantity



Note: gap in prices because only get about 5-10% kerosene from crude

From an exhaustible to a non-renewable resource needing knowledge investment



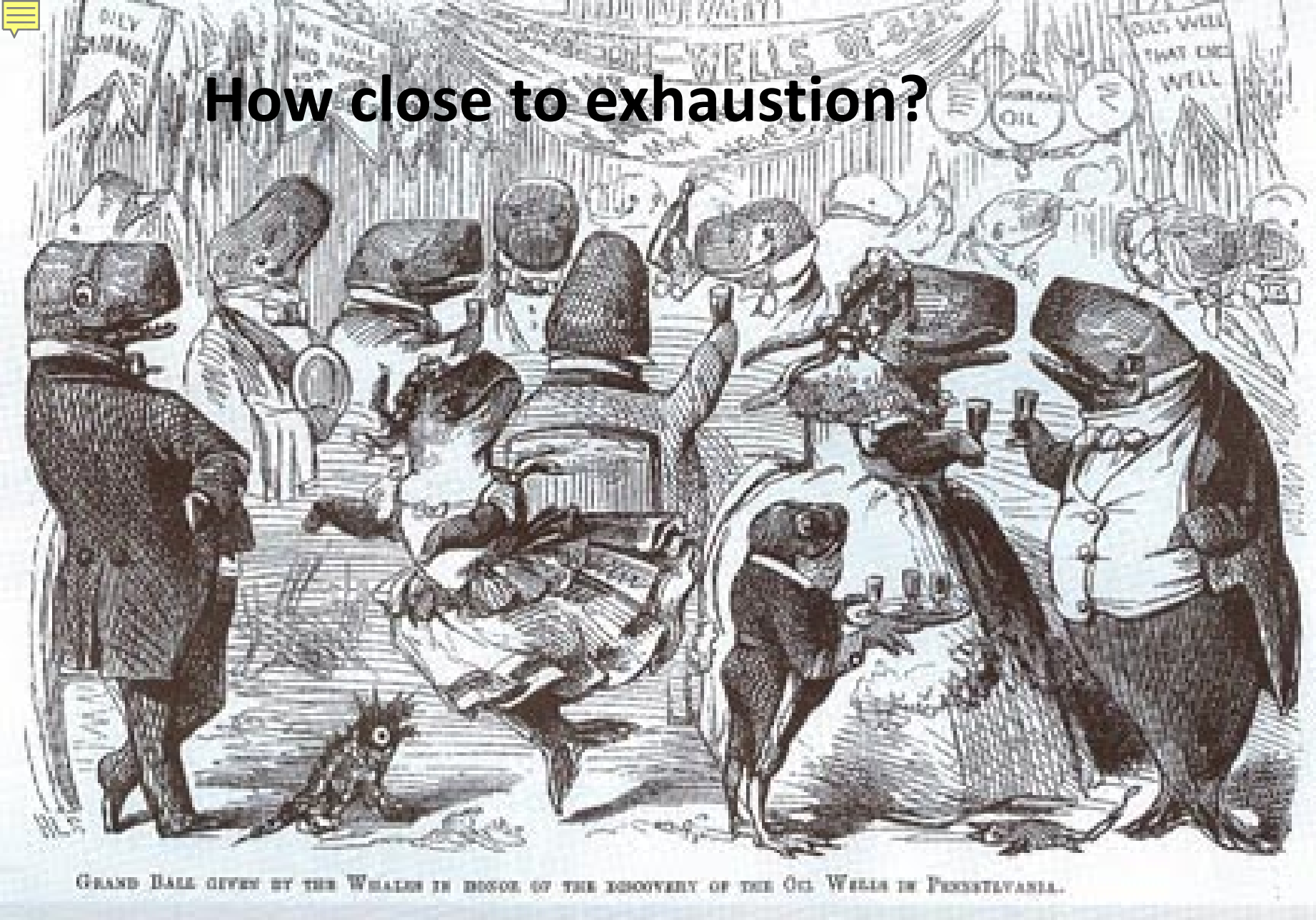
Theoretical Model

- An adapted model from Tsur and Zemel (2003, 2005) of resource transitions
- Maximize net benefits over time from whale extraction, oil investment, oil extraction, subject to:
  - Dynamics of whale population
  - Dynamics of knowledge over new backstop (oil)
  - Dynamics of non-renewability of backstop
  - Time of transition between whale oil and oil

Conventional Wisdom and Economic History

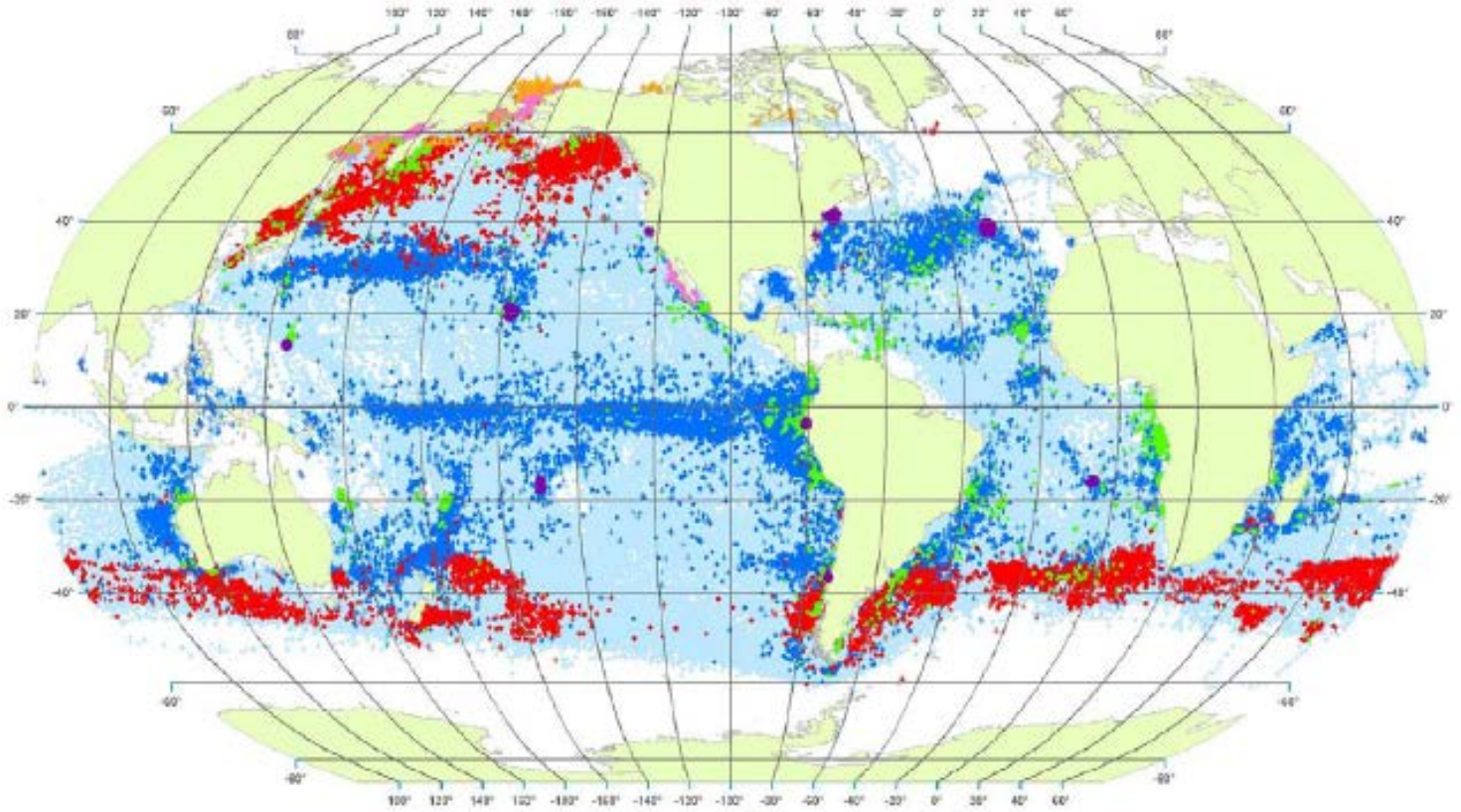
- Contemporary opinion: Whales doomed without petroleum
- Daum (1957) revision: substitutes well under development. No direct statement about whale popn's but implication was transition was already underway - and diffuse
- Davis, Gallman, Hutchins (1988) revision: sperm whale populations high; reproduction rapid; extinction risk therefore low
- Treatment of discovery of drillable petroleum as exogenous but transformative

How close to exhaustion?



"Grand Ball given by the Whales in honor of the discovery of the Oil Wells in PA"

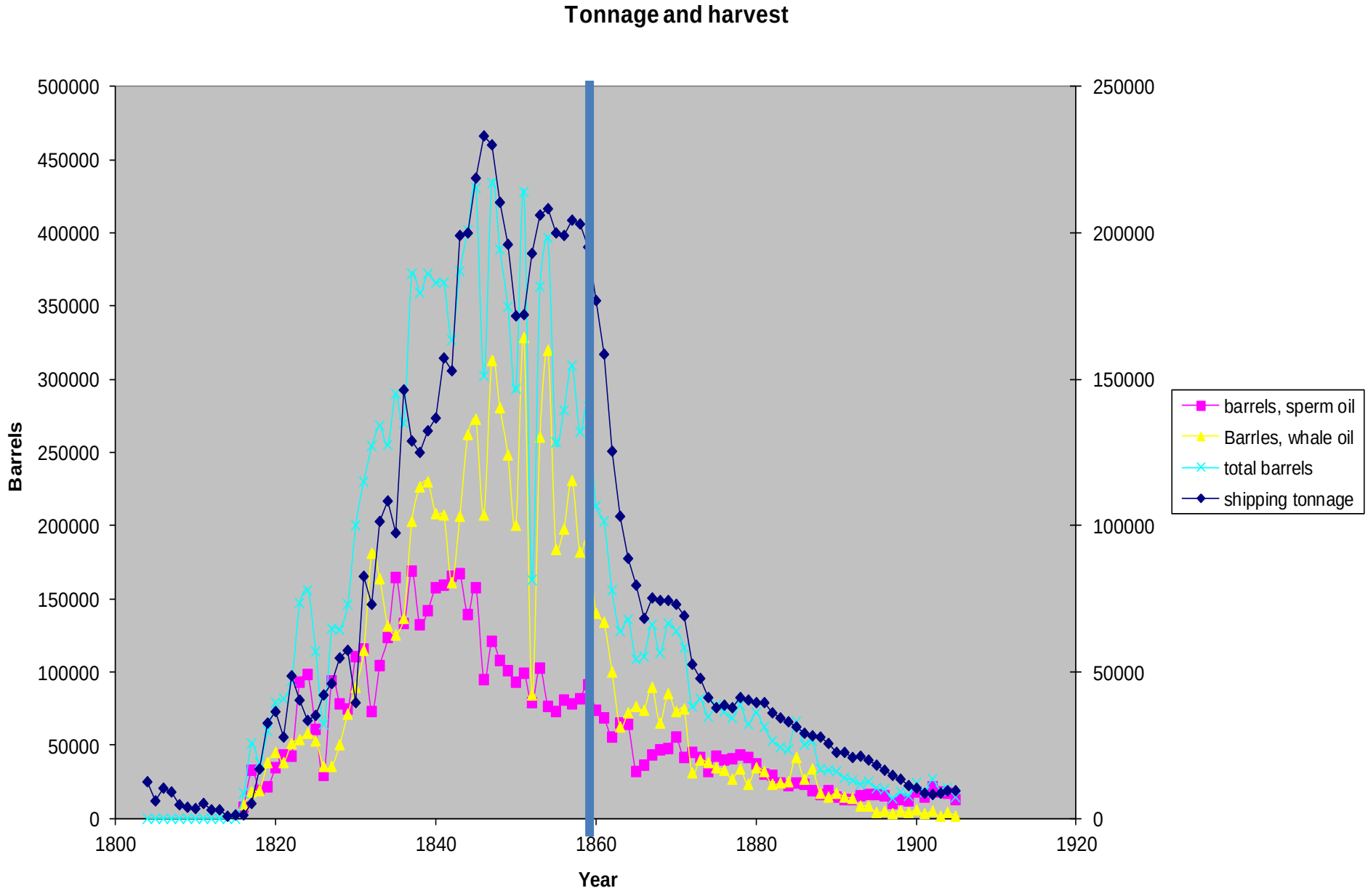
– Vanity fair 1861

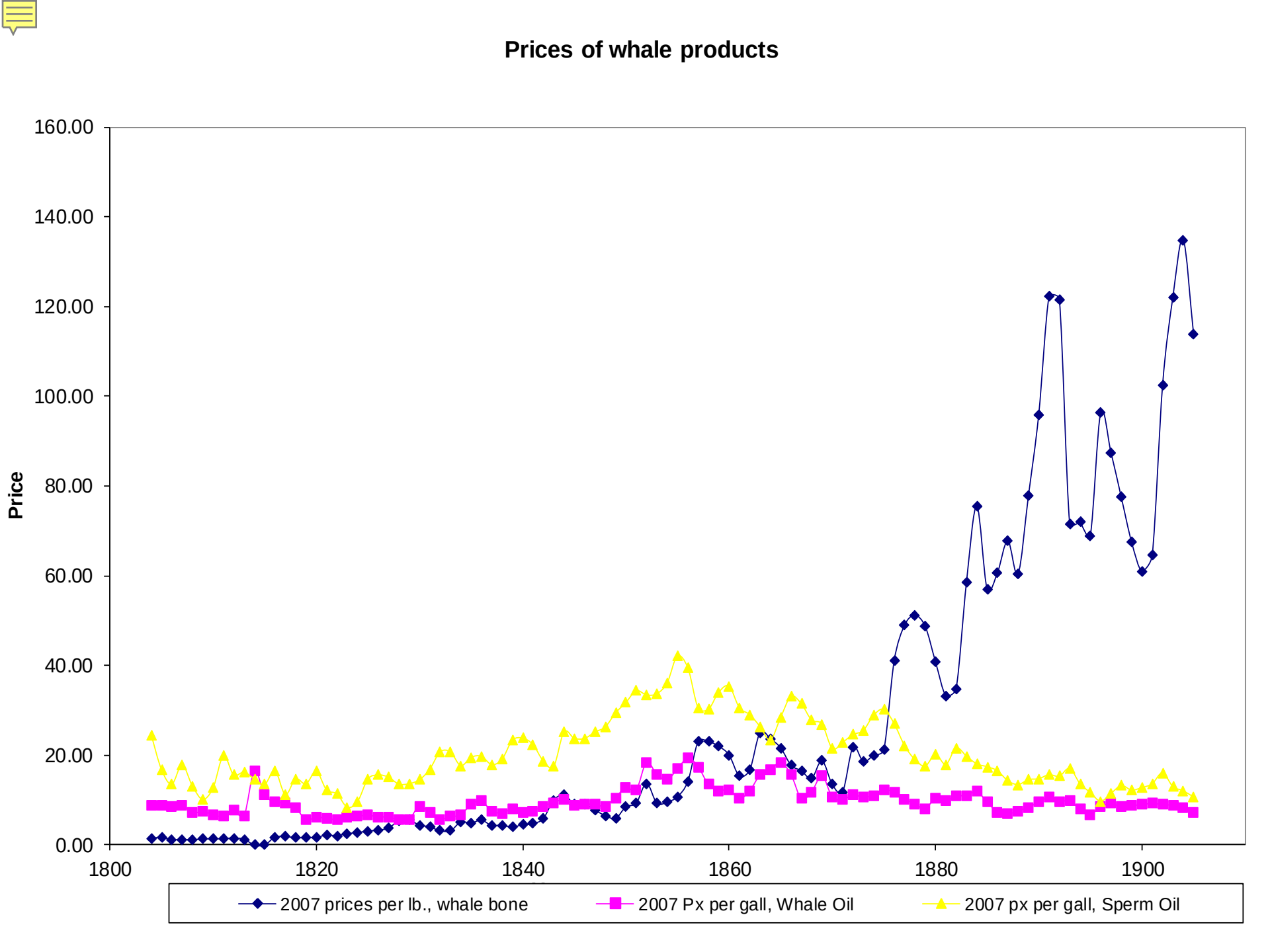


Light Blue	Days when none of these 5 species of whales were sighted or caught (•)
Dark Blue	Days when one or more sperm whales were sighted (•) or caught (+)
Red	Days when one or more right whales were sighted (•) or caught (+)
Orange	Days when one or more bowhead whales were sighted (•) or caught (+)
Green	Days when one or more humpback whales were sighted (•) or caught (+)
Pink	Days when one or more gray whales were sighted (•) or caught (+)
Violet	Locations of home ports (*) and more frequently used ports (•)

Figure 1. All observations of sperm, right, bowhead, gray, and humpback whales. Daily locations of vessels were extracted from a sample of American whaling logbooks for voyages departing between 1780 and 1920. Days with no whale observations and days with observations of sperm, right, bowhead, humpback, and gray whales and locations of key ports were distinguished by the colors indicated. Whalemen from other countries caught whales in many of the same areas and in some areas where American whalemen did not go (see text).
doi:10.1371/journal.pone.0034905.g001

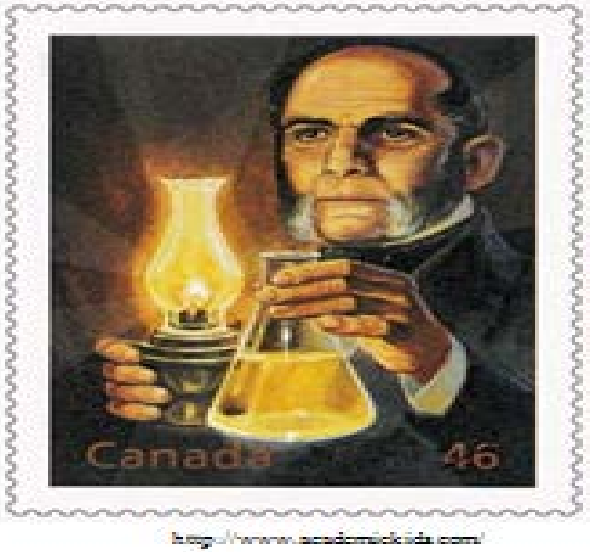
Whale Ships


Tonnage and harvest
Barrels
Year
500000
450000
400000
350000
300000
250000
200000
150000
100000
50000
0
250000
200000
150000
100000
50000
0
1800
1820
1840
1860
1880
1900
1920
barrels, sperm oil
Barrles, whale oil
total barrels
shipping tonnage


Prices of whale products
Price
160.00
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
1800
1820
1840
1860
1880
1900
2007 prices per lb., whale bone
2007 Px per gall, Whale Oil
2007 px per gall, Sperm Oil

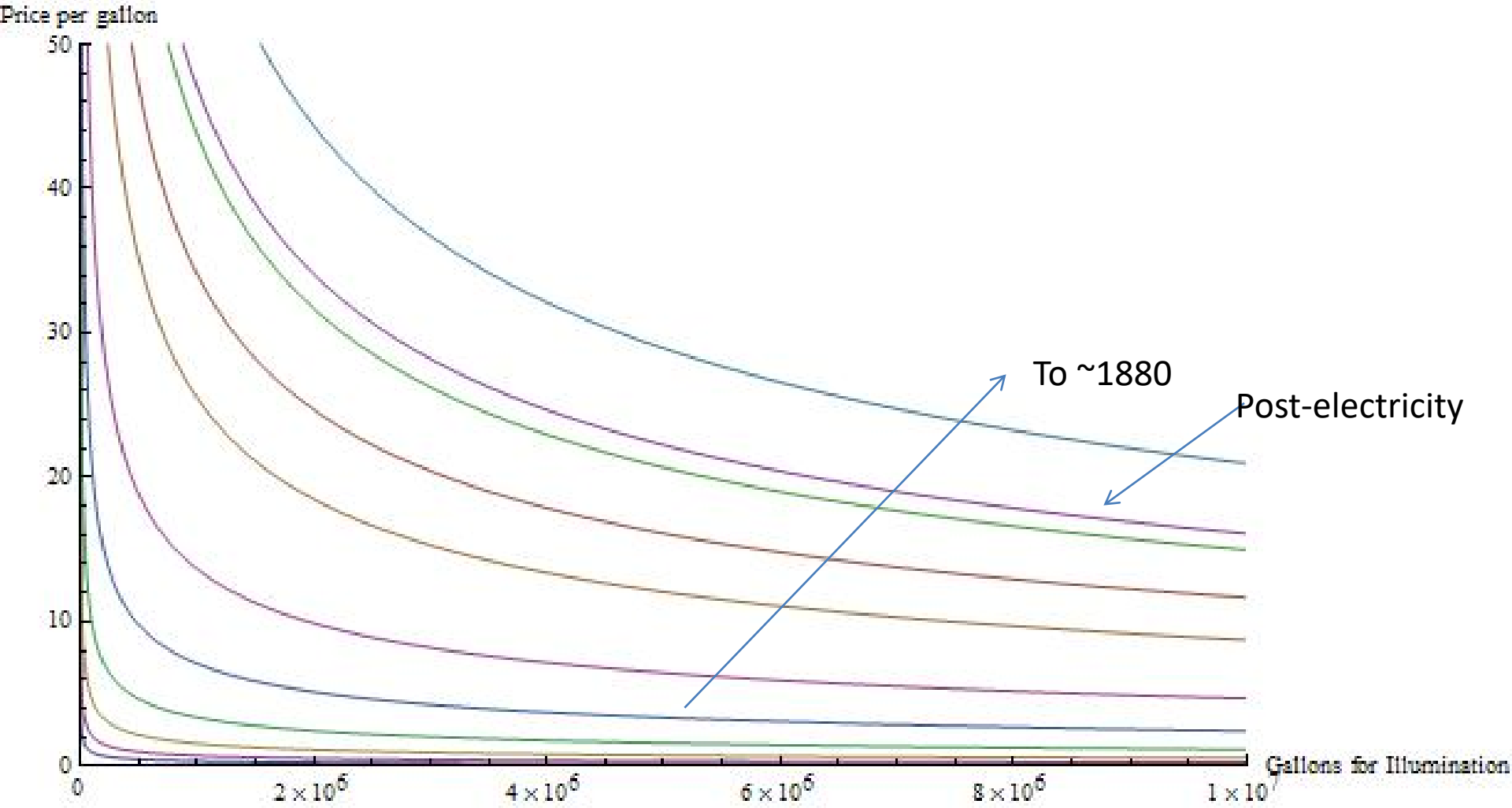
Illuminating oils Market

- Demand for Illuminating oils
- Supply of illuminants
- Progress of scientific knowledge/technology in the industry -- interpret as MC of substitute technologies changing

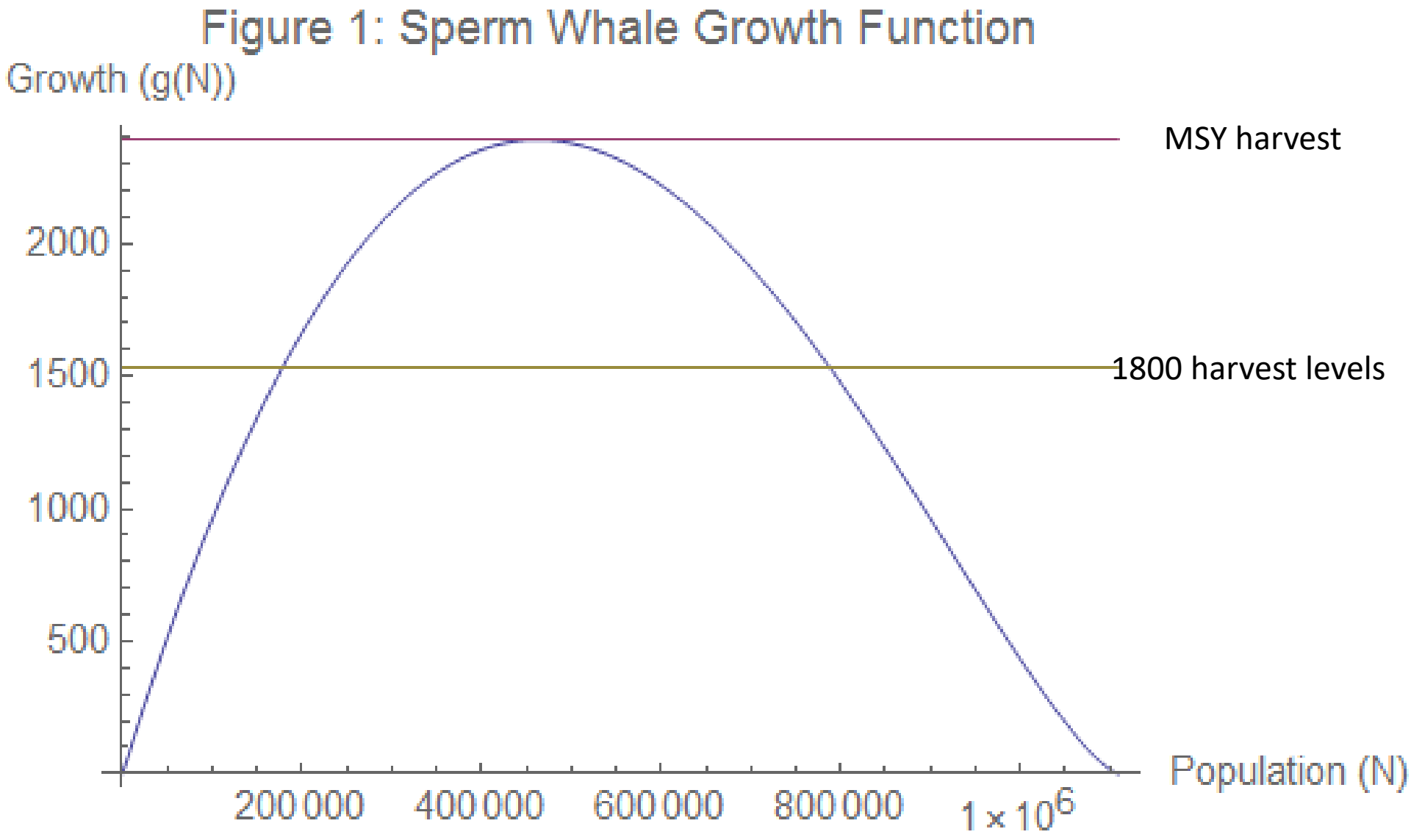


Recall: urban electrification takes off 1880s

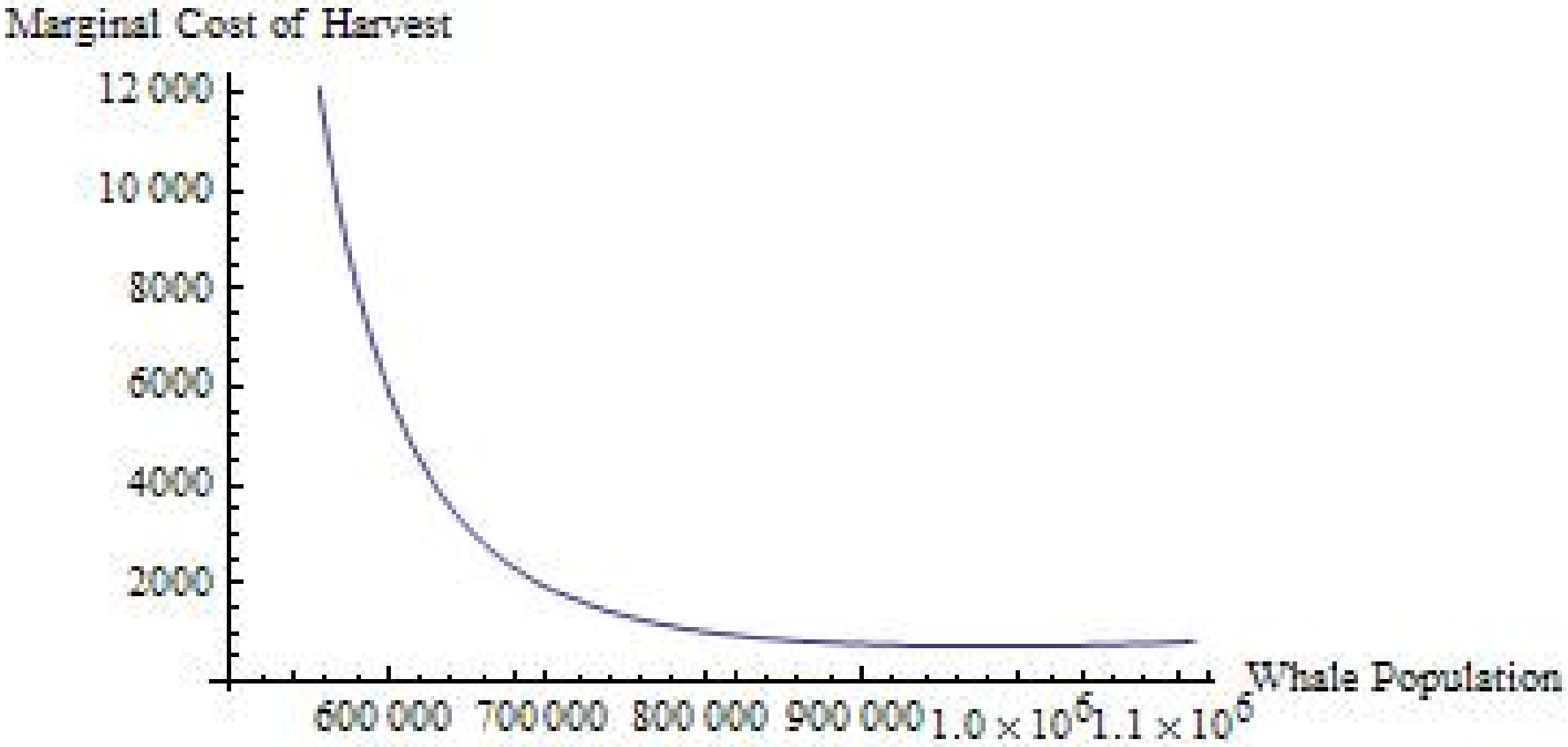
Demand Curves for Illumination Oils as time, substitutes vary



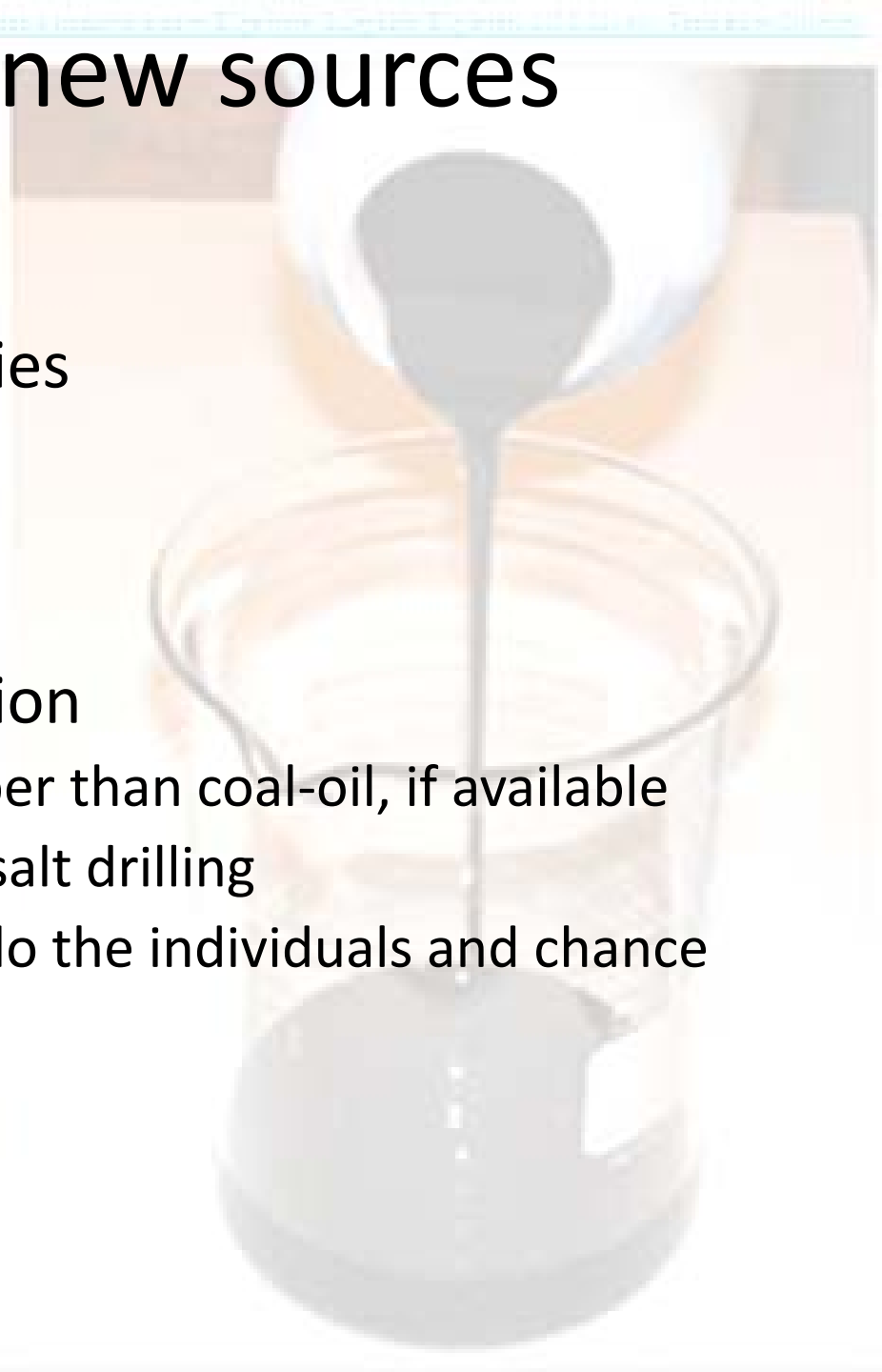
Marginal Costs of Whaling dependent on Whale population



MC (Supply) of Sperm Oil as function of whales: Costlier as More Scarce



Transition to new sources

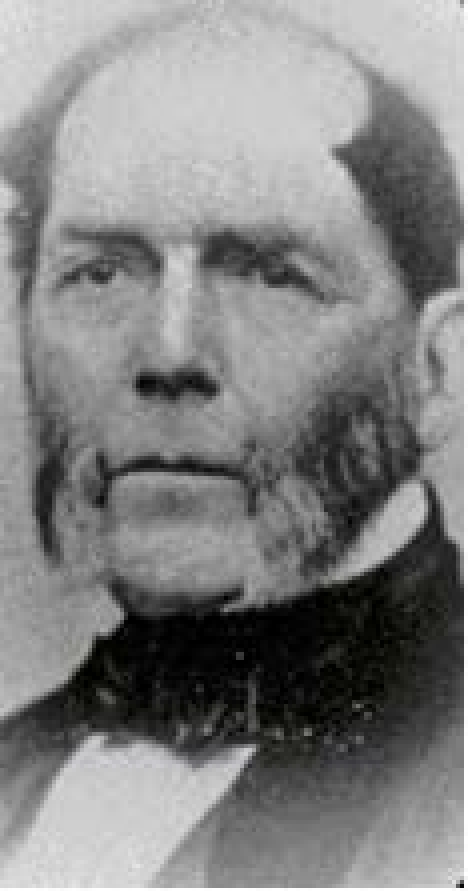


- Intermediate technologies
  - Town gas
  - Camphene
  - Coal-oil
- Petroleum and exploration
  - Thought would be cheaper than coal-oil, if available
  - Begins as by-product of salt drilling
  - Timing and Innovation: do the individuals and chance matter much?

Some evidence on timing

Share of lighting market	1850	1860
Town gas	16%	38%
Camphene	-	8.9%
Castor Oil	5%	1%
Coal Oil (Kerosene)	-	20.3%
Cottonseed Oil	-	2.4%
Lard	13.5%	8.1%
Rosin	-	1.7%
Whale	65.5%	19.4%

Data: U.S. Censuses
Daum (1957)



Abraham Gesner
(Webster's Online)

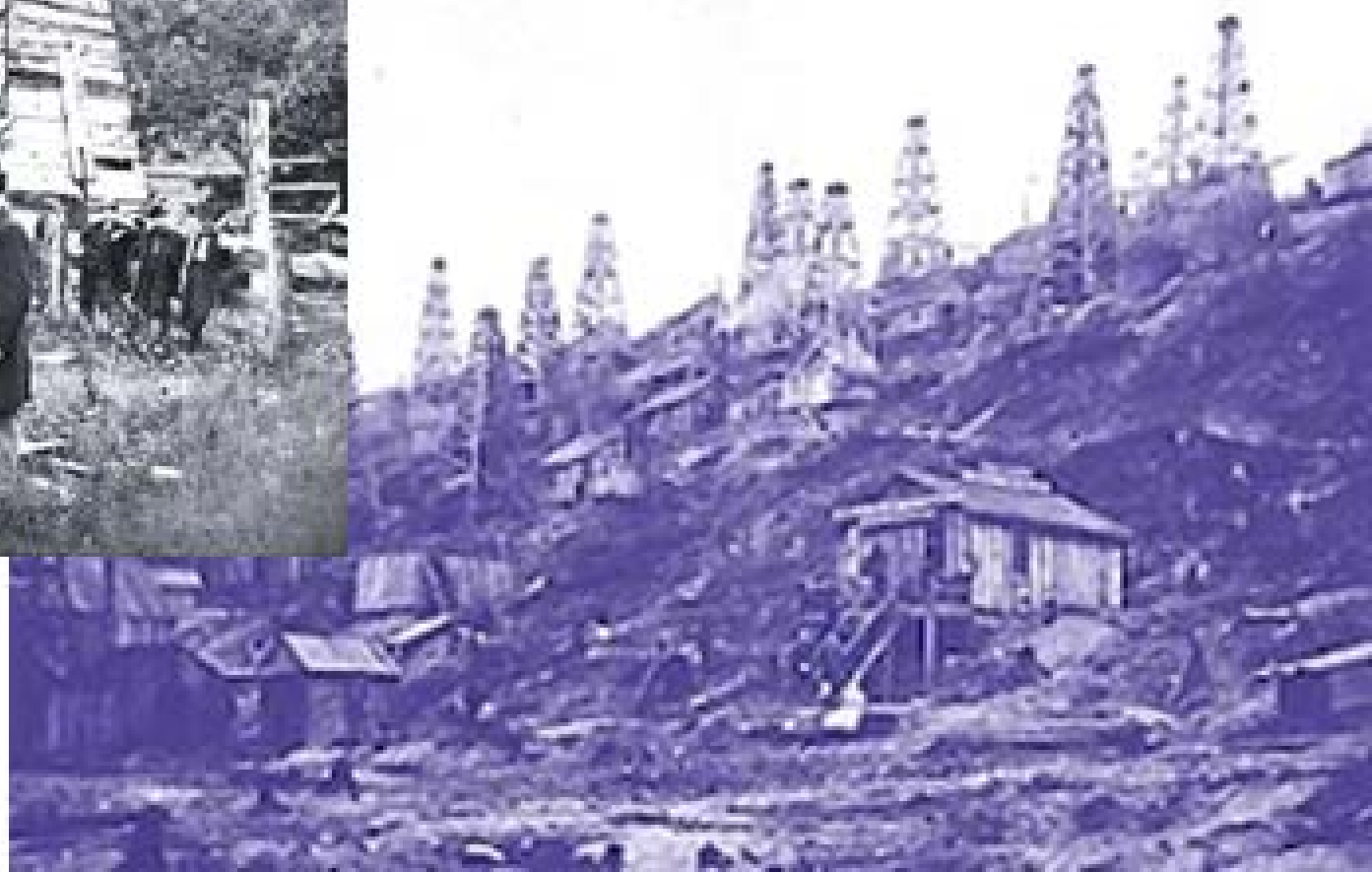
George Bissell
(www.oil150.com)

Kier's Seneca Oil
(explore PA history)

"Col." Drake
(BA Historical & Museum Commission)

Benjamin Silliman, Sr
(Yale University)

Benjamin Silliman, Jr
(Picture History)



Drillable Petroleum: not a deus ex machina

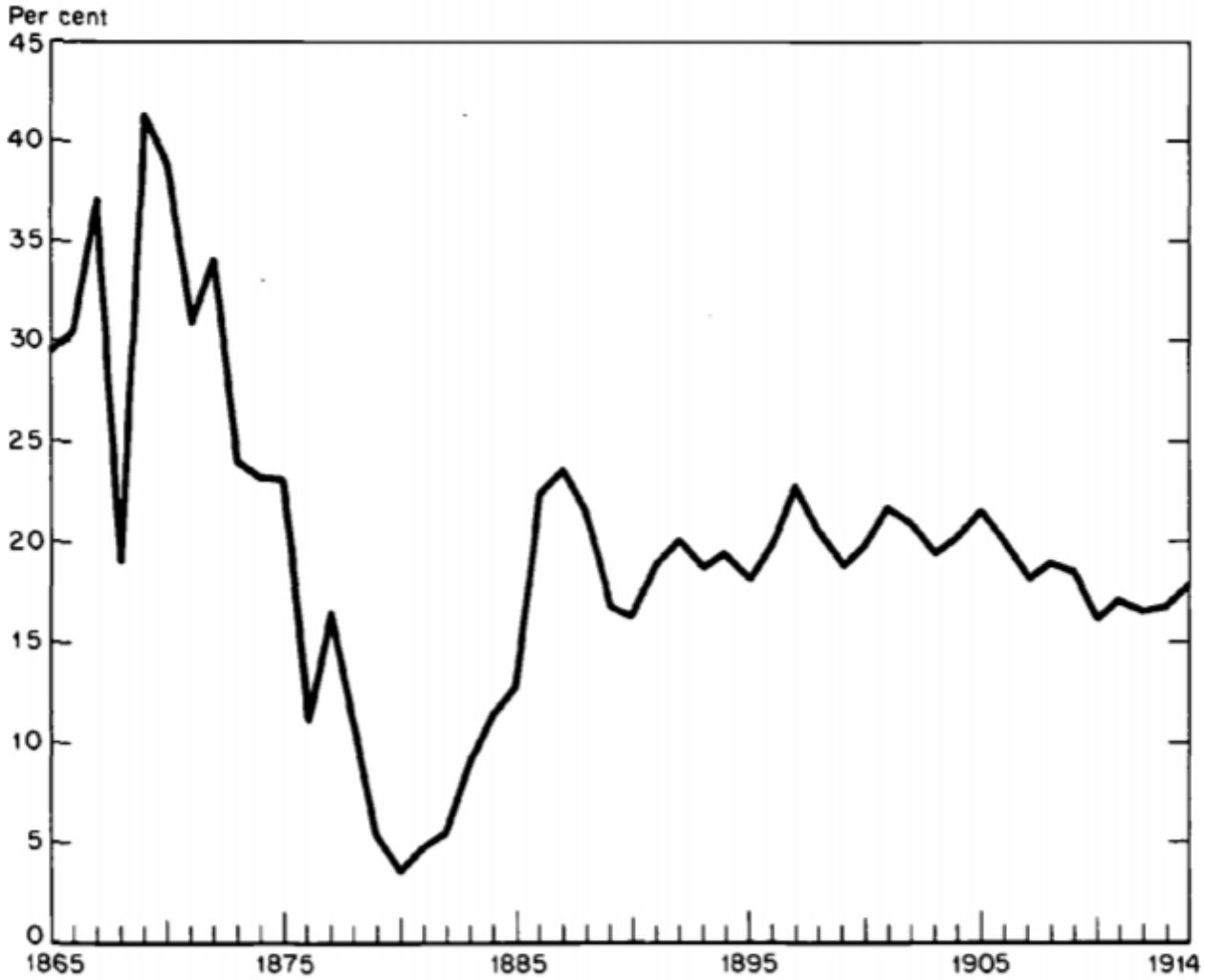
- The first strike at Pithole in August 1859 had required tenacity, curiosity, the professionalization of chemistry, and $300,000 in capital (~$1b dollars converted using share of GDP).
- After the drilling technology proved effective, wells sprang up rapidly, with over $800 million dollars (~$500 billion 2015 dollars) invested by 1903 in over 210,000 wells, and another $900 million dollars (~$550b 2015 dollars) invested in pipelines and transport from the wells. (Whiteshot, 1905)
- About 1/3 of the wells drilled were dry holes.
- Thus on average, a well cost $3782 (~$2.34 million 2015 dollars) and the expected cost of a producing well would be $5644 (~$3.50 million 2015 dollars).

Investment in Knowledge

$$R_t = \frac{\dot{p} - r(\mathrm{p}_t - M(\mathrm{K}_t))}{M'(K_t)} - \delta K_t$$

CHART 2

Dry Holes as Percentage of Total Wells Drilled, 1865–1914



Source: For 1865–82, *Derrick's Hand-Book*, I, Folger Report, Wrigley Report, and Carll Report; for 1883–1914, *Mineral Resources of the U.S.*, 1883–1914.

Williamson et al, 1966

Oil Exploration and Marginal Costs, 1859-1903

State	Total Production	Wells	E[Costs/Gallon]
PA, NY, OH, WV	1,089,752,446	180,210	2.95E-03
CA	62,216,945	6,000	5.06E-03
KY, TN	1,187,498	2,125	2.73E-04
CO	7,336,851	400	8.95E-03
IN	55,022,626	19,000	1.41E-03
IL	6,585	Unk	Unk
KS	1,959,707	1,500	6.37E-04
TX	42,551,796	2,000	1.04E-02
MO	8,299	Unk	Unk
I.T.	193,565	98	9.63E-04
WY	49,450	250	9.65E-05
LA	1,466,388	Unk	Unk

MC of petroleum as function of discovery (IV estimates)

Variable	Coef.	Std. Err.	z	P>|z|
K expenditures to date	−0.0024	0.0036	−0.66	0.51
Pre−1866 dummy	10.58***	1.51	6.99	0.
Pre−1866∗Exp. to date	−2.44***	0.468	−5.21	0.
Constant	1.38**	0.673	2.06	0.04
R^2 (Uncentered)	0.66			
F(3,42)	17.93***			
Instruments	GDP per Capita			
	Index of Industrial Production			

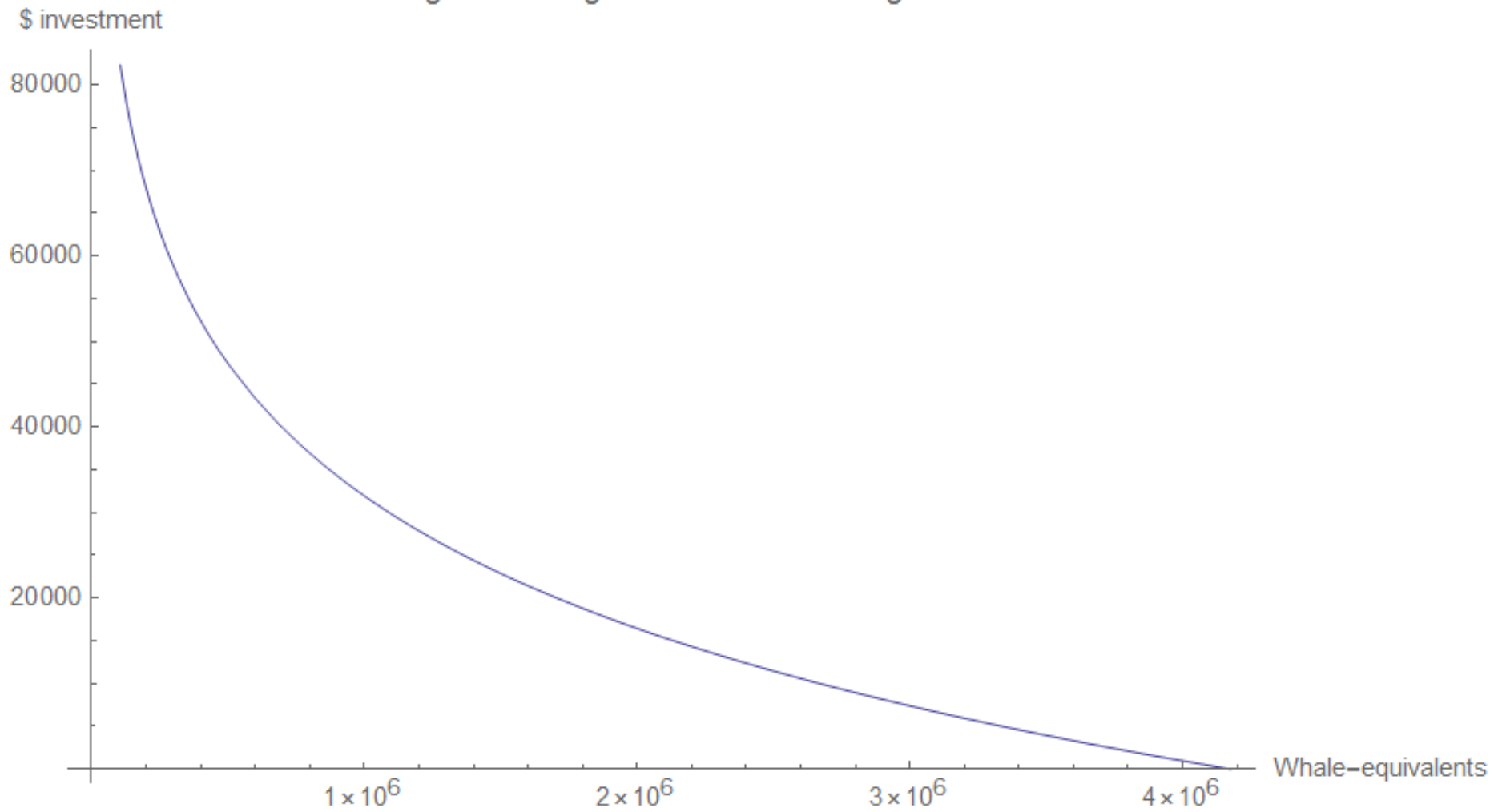
$M(K_t)$ $=11.96-2.44K$ for $t < 1867$

$=1.38-.0024K$ for $t \geq 1867$

K=knowledge of petroleum

M(K)= marginal costs of petroleum

Figure 5: Marginal Cost of Knowledge



Marginal User Cost

$$p_t - c(n_t) = \frac{\mathrm{c}'(\mathrm{n}_t)((\mathrm{g}(\mathrm{n}_t) - \mathrm{q}_{wt} + 1) - (r + \delta)(R_t - \delta K_t) + r(M(K_t) - c(n_t)}{g'(n_t)}$$

P_t = Price of illuminating oils pt
$c(n_t)$ = Marginal cost of harvest, dependent on whale population

g(n) = Growth rate of whale population
q_{wt} = Harvest of whale population (supply of illuminating oil)

$R_t - \delta K_t$ = Net investment
$M(K_t)$ = Marginal cost of backstop production as a function of Knowledge

r = discount rate
δ= depreciation rate of knowledge

Conclusions/ Further research

- Petroleum discoveries do not need to be thought of as “lucky” or “by chance” -- a long evolution -- implications for renewable energy investments today
  - This transition fits the theory as adapted
- Nothing like optimal management or transition for the resources: open access fishery, rule of capture petroleum – but in this case the open access fishery may have hastened investments (which should happen v. quickly under optimal management) by pushing MC whaling up substantially
- Who are “transitioners”? Whaling industry ‘heirs’ had lots of K, could have done much better if got K out of whaling (and into oil?) earlier.

Small aside: lighting with kerosene a temporary transition itself; replaced by electricity
But petroleum finds other profitable uses

AVERAGE NEW YORK WHOLESALE PRICE OF ILLUMINATING OIL AND NAPTHA-GASOLINE, 1865-1914
(cents per gallon)

Year	Price of Illuminating Oil	Price of Naptha-Gasoline
1865-69	26.6[a]	
1870-74	18.1[a]	
1875-79	13.3	
1880-84	8.1	6.0 (1884)
1885-89	7.3	6.0
1890-94	6.1	6.3
1895-99	6.9	7.5
1900-04	9.4	14.0 (1904)
1905-09	9.1	13.4 (1909)
1910-14	8.1	16.4

Source: Williamson and Daum, *American Petroleum Industry, 1859-1899*, pp. 326, 524, 680; Williamson, Andreano, Daum and Klose, *American Petroleum Industry, 1900-1959*, p. 172.

[a]Price in gold.

Data for Demand and Cost

- Whales and whaling industry:
  - Davis, Gallman and Gleiter (1997) from Tower (1907)/Starbuck(1876) for annual fleet aggregates, 19th C
    - Note: whaling was about 5% of US GDP in early-mid 1800s.
  - American Offshore Whaling Database (2011) for individual vessel voyages from 18th-early 20th C.
  - Whitehead (2002) sperm whale populations & growth
- Petroleum industry:
  - Price and Quantity data [crude oil]: U.S. Bureau of Mines, *Mineral Resources of the United States*(annual, 1859-1931), from Hist. Stat. of the US
- Historical Statistics of US (e.g. Davis Industrial Index, GDPpc, pop)