Energy Economics and Policy
AUEB

Christos Karydas

ex: ETH Zurich – Chair of Economics / Resource Economics
now: Ernst & Young – Financial Services Risk Consulting

Lecture 6:
Non-renewable
Resources 1/2

Objectives

- What is the optimal extraction of a non-renewable resource/

  (οικονομικά) βέλτιστη εξόρυξη ενός μη ανανεώσιμου πόρου?

- What drives resource prices in a dynamic world?

  Τι οδηγεί τις τιμές σε ένα δυναμικό κόσμο;

- Mineral fuel scarcity/έλλειψη ορυκτών καυσίμων
  - What is feasible / what is sustainable? Δυνατό vs βιώσιμο
  - can we avoid a doomsday scenario?

    Είναι η οικονομία μας καταδικασμένη λόγω ελλειπών ορυκτών πόρων;
  - Substitution/υποκατάσταση μη-ανανεώσιμων πηγών με κεφάλαιο
  - Resource-saving technical progress / τεχνολογική πρόοδος

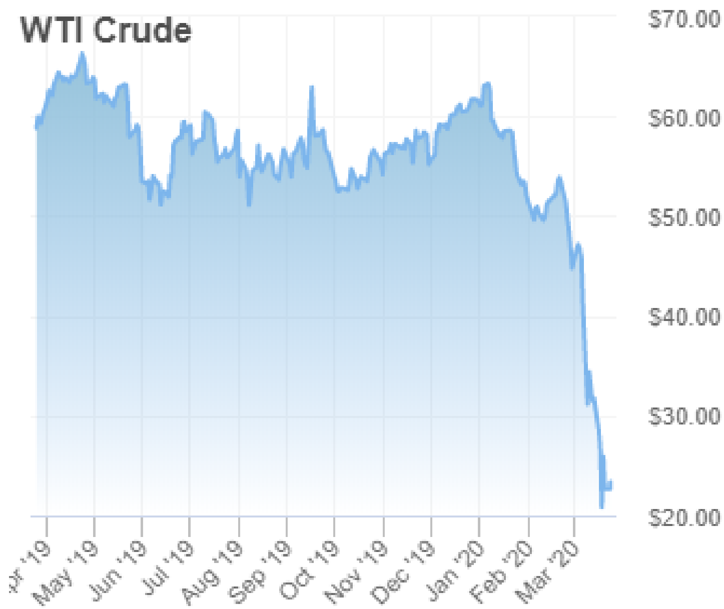
What shapes the price of NRR?

The Washington Post
Democracy Dies in Darkness

Monkey Cage • Analysis

Saudi Arabia is launching an oil price war.

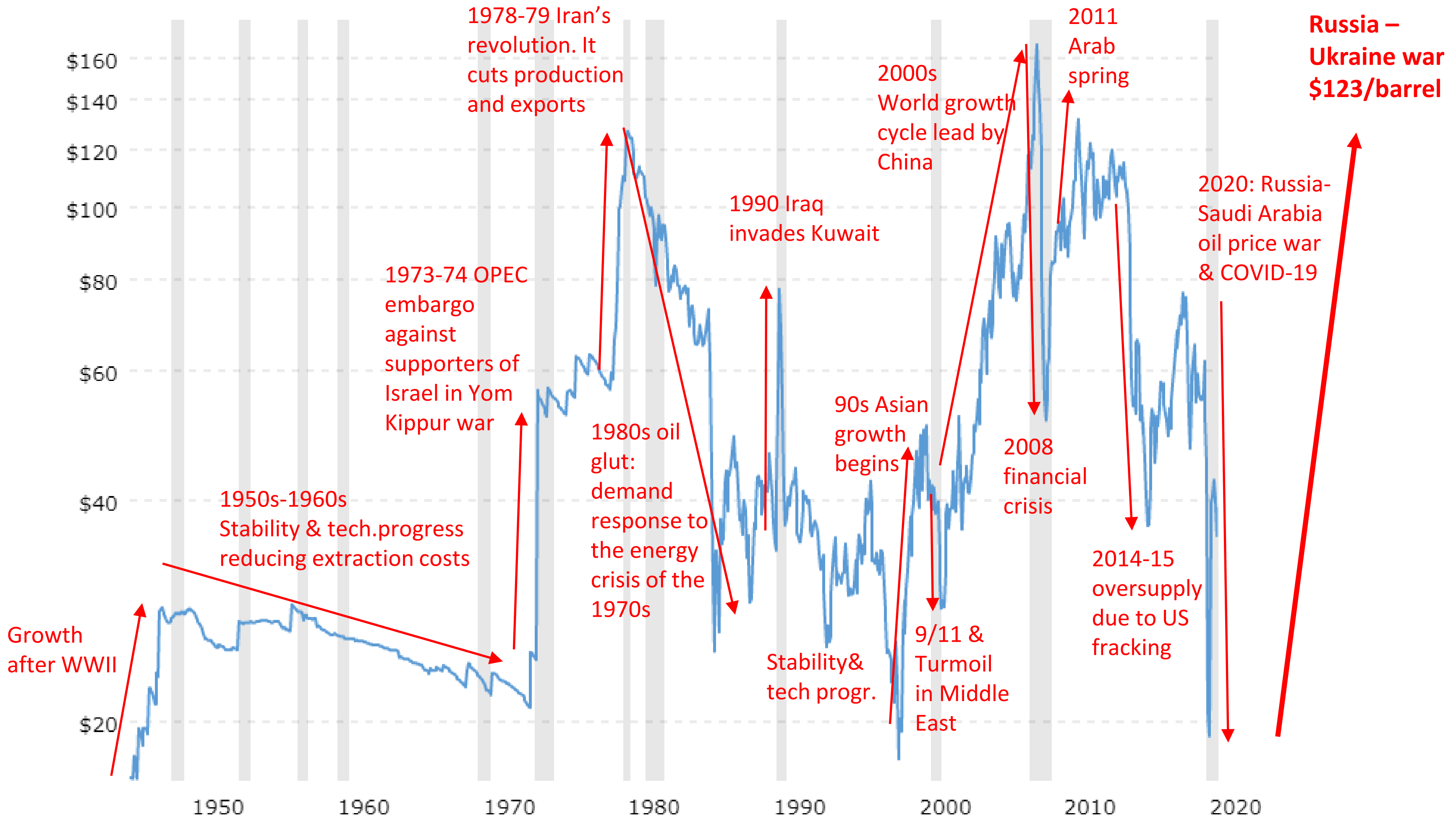
Without oil revenues, the monarchy could be in trouble



OilPrice.com

What shapes the price of NRR?

Spot price of WTI since 1946 ($/barrel)



https://www.macrotrends.net/1369/crude-oil-price-history-chart

What shapes the price of NRR?

What we saw so far: Static theory – Supply/Demand

- Market power / OPEC behaviour
- Techn. Progress, e.g. Shale oil/gas
- Economic situation, e.g. econ. crisis
- Public policy, e.g. taxes, subsidies
- Growth of emerging economies
- Geopolitics/tensions/embargoes

But resource extraction is dynamic

- Resource scarcity
- Time value of money
- Social aspect: energy found underground belongs equally to current and future generations (E.g. Norway's sovereign wealth fund)
- We need to consider the dynamics of resource extraction → when we extract, less is left underground

Limits to growth

The history of energy "scarcity" – Ιστορική αναδρομή της έλλειψης ενέργειας

Jevons (1866) – Reliance of England on coal

"Are we wise in allowing the commerce of this country to rise beyond the point at which we can no longer maintain it?"

Club of Rome / Meadows et al. (1972) – Reliance on oil

- Exhaustible resources essential inputs in production
- Long-run prospect may be worse than stagnation

Oil price shocks in the 1970s

- Yom-Kippur war 1973 $\rightarrow$ First price shock
- Iran-crisis 1979 $\rightarrow$ Second price shock

→ Resource economics (re-)emerges as a field

What is feasible vs sustainable

"Contemplation/η εξέταση of the world's disappearing supplies of minerals, forests, and other exhaustible assets has led to demands for regulation of their exploitation.

The feeling that these products are now too cheap for the good of future generations, that they are being selfishly exploited at too rapid a rate, and that in consequence of their excessive cheapness they are being produced and consumed wastefully has given rise to the conservation movement."

H.Hotelling (1931), The Economics of Exhaustible Resources

Economics 101:
What is an asset/περιουσιακό στοιχείο?

Anything with **economic value** that an individual, firm, or country owns/controls. It can generate a consumption cash flow in the **future.** Maintaining / accumulating an asset usually needs **investment**

Οτιδήποτε (χρηματο-)οικονομικής αξίας που μπορεί να αποδόσει μελλοντική ικανότητα κατανάλωσης. Η συσσώρευση/ συντήρηση του περιουσιακού στοιχείου χρειάζεται επένδυση.

<u>Examples</u>

- Physical capital – buildings, machinery, infrastructure
- Human capital – education, skills
- Technology – innovation protected by a patent
- Energy reserves – oil, gas, coal
- Clean environment
- ...

Economics 101: No-arbitrage condition

- If we adjust for their risk and cost/depreciation, investing in every asset should yield the same return

Or

- All associated assets are priced appropriately such that all high-risk opportunities are associated with high-reward

→ Δεν υπάρχει δωρεάν γεύμα: επένδυση υψηλού κέρδους (κατά προσδοκία) περιέχει υψηλό κίνδυνο.

Example:

Imagine you have to evaluate two investment options for the same amount

a) Leave the money in the bank at an interest rate r % p.a.
b) Buy and rent out real estate with a yearly depreciation rate of δ % p.a. (δ is the rate at which capital depreciates – e.g. 2% p.a.)

You should be indifferent between a) and b) if real estate yields a rental rate of $r + \delta$ % per year → No arbitrage

Economics 101:
Opportunity cost-κόστος ευκαιρίας

- Foregone benefit an individual or firm misses out when choosing one alternative over another / Διαφυγόν κέρδος που θα προέκυπτε από μία συναλλαγή ή επένδυση η οποία δεν πραγματοποιήθηκε

- Example: with 10€ one can go to the movies or eat a pizza at home. If cinema is chosen, the benefit of the pizza at home is the opportunity cost

- One needs to consider “all” lost opportunities when making an investment decision.

Story of a mine-owner

Production by a normal firm is different from mineral extraction

Trade-off/αντιστάθμιση επιλογών:

- Too high extraction now → less available for future extraction
- Letting resource in the ground → lower profits in the present

There is a specific <u>opportunity cost/**κόστος ευκαιρίας**</u> of extraction:

If you extract everything now, you lose the opportunity of selling next period at (maybe) higher prices

Story of a mine-owner

Decision:

how much of the mineral to extract in each time period so as to earn maximum profits now as well as in the future

- With each year's extraction, the reserves will be reduced and eventually depleted
- Extraction vs conservation of the mineral depends on the expected future prices: price of the resource, extraction cost and the price of money (interest / discount rate)

Intuition (no-arbitrage condition)

Oil in the ground is like money in the bank:

- Keep it in the ground if it earns a safe return at least as high as the market's interest rate *r*
- If you expect oil prices to remain relatively constant, you are better of extracting now and investing the profits. If you expect prices to rise rapidly you should wait and extract at a later period

Hotelling rule

How fast must the price rise for you to delay extraction by one period?

Let p_t be the price of oil at time t and c the per unit extraction cost, which we assume constant. Profit from extracting and selling Q barrels at time t reads:

$$\pi_t = \underbrace{p_t \times Q}_{revenue} - \underbrace{c \times Q}_{cost}$$

The resource owner has two options between any two periods:

(a) Extract now, sell at current price, put profit it in the bank

(b) Wait and extract next period, sell at next period's price, earn next period's profit

No-arbitrage principle says that from the next period's viewpoint, he/she should be indifferent between the two options if price appreciates at the same rate as the interest he/she gets from the bank

Hotelling rule

We then have the following production rule:

If $(p_t - c)(1 + r) < p_{t+1} - c$ → keep oil in the ground

If $(p_t - c)(1 + r) > p_{t+1} - c$ → sell all the oil now

If $\underbrace{(p_t - c)(1 + r)}_{\substack{extract\\now}} = \underbrace{p_{t+1} - c}_{\substack{extract\\later}}$ → indifference between now or later

Depending on our <u>expectation</u> for the evolution of prices and interest rates we can use the above rule to determine our production

But how fast do we expect oil prices to rise over time? Think:

- If $(p_t - c)(1 + r) < p_{t+1} - c$ no-one would extract now → excess demand → price rise
- If $(p_t - c)(1 + r) > p_{t+1} - c$ everyone extracts now → oversupply → price falls
- $(p_t - c)(1 + r) = p_{t+1} - c$ **continuous production occurs when price less cost per barrel rise at the rate of interest → Hotelling rule**

Hotelling rule

In its complete form the Hotelling rule says:

For a non-renewable resource, the marginal profit $M\pi$=MR-MC should grow at the rate of interest:

$$M\pi_{t+1} = (1+r)M\pi_t$$

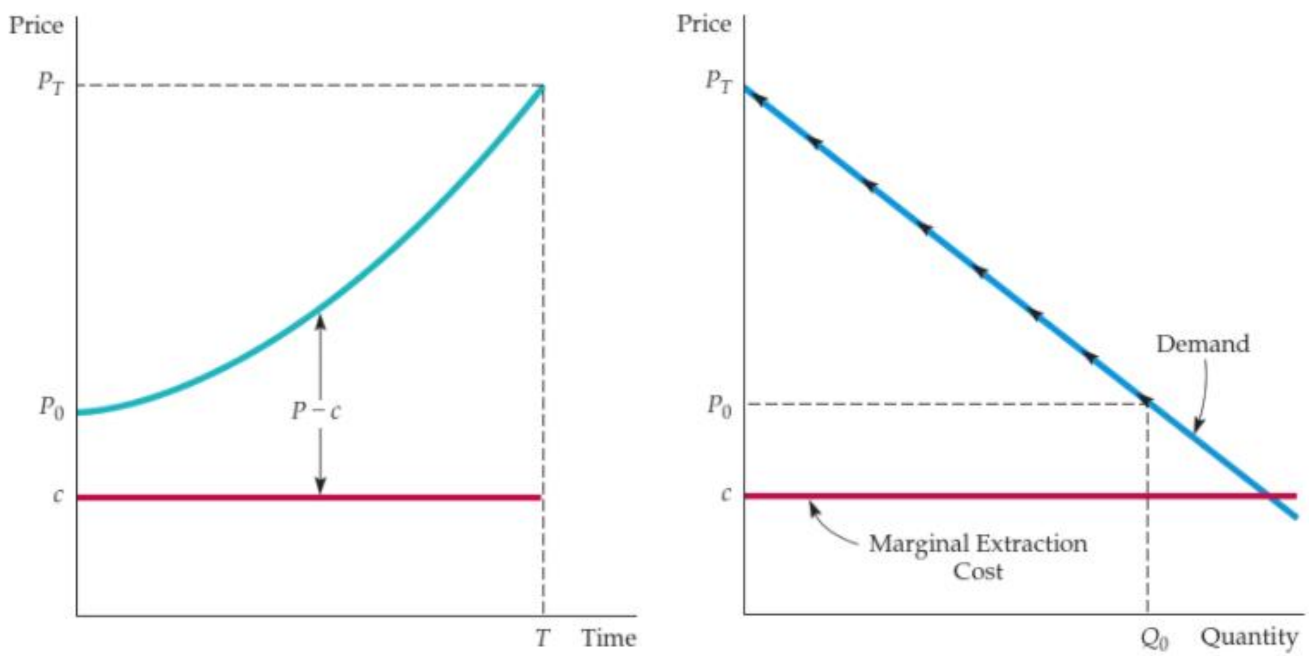
The opportunity cost of extracting now is the higher profit you would expect from future extraction

If expected marginal profit grows at a rate equal to the economy's interest rate, then you are indifferent between extracting now of in the future

- In the previous slide we had MC=c such that $M\pi$=MR-MC=p-c
- In perfect competition MR=p. In a monopoly MR=p(1+1/ε) (lecture 2)

Depletion path

- Hotelling rules comes from the optimization of producer profits
- But equilibrium values $\{Q_0, Q_1, Q_2, \dots\}$ depend also on the market demand for the resource (see below)
- Basic (micro-) economic principle: inverse relation between Q and p (demanded quantity decreases as price increases)
- Hence, since prices keep rising, the optimal depletion path features decreasing extracted quantities: $Q_0 > Q_1 > Q_2 > \cdots$ → depletion inevidable



Market equilibrium

Μέχρι στιγμής είδαμε μόνο γραμμική καμπύλη ζήτησης, όπου η ελαστικότητα ζήτησης αλλάζει κατα μήκος (δείτε διάλεξη 2). Δηλ, σε άλλο σημείο ισορροπίας της αγοράς θα υπάρχει άλλη ελαστικότητα.

Υπάρχει και μία άλλη κατηγορία καμπυλών ζήτησης με σταθερή ελαστικότητα κατά μήκος της καμπύλης. Η παρακάτω είναι μία τέτοια. Η παράμετρος ε είναι η ελαστικότητα ζήτησης σε σχέση με την τιμή του αγαθού.

Supply = Demand

Assume producers have MC=0, then

$$p_{t+1} = (1+r)p_t \rightarrow p_t = p_0(1+r)^t$$

Assume also that consumers have isoelastic demand curve $p = Q^{-1/\varepsilon}$

Supply = Demand then gives:

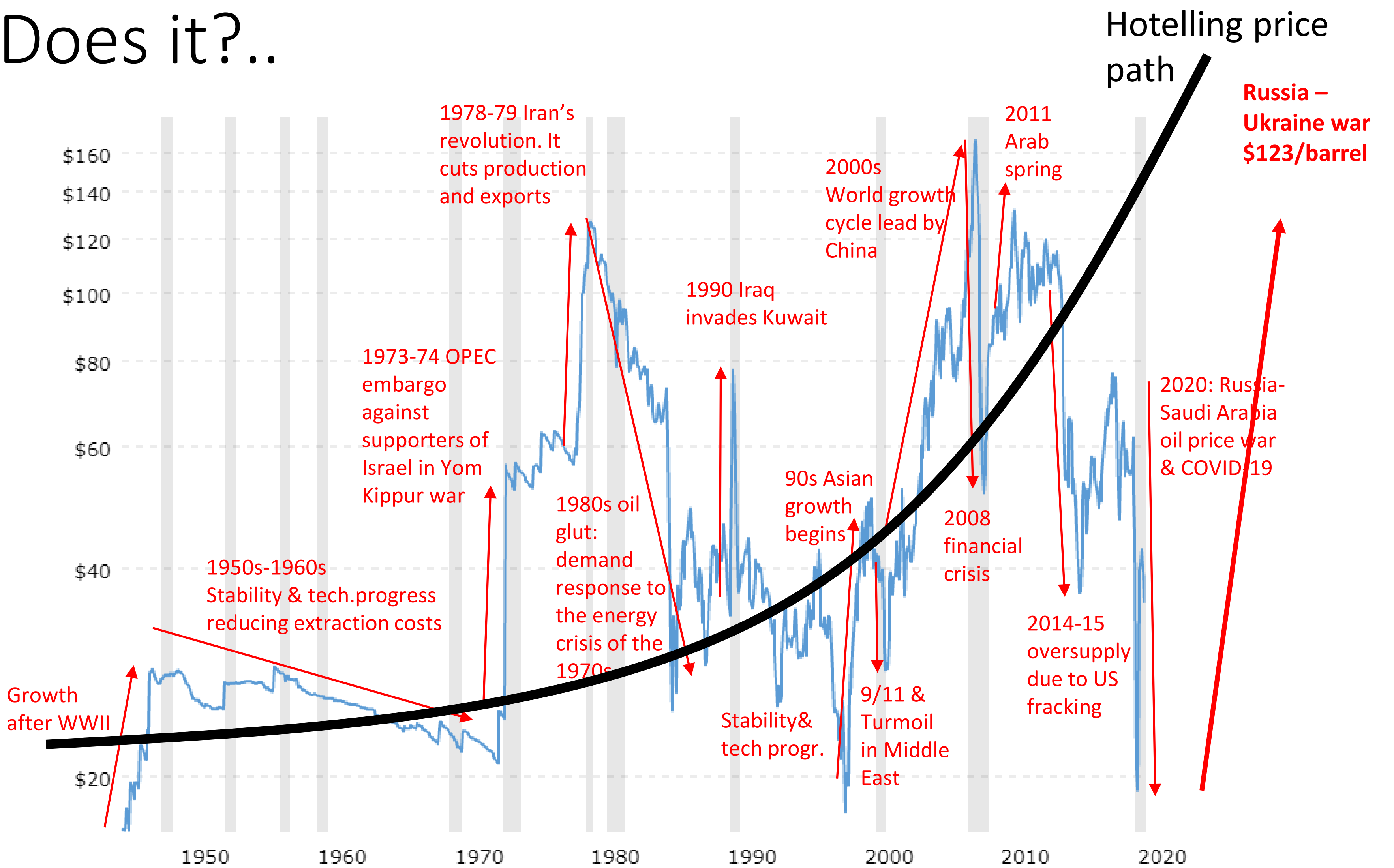
$$p_t = \underbrace{p_0(1+r)^t}_{supply} = \underbrace{Q_t^{-1/\varepsilon}}_{demand}$$

Using the <u>exhaustibility constraint</u> $\underbrace{Q_0 + Q_1 + Q_2 + \cdots}_{total\ extraction} = \underbrace{S}_{stock\ of\ resource}$

we can calculate $p_0 = p_0(S, r, \varepsilon)$

- Once we know p_0 we know the whole price path $p_t = p_0(S, r, \varepsilon)(1+r)^t$
- Then from market equilibrium we know the extraction path $Q_t = p_t^{1/\varepsilon}$ (which is a decreasing one)

Hotelling rule doesn't seem to apply
Does it?..



https://www.macrotrends.net/1369/crude-oil-price-history-chart

Hotelling rule doesn't seem to apply
Does it? Not exactly true if we consider:

New discoveries $(S \uparrow \rightarrow p \downarrow)$: an increase in the stock induces downward jump in prices (oversupply). Price path then follows Hotelling

→ Continuous discoveries keep prices low

Interest rates $(r \uparrow \rightarrow p \downarrow)$: an increase in the interest rate induces downward jump in prices (opportunity cost increases). Price path then follows Hotelling <u>with higher r</u>

→Constantly changing interest rates constantly move prices

Consumer behaviour $(\varepsilon \uparrow \rightarrow p \downarrow)$: a change in price elasticity of demand induces downward jump in prices (consumers don't tolerate higher prices anymore). Price path then follows Hotelling

→ Consumer preferences change in time

…

What else drives prices?

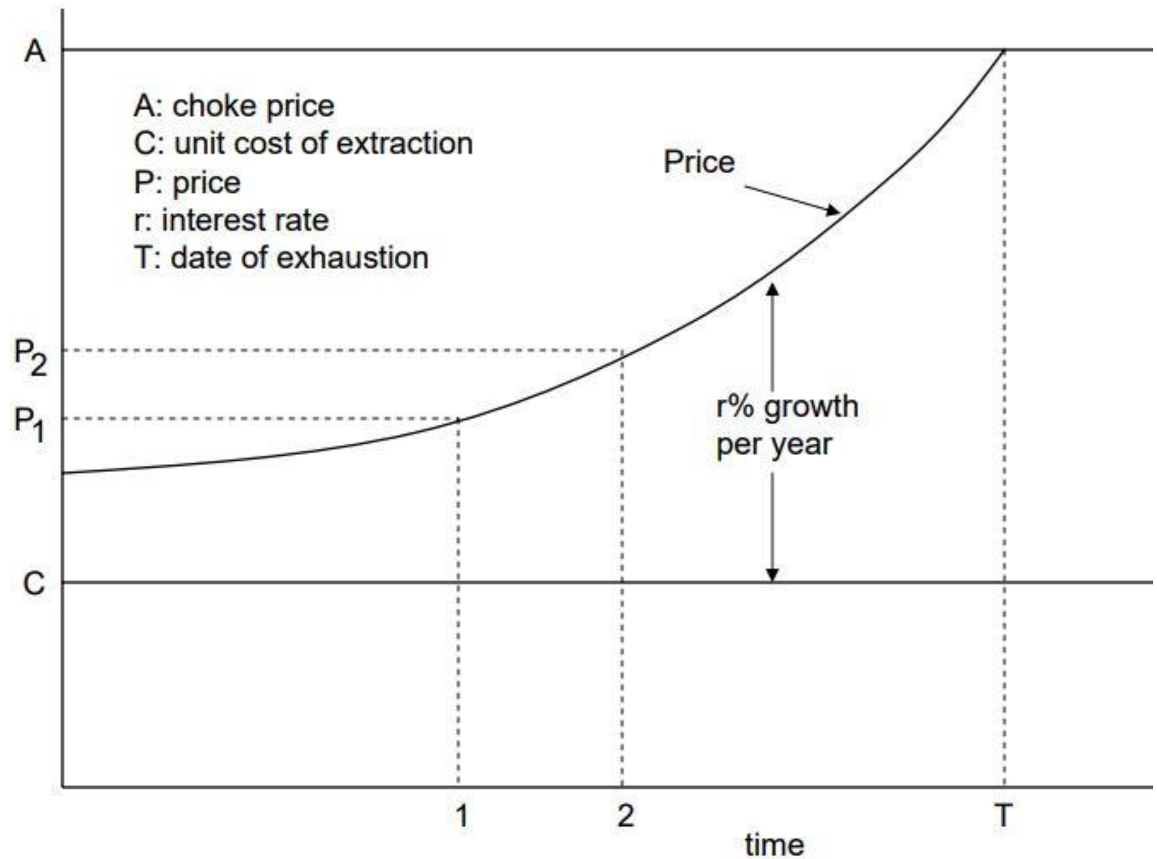
Backstop technology / νέα ανταγωνιστική τεχνολογία:

- any technology / resource that can substitute a non-renewable technology once the latter becomes comparatively more expensive
- The price at switching point is called ***choke price*** (last unit sold sells at choke price)
- Backstop technologies benefit a lot from technological progress: reduces their marginal costs; brings the switching time closer to date (see next 2 figures)
- It is optimal to extract the whole resource before the backstop becomes profitable

→ A sudden arrival of a (new) backstop induces price to fall

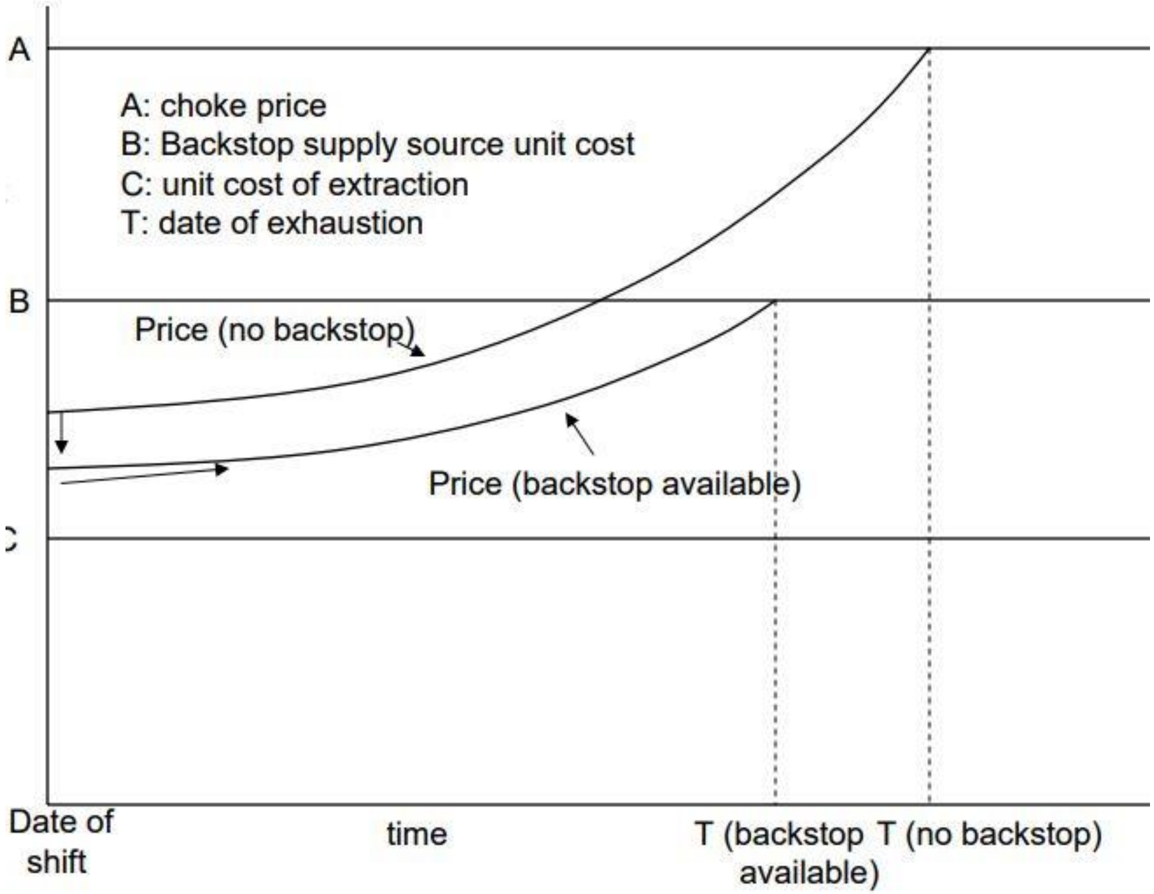
Backstop technology

- Assume we had perfect information on the arrival of the backstop
- We would then want to extract the whole stock before the backstop becomes widely available



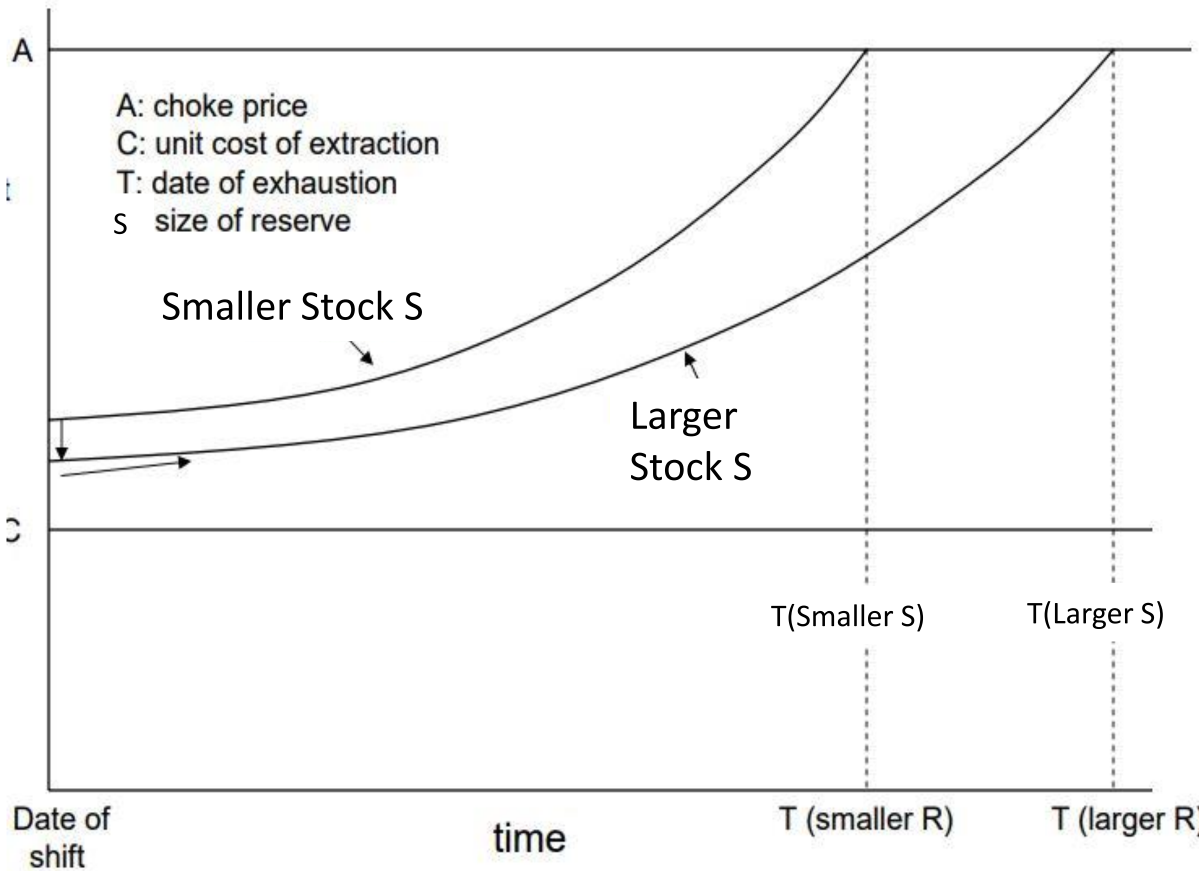
Backstop technology

Introduction of a new backstop technology with lower unit cost



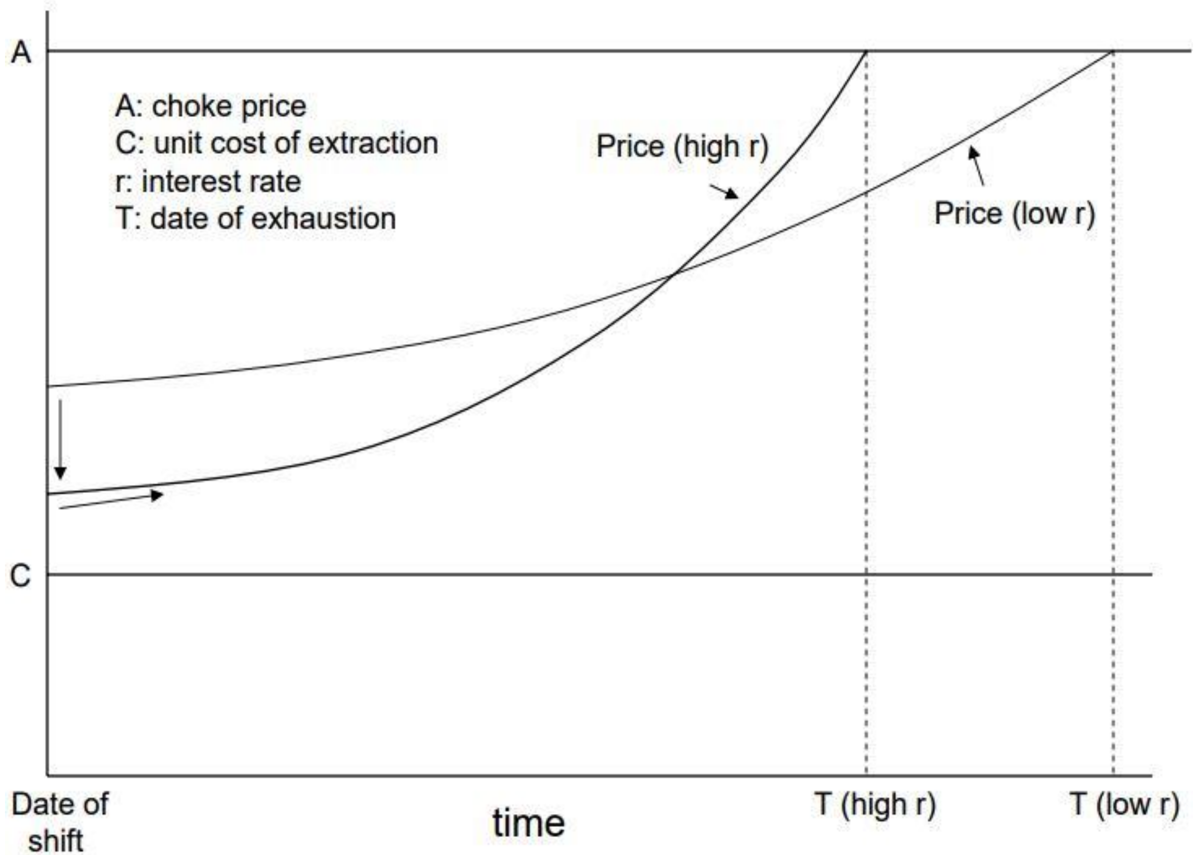
New discoveries

New discoveries : an increase in the stock induces downward jump in prices. Price path then follows Hotelling rule



Interest rates

Interest rate: an increase in the interest rate induces downward jump in prices. Price path then follows Hotelling <u>with higher r</u>



What else drives prices?

Assume we had **extraction costs** that can change over time

Profit now is $\pi_t = (p_t - c_t)R_t$ and the Hotelling rule becomes:

$$\frac{M\pi(R_{t+1})}{M\pi(R_t)} = \frac{p_{t+1} - c_{t+1}}{p_t - c_t} = 1 + r$$

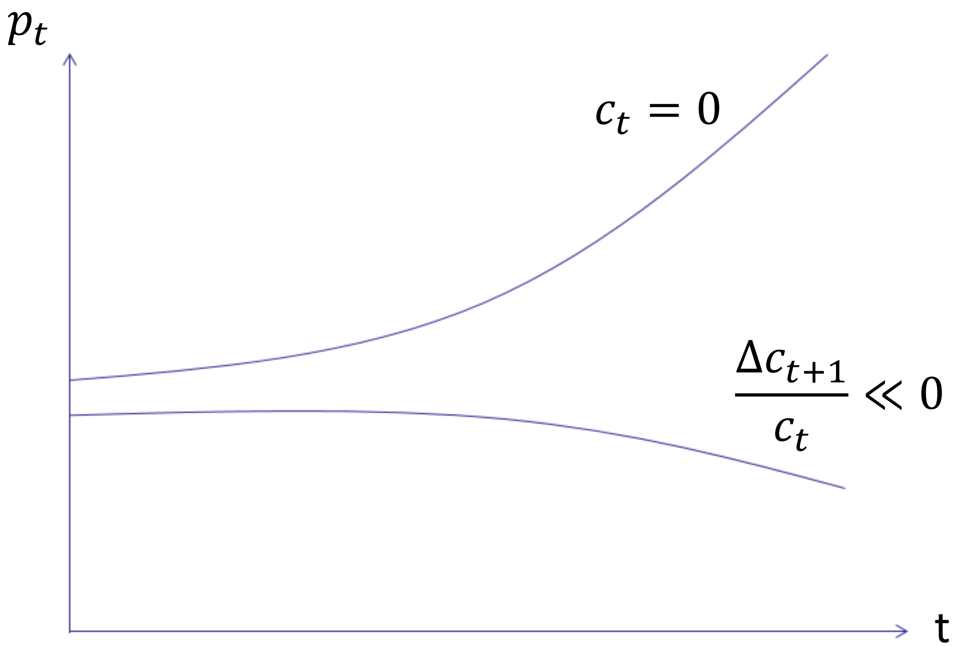
Above can be rewritten as (with $\Delta p_{t+1} = p_{t+1} - p_t$) :

$$\frac{\Delta p_{t+1}}{p_t} = r + \frac{c_t}{p_t}\left(\frac{\Delta c_{t+1}}{c_t} - r\right)$$

- If c=0, we are back at the simple Hotelling rule $p_{t+1} = (1 + r)p_t$
- **Growth rate (percentage change) of resource price** $\frac{\Delta p_{t+1}}{p_t}$ **depends on the dynamics of extraction costs**

What drives prices?

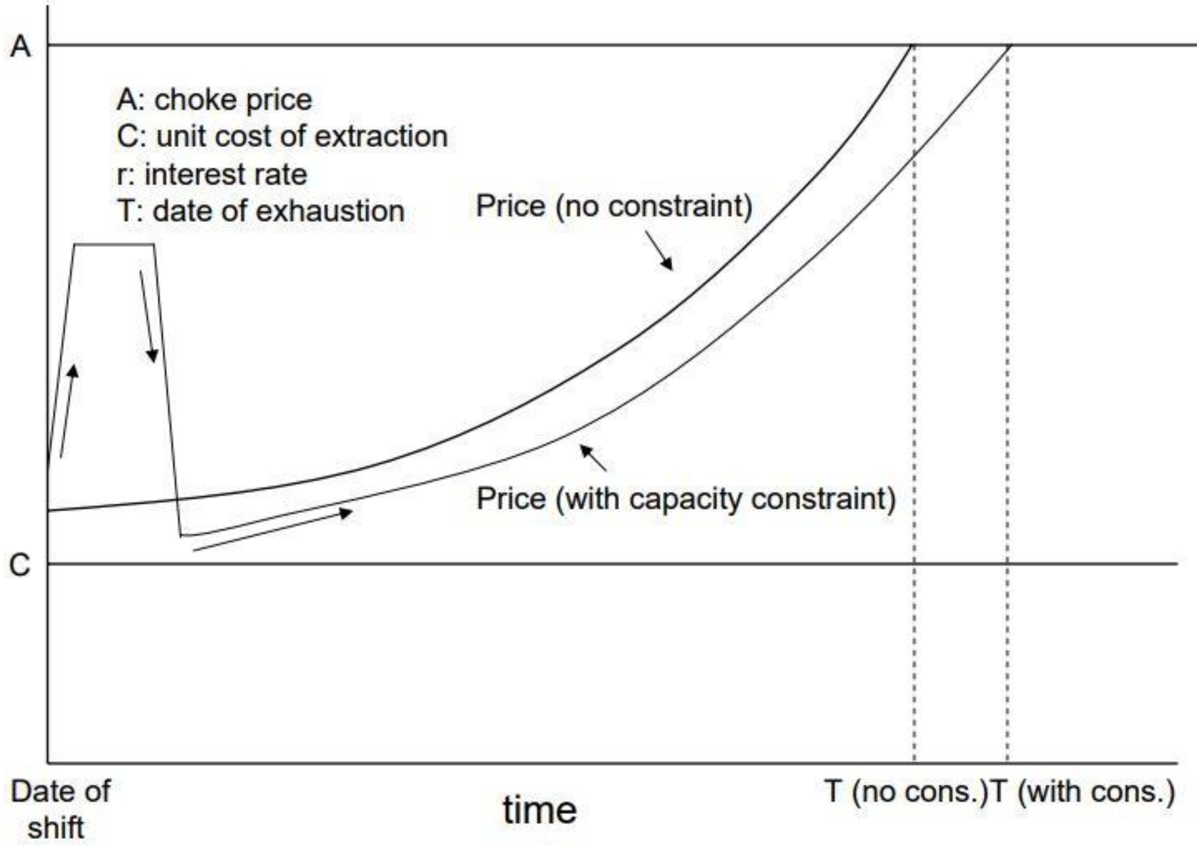
$$\frac{\Delta p_{t+1}}{p_t} = r + \frac{c_t}{p_t}\left(\frac{\Delta c_{t+1}}{c_t} - r\right)$$



- price evolution depends on extraction costs.
- Steeply decreasing costs <u>due to technol. progress</u> reduce prices

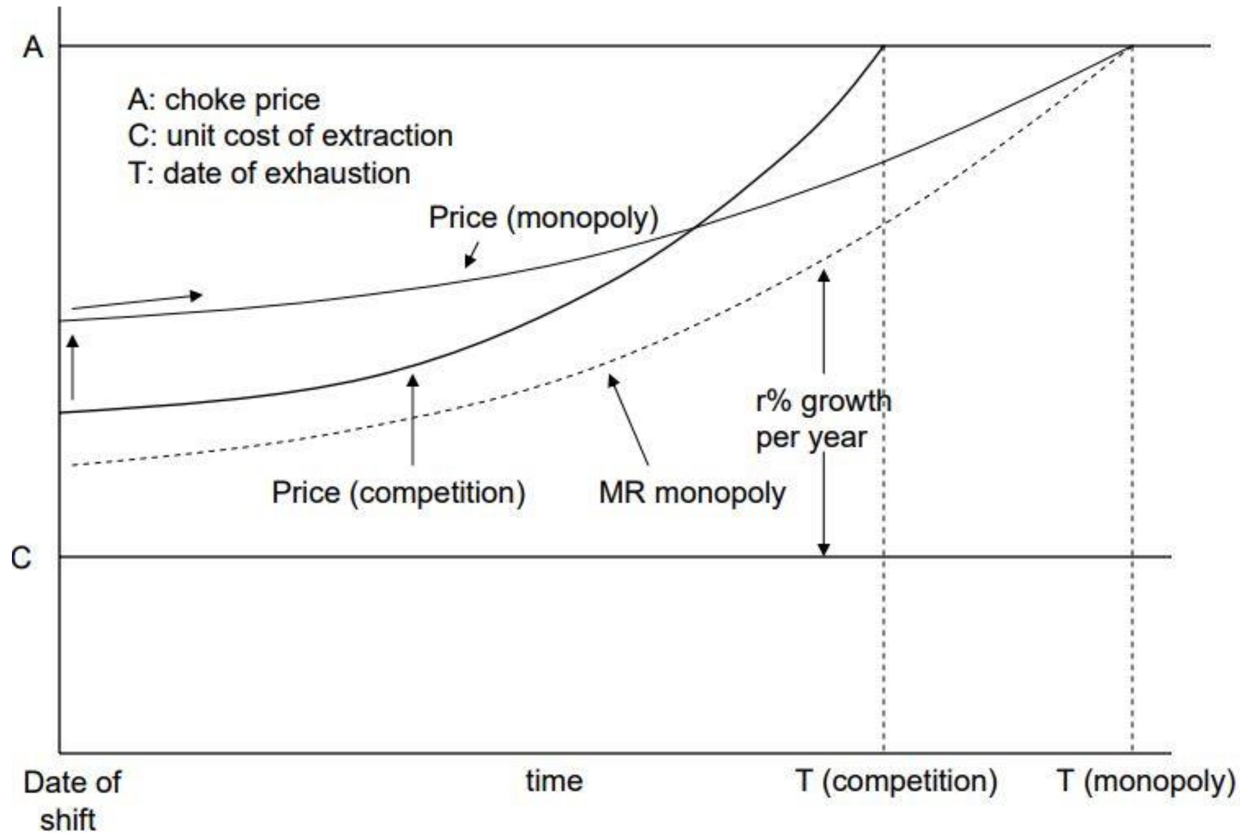
Capacity constraints

Temporary capacity constraints – e.g. embargoes/wars



Monopoly power

Monopoly price has to go eventually lower than competition



What drives the price of a NRR?

- Interest rates
- New discoveries
- New backstop technologies
- Changes in consumer behaviour
- Market power - monopoly, cartels
- Political shocks – wars, embargoes etc.

What drives the price of a NRR?

Further issues:

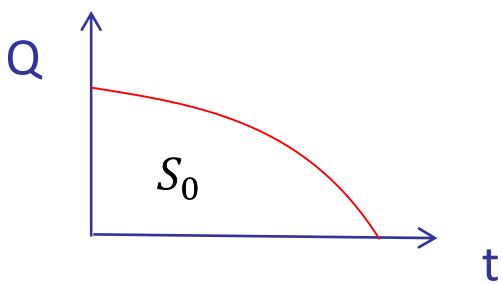
- Geology constraints: cost that depends on the extraction depth, amount of remaining stock, and morphology of the resource
  - MC can depend on the remaining stock → MC increases as stock gets depleted
  - Morphology of the accumulation
- Policy: E.g. what could happen in the price of oil if the government pre-announced a very high tax on carbon emissions?

Limits to growth or not?

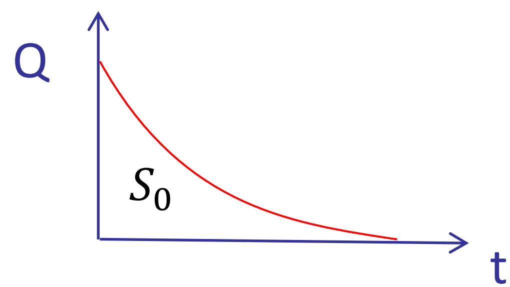
Limits to growth…

1970s: increasing dependence on oil → limits to growth

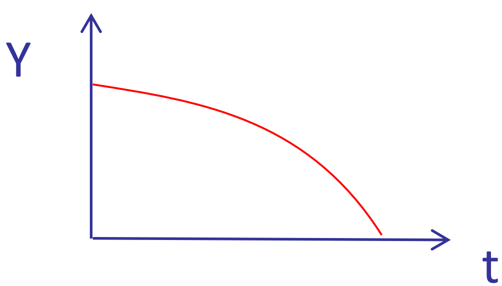
Linear demand

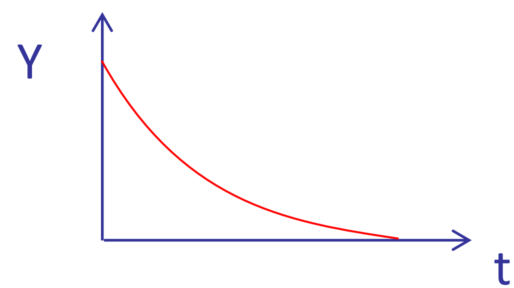


Isoelastic demand



Assume production follows $Y = Q^{\gamma}$ $(0 < \gamma < 1)$. This yields





…or not?

Dasgupta & Heal (1974), Solow (1974a), Stiglitz (1974a, 1974b):

What are the technical conditions needed to avoid a falling level of per capita consumption?

From the production side, there are two relevant ways to counterbalance decline in resource use

1. **Substitution between inputs**

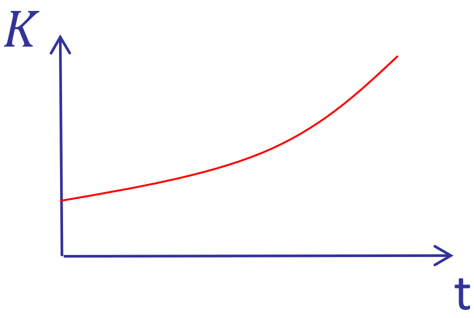
   Substitute diminishing resources with accumulative inputs (capital)

2. **Technical progress**

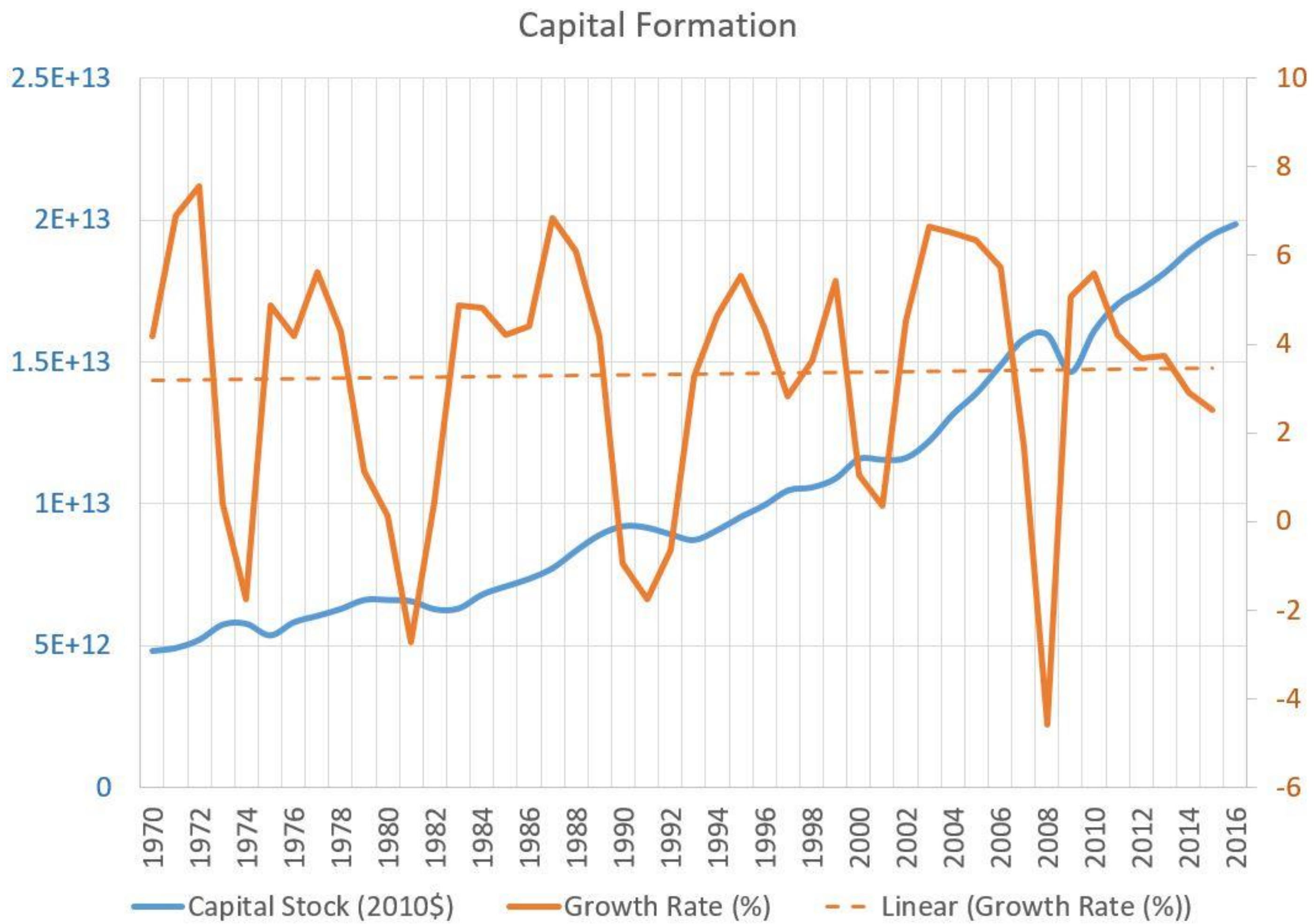
   Technical progress that makes energy use ever more efficient, or increases substitution (development of technological substitutes), or both..

Importance of accumulative inputs

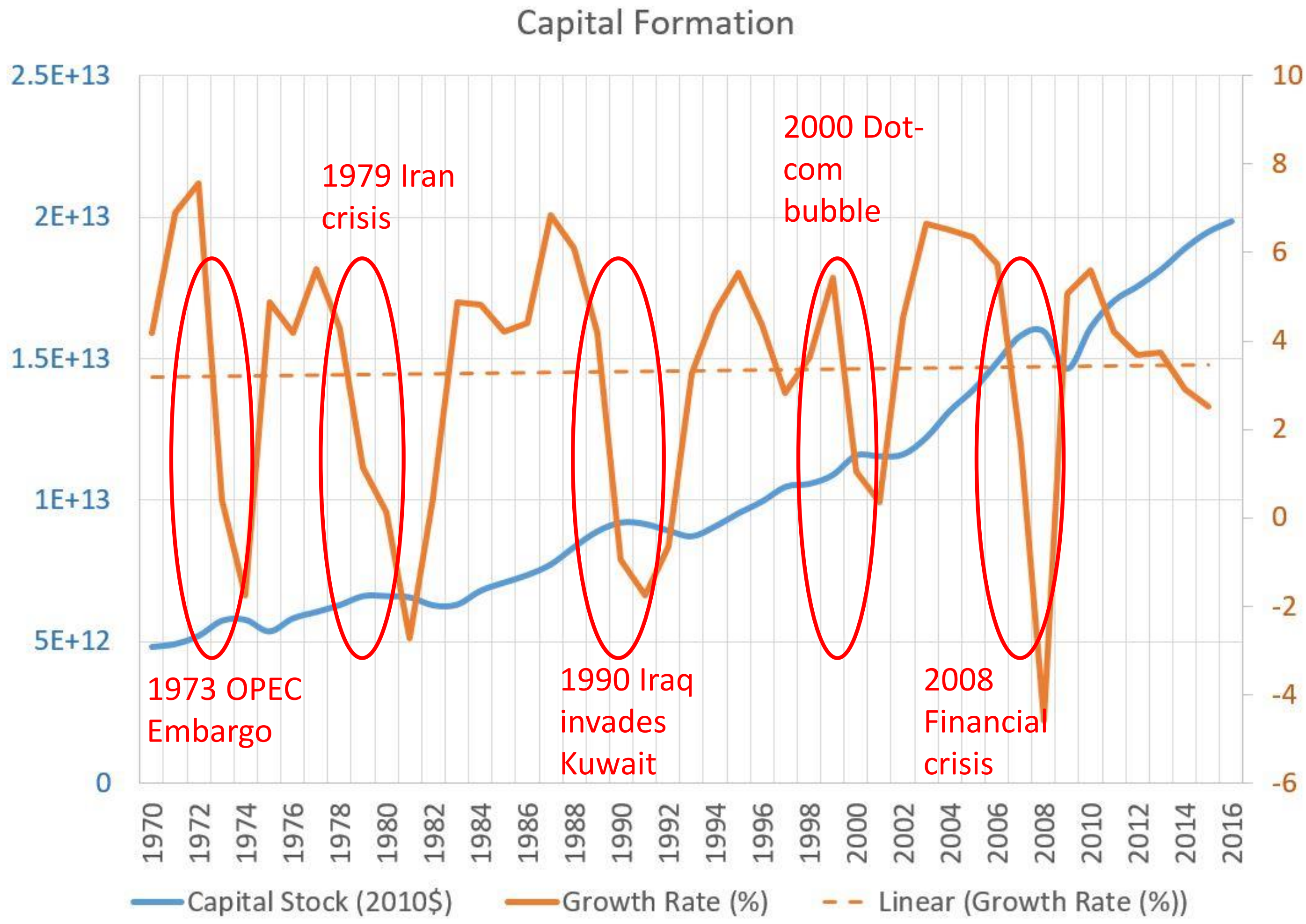
- Introduce capital K
  - Physical
  - Human
  - Knowledge
  - Technology
  - …
- Capital accumulates through intentional investments…
  - … in infrastructure
  - … in education
  - … in innovation
  - …
- Renewables are also form of durable capital K that accumulates through investments



Importance of accumulative inputs



Importance of accumulative inputs



Economics 101: Elasticity of substitution

Measures the relative change of the factor input ratio in response to relative change in factor price ratio

Let $Y = Y(K, Q)$ with p_K, p_Q prices of inputs K, Q , then

$$\sigma = -\frac{\frac{\Delta(Q/K)}{Q/K}}{\frac{\Delta(p_Q/p_K)}{p_Q/p_K}}$$

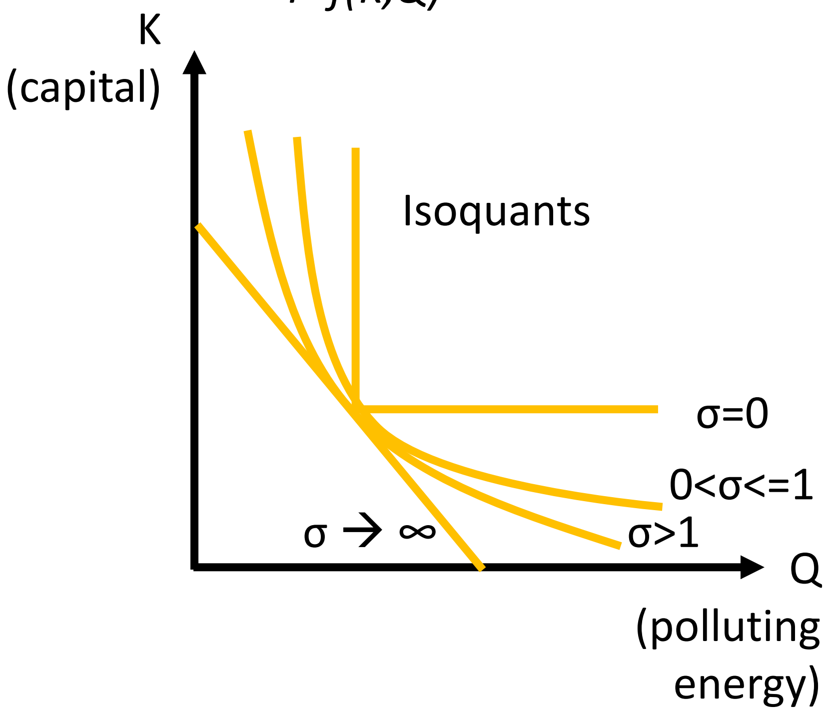
σ tells us *"how much percent <u>less</u> of Q relatively to K the firm will use if Q becomes* $\frac{\Delta(p_Q/p_K)}{p_Q/p_K}$ *percent more expensive, <u>keeping output constant</u>"*

Important parameter of sustainability: How easily can we substitute polluting non-renewable resources with non-polluting capital (e.g. renewables)?

Economics 101: Elasticity of substitution

Production function

Y=f(K,Q)



$\boldsymbol{\sigma} = \mathbf{0}$ (no substitution)

K, Q perfect complements (e.g. shoes and shoe laces) – K and Q in equal ratios. Q essential for production (if Q=0, then Y=0)

$\mathbf{0} < \boldsymbol{\sigma} < 1$ (poor substitution)

K, Q complements (Q is essential for production)

$\boldsymbol{\sigma} > 1$ (good substitution)

K, Q substitutes (Q not essential for production

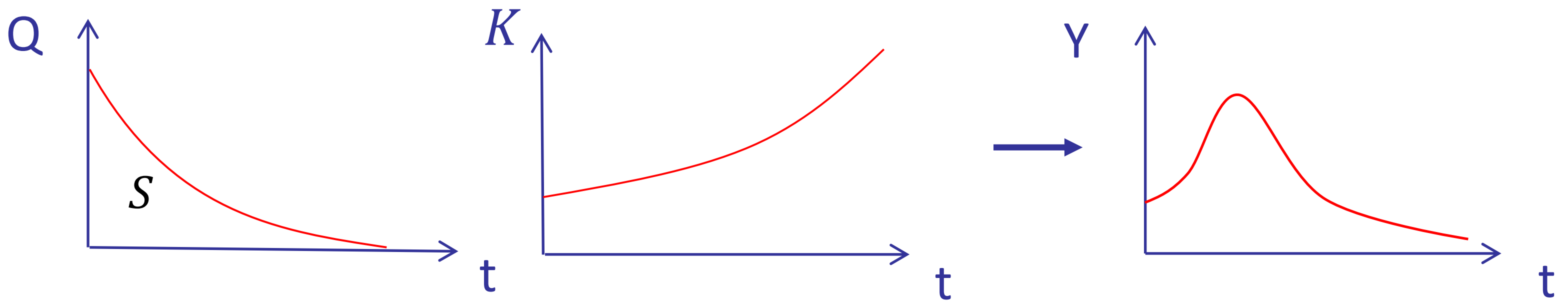
$\boldsymbol{\sigma} \to \infty$ (perfect substitution)

K, Q Perfect substitutes

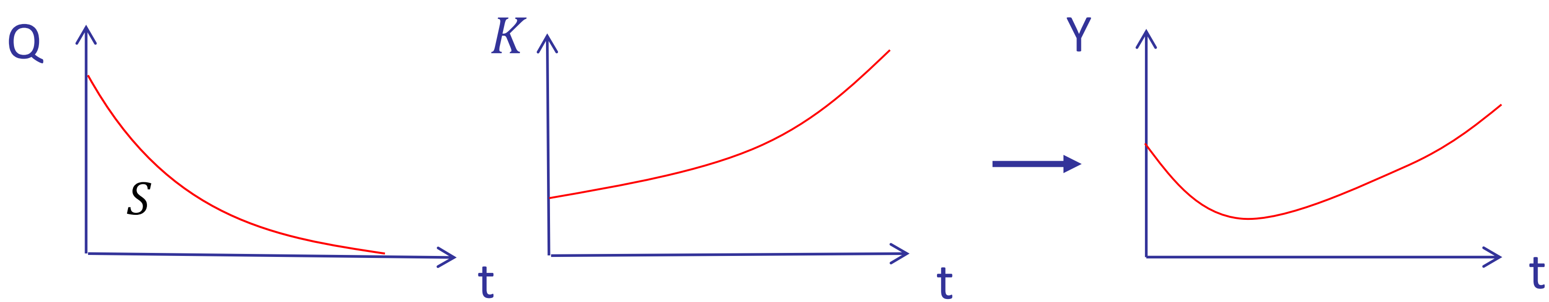
Substitution between inputs

Possible output profiles

Assume poor substitution $(0 < \sigma < 1)$:



Assume good substitution $(\sigma > 1)$:



Substitution

368pp. per issue
8 1/2 x 11
Founded: 1917
2019 Impact Factor: 4.345
2019 Google Scholar h5-index: 71
ISSN: 0034-6535
E-ISSN: 1530-9142

Follow

Substitution between Clean and Dirty Energy Inputs: A Macroeconomic Perspective

Chris Papageorgiou, Marianne Saam and Patrick Schulte

Posted Online May 02, 2017
https://doi.org/10.1162/REST_a_00592

© 2017 The President and Fellows of Harvard College and the Massachusetts Institute of Technology

Review of Economics and Statistics
Volume 99 | Issue 2 | May 2017
p.281-290

Downloa

Favorite

Download Citation

RSS Citation

Abstract Authors Supplemental Material

In macroeconomic models, the elasticity of substitution between clean and dirty energy inputs within the energy aggregate is a central parameter in assessing the necessary conditions for long-run green growth. Using new sectoral data in a panel of 26 countries, we formulate specifications of nested constant elasticity of substitution production functions that allow estimating this parameter for the first time. We present evidence that it significantly exceeds unity, a favorable condition for promoting green growth.

Substitution

The Elasticity of Substitution between Clean and Dirty Energy with Technological Bias

Ara Jo*

October 13, 2020

Abstract

The elasticity of substitution between clean and dirty energy and the direction of technological change are central parameters in discussing one of the most challenging questions today, climate change. Despite their importance, there are few studies that empirically estimate these key parameters. In this paper, I estimate the elasticity of substitution between clean and dirty energy from micro data, jointly with technological parameters that reflect the direction of technological change within the energy aggregate. I find estimates of the elasticity of substitution ranging between 2 and 3. The largely dirty-energy-biased technological change observed in the data validates the framework of directed technological change, given the historical movement of relative energy prices and the estimated elasticity of substitution above unity. However, I also find suggestive evidence that clean-energy-augmenting technology is growing faster than dirty-energy-augmenting technology in recent years with changes in relative energy prices and higher subsidies for clean energy.

Substitution

What is the empirically-relevant value of σ?

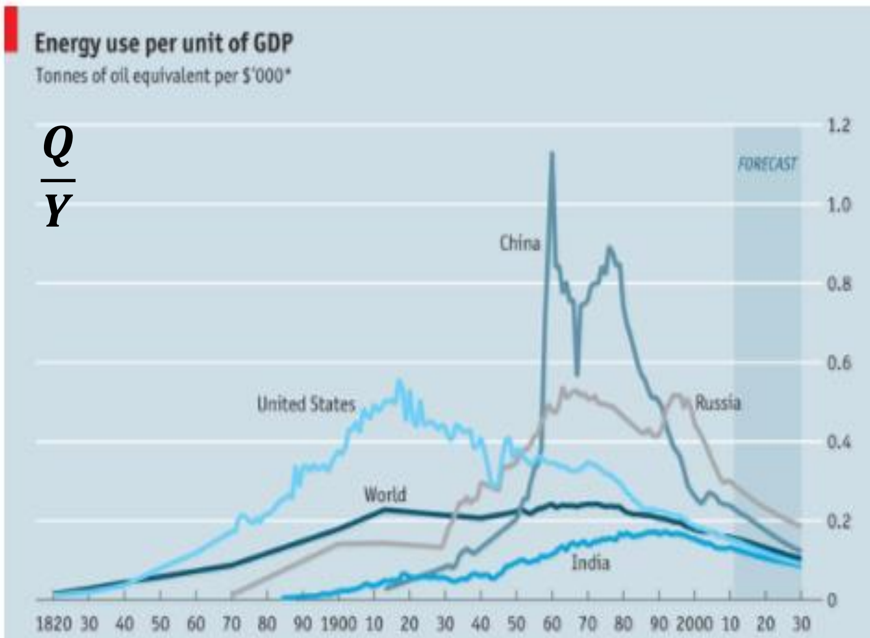
- $\sigma \approx 0$ in short run, $\sigma \geq 1$ in the long-run plausible (Hassler et al. 2012)
- $\sigma \geq 1$ between clean & dirty energy inputs (Papageorgiou et al. 2017)
- $2 < \sigma < 3$ between clean & dirty energy (Jo, 2020)

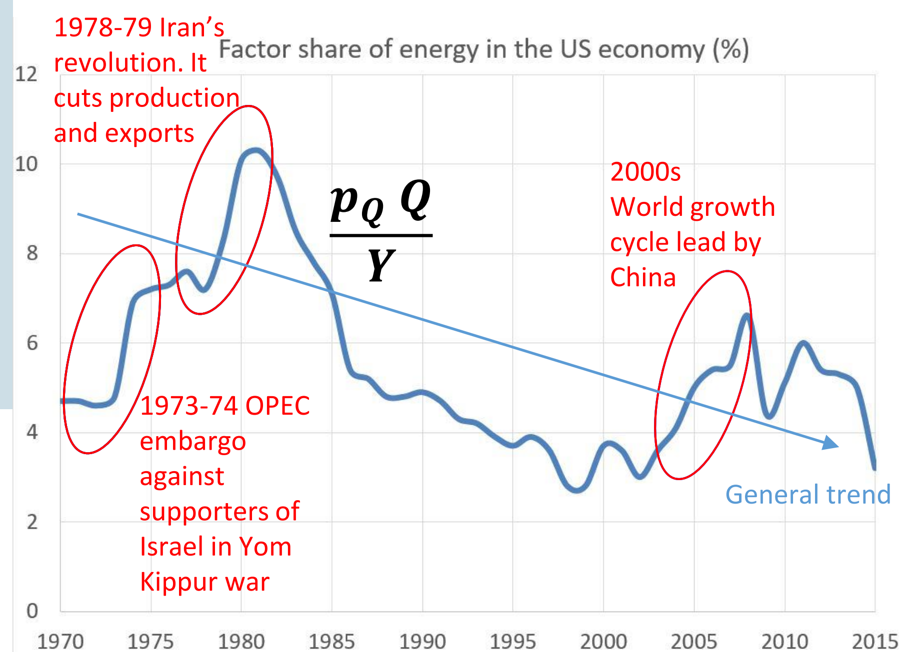
→ $\boldsymbol{\sigma \leq 1}$ for the short-run; $\boldsymbol{\sigma \geq 1}$ for the long-run

Substitution – Example to support σ>1

Declining factor share of energy

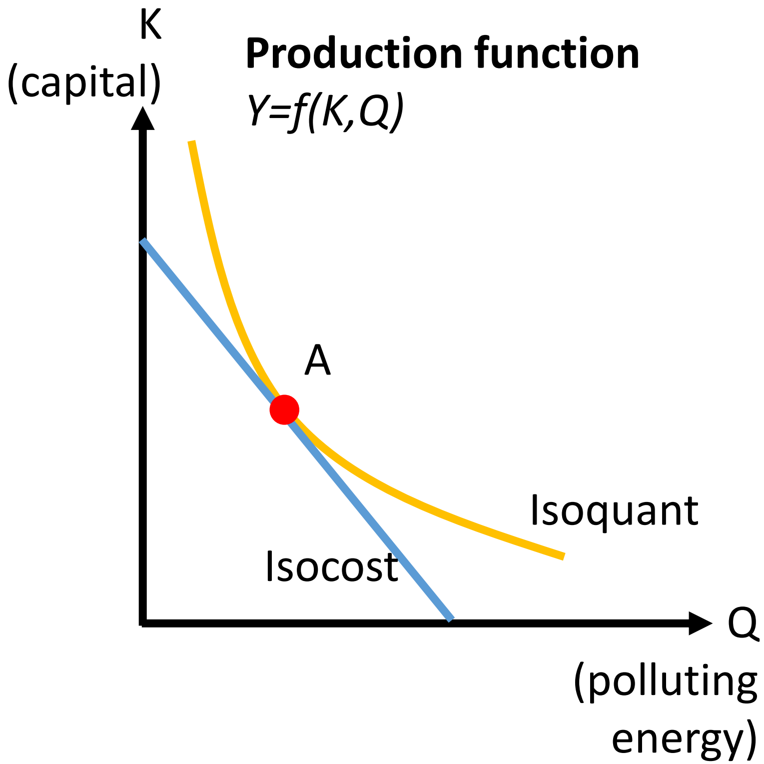
$$\theta = \frac{p_Q\, Q}{Y} = \frac{energy\ expenditure}{total\ output}$$





Source:www.eia.gov/aer

Substitution – Example to support σ>1



- $Y = f(K,Q) = \left(\alpha\, K^{\frac{\sigma-1}{\sigma}} + (1-\alpha)\, Q^{\frac{\sigma-1}{\sigma}}\right)^{\frac{\sigma}{\sigma-1}}$

→ $K = \left(\frac{1}{\alpha}\, Y^{\frac{\sigma-1}{\sigma}} - \frac{1-\alpha}{\alpha}\, Q^{\frac{\sigma-1}{\sigma}}\right)^{\frac{\sigma}{\sigma-1}}$ (isoquant)

- $Cost = p_K K + p_Q\, Q$

→ $K = \frac{Cost}{p_K} - \frac{p_Q}{p_K} Q$ (isocost)

Profit maximization of the firm (isocost <u>tangent/εφαπτεται </u>to isoquant) leads to:

$$\frac{p_Q\, Q}{Y} = \theta = (1-\alpha)\left(\frac{Q}{Y}\right)^{\frac{\sigma-1}{\sigma}}$$

Since $\frac{Q}{Y}$ is empirically decreasing, share $\theta = \frac{p_Q\, Q}{Y}$ is decreasing (which we also observed) only if $\sigma > 1$

Technological progress

$$Y = \left(\alpha\, K^{\frac{\sigma-1}{\sigma}} + (1-\alpha)\,(\boldsymbol{A_Q}\, Q)^{\frac{\sigma-1}{\sigma}}\right)^{\frac{\sigma}{\sigma-1}}$$

What is the role of technology $\boldsymbol{A_Q}$ that improves the energy efficiency of polluting non-renewable resources?

Profit maximization of the firm → $\theta = (1-\alpha)\left(\frac{\boldsymbol{A_Q}\, Q}{Y}\right)^{\frac{\sigma-1}{\sigma}}$

Tech. progress (growth in technology)
$g_Q = (A_{Q,t+1} - A_{Q,t})/A_{Q,t} = \Delta A_{Q,t+1}/A_{Q,t}$ helps in both directions:

- explain decreasing θ even for $\sigma < 1$
- sustained growth of output despite resource depletion

→ If g_Q sufficiently high, θ can be decreasing even for $\sigma < 1$
→ High rate of tech. progress compensates for depleting resources Q

Μέχρι εδώ σε αυτή τη διάλεξη

Feasible vs. Sustainable (Will continue next Lecture)

Wealth of a nation

stocks of assets that can generate future income and well-being

- Physical capital – machines, buildings...
- Human capital – skills, education...
- Natural capital – forests, minerals (fuels) fish stocks...
- Intellectual property – innovations, databases, patents...
- Social capital – quality of institutions

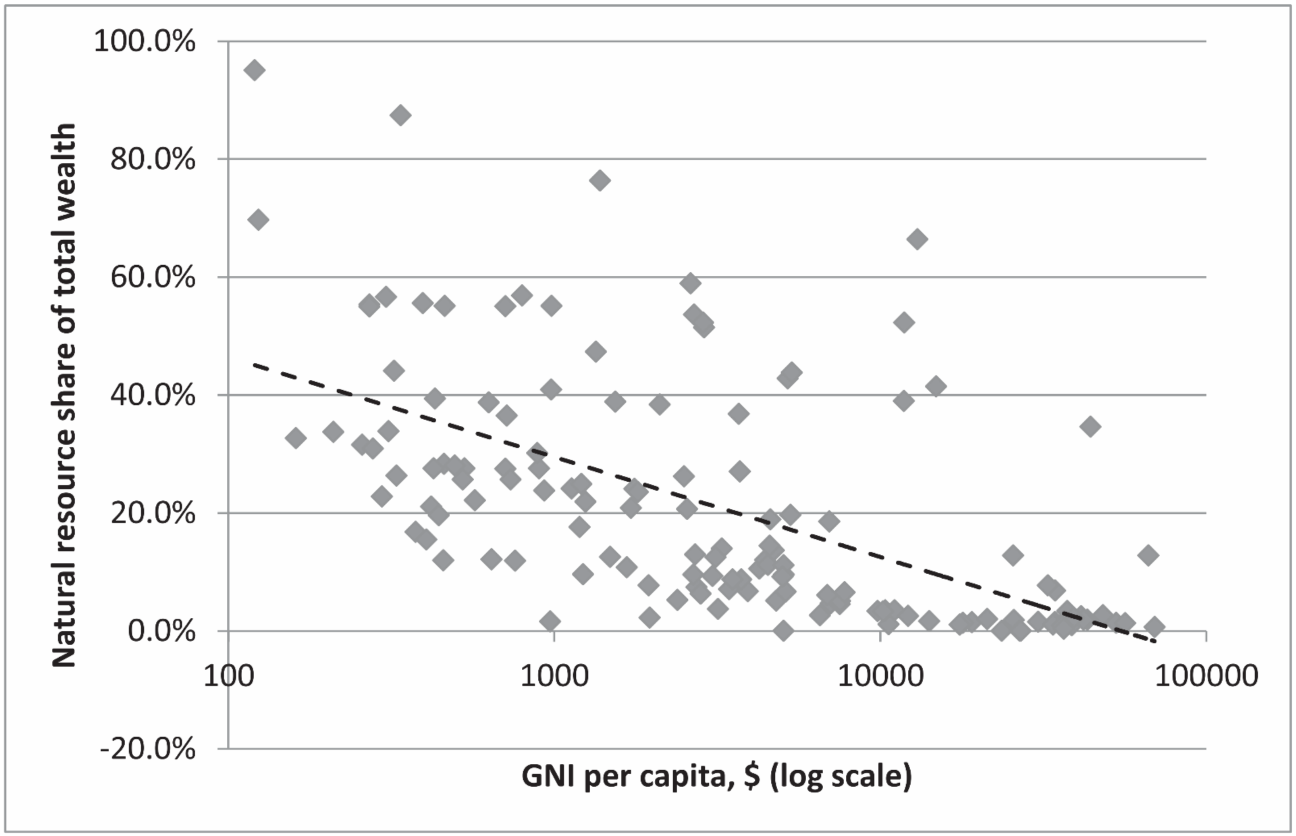
Sustainable Development

The **Brundtland report** defines sustainable development as…

“…the kind of development that meets the needs of the present without compromising the ability of future generations to meet their own needs.” (United Nations, 1987)

Resource curse

Resource abundance leads (?) to lower economic development (measured by Gross National Income GNI)



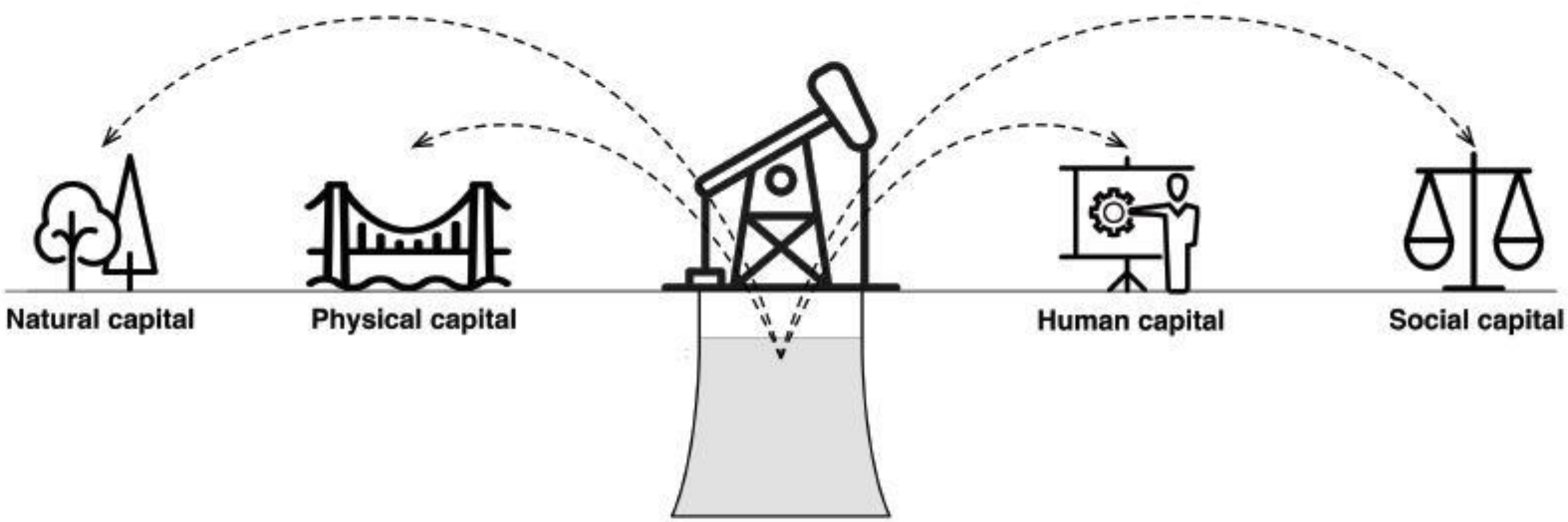
Sustainable investment

Hartwick rule of sustainable investment

- Diversification / interchangeability of capital stocks

→ Invest profits from non-renewable resources in other forms of capital

- Adjusted Net Savings (ANS) as indicator of sustainable development20



Adjusted Net Savings

Indicator of sustainability

ANS = Net capital formation (includes depreciation)

- Energy / Minerals / Forest depletion

+ Education expenditure

- Damages from global pollution

- Damages from local particulate emissions

Source: World Bank

Adjusted Net Savings

Resource curse – on the news

Bloomberg

Politics

Maduro Says Oil Price Crash Is 'Brutal Blow' to Venezuela

By Fabiola Zerpa
March 12, 2020, 8:40 PM GMT+1

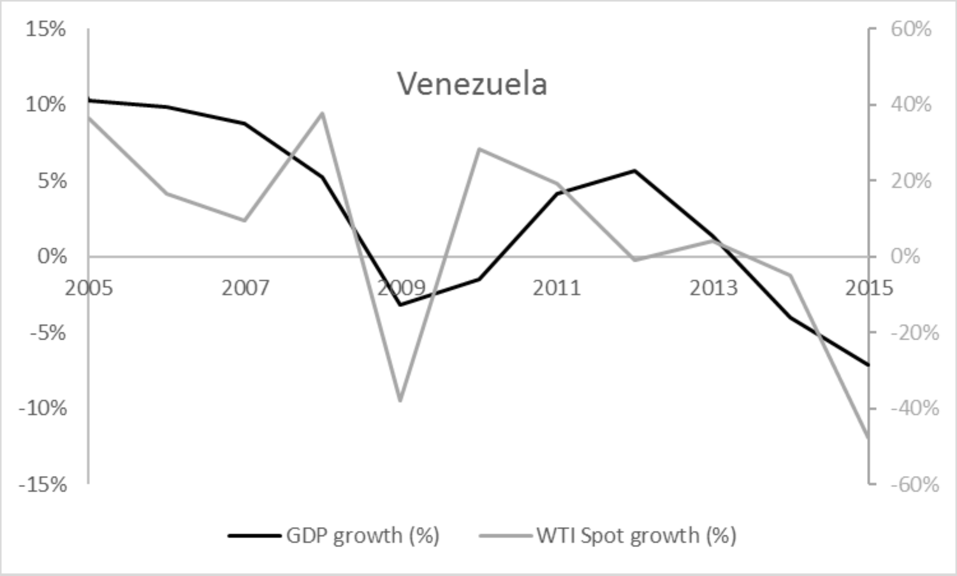
Example – Norway vs. Venezuela

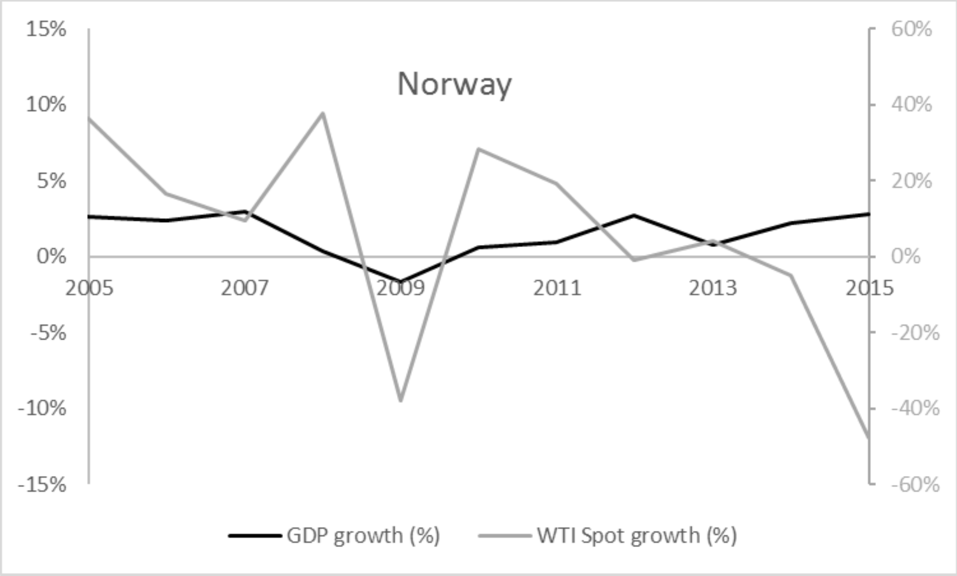
- Correlation between GDP growth and WTI Spot growth

  Venezuela 0.71 Norway 0.09

- Oil rents (% of GDP – on average)

  Venezuela 24% Norway 9%





Explaining the resource curse

Economic explanation

- Dutch disease
- Poor capital accumulation and diversification

Political / Institutional reasons

- Rent seeking / patronage