NONRENEWABLE RESOURCES

1. Introduction: definitions, policy questions, topics.
2. Measures of abundance and responses to scarcity
3. Nonrenewable resource markets
    a. Investments in exploration and development
    b. Production from known reserves
4. Hotelling's model of nonrenewable resources
    a. Hotelling's rule for price
    b. Comparative dynamics of price paths
    c. Monopoly vs. competition
    d. What drives oil prices?

NONRENEWABLE RESOURCES (cont.)

5. Applications and policy issues
    a. Effects of a backstop technology
    b. Extraction from a common pool
    c. Environmental impacts: PXP project
    d. ANWR and the price of gasoline
    e. Political risk and resource use
    f. The ‘resource curse’ (mention)

Measures of Abundance, 1:

Current (Proved) Reserves: Deposits that have been discovered, are known to exist, and can be extracted profitably; current price exceeds development and extraction cost.

Measures of Abundance, 2:

Potential Reserves: (Ultimately Recoverable Resources)

Deposits for which technical feasibility of extraction has been demonstrated or seems likely; price may or may not cover development and extraction cost.

Measures of Abundance, 3:

Resource Endowment (Resource Base or Crustal Abundance): Natural abundance of a mineral in the earth's crust (to depth of 1 km., concentration > 1 pp mill), oceans, atmosphere, regardless of whether or not extraction and use is technically or economically feasible.

Mineral	(1) Reserves/ consumption	(3) Crustal abundance/ consumption	(2) Ultimately* recoverable resources/ consumption
Copper	45	242×10^6	340
Iron	117	$1,815 \times 10^6$	2,657
Phosphorus	481	870×10^6	1,601
Molybdenum	65	422×10^6	630
Lead	10	85×10^6	162
Zinc	21	409×10^6	618
Uranium	50	$1,855 \times 10^6$	8,455
Aluminum	23	$38,500 \times 10^6$	68,066

*0.01% of total availability to a depth of 1 km.

Source: USGS.

TABLE 12-1 *Reserve Estimates for Selected Minerals* (1)

Mineral	*Annual Consumption (thousand metric tons)*	*Total Reserves (thousand metric tons)*	*Reserve Base (thousand metric tons)*	*Reserve Index (years)*	*Reserve Base Index (years)*
Aluminum	103,625*	23,000,000	28,000,000	222	270
Cadmium	20	600	1,200	30	60
Copper	10,714	340,000	650,000	32	61
Iron Ore	959,609	71,000,000	160,000,000	74	167
Lead	5,342	64,000	130,000	12	24
Mercury	6.6	120	240	18	36
Nickel	882	49,000	150,000	56	170
Tin	218	9,600	12,000	44	55
Zinc	6,993	190,000	430,000	27	62

Source: Derived from World Resources Institute, 1994; and U.S. Geological Survey, 2001.

*Annual consumption of bauxite ore.

1

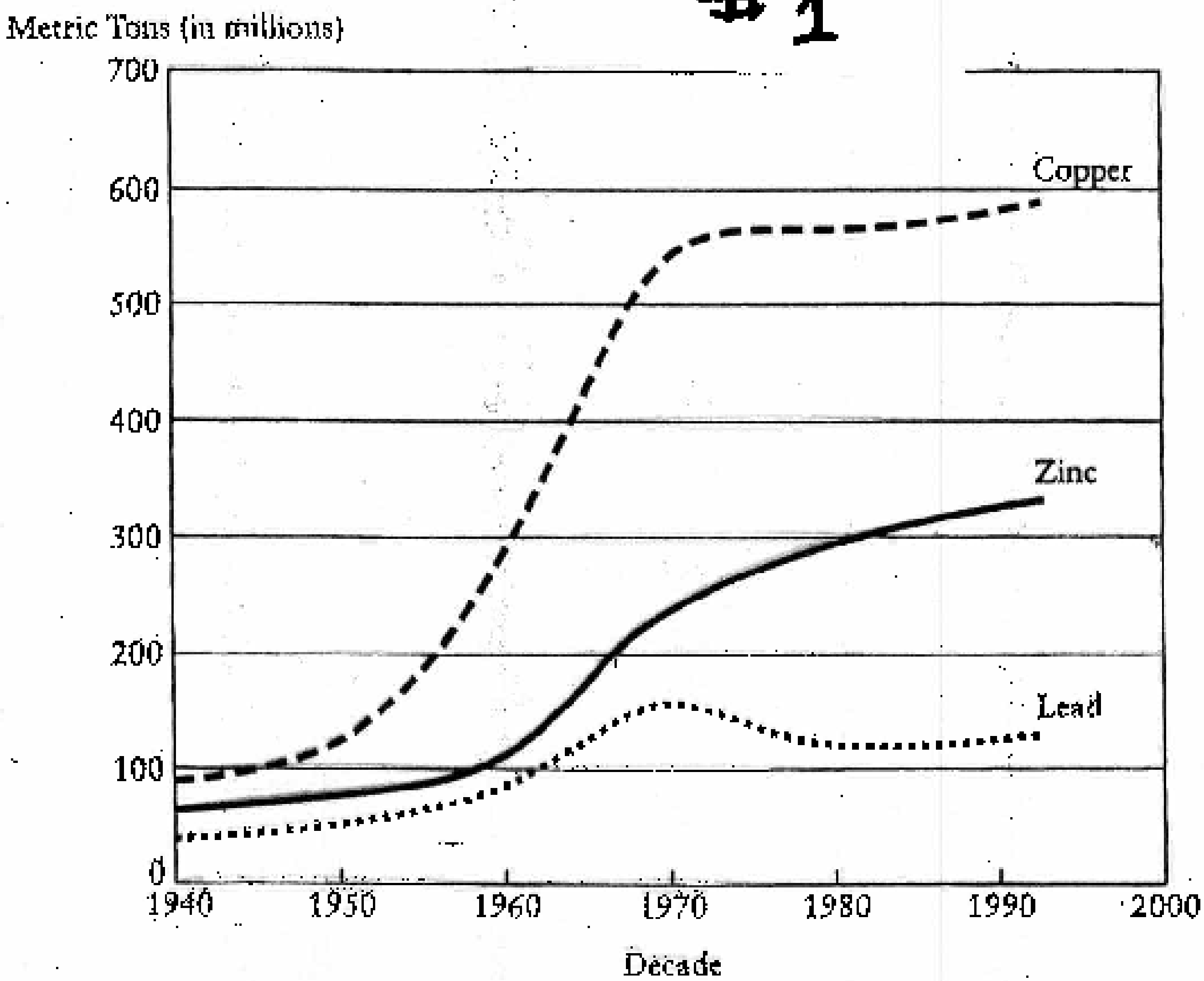


FIGURE 12-5 *Change in World Reserve Base for Selected Minerals*
Source: Hodges, 1995, p. 1306.

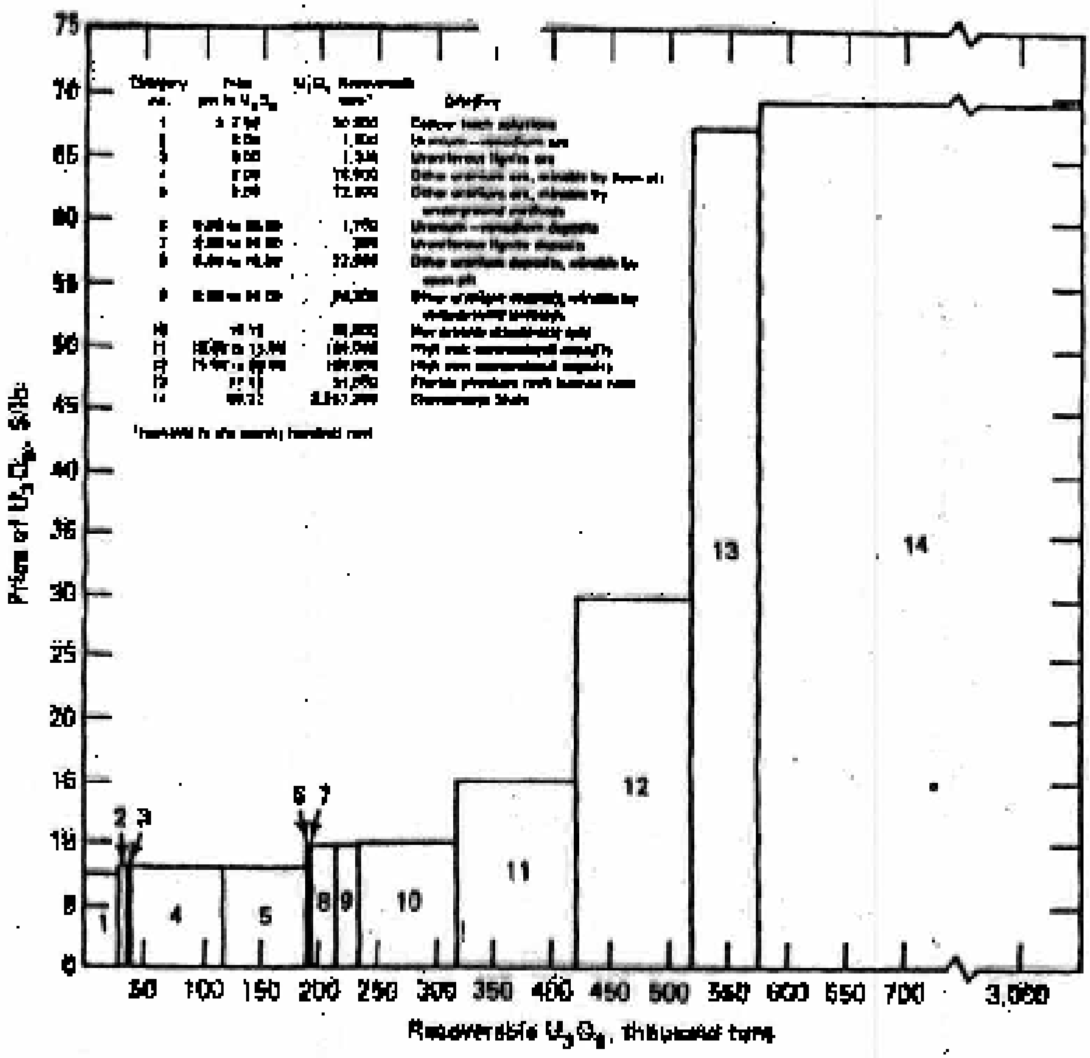


Figure 2.2 Availability diagram for uranium (expressed as U_3O_8). Source: C. L. Bieniewski, F. H. Persse, and E. F. Brauch, U.S. Bureau of Mines Information Circular 8501, *Availability of Uranium at Various Prices from Resources in the United States*, Washington, GPO, 1971, p. 14.

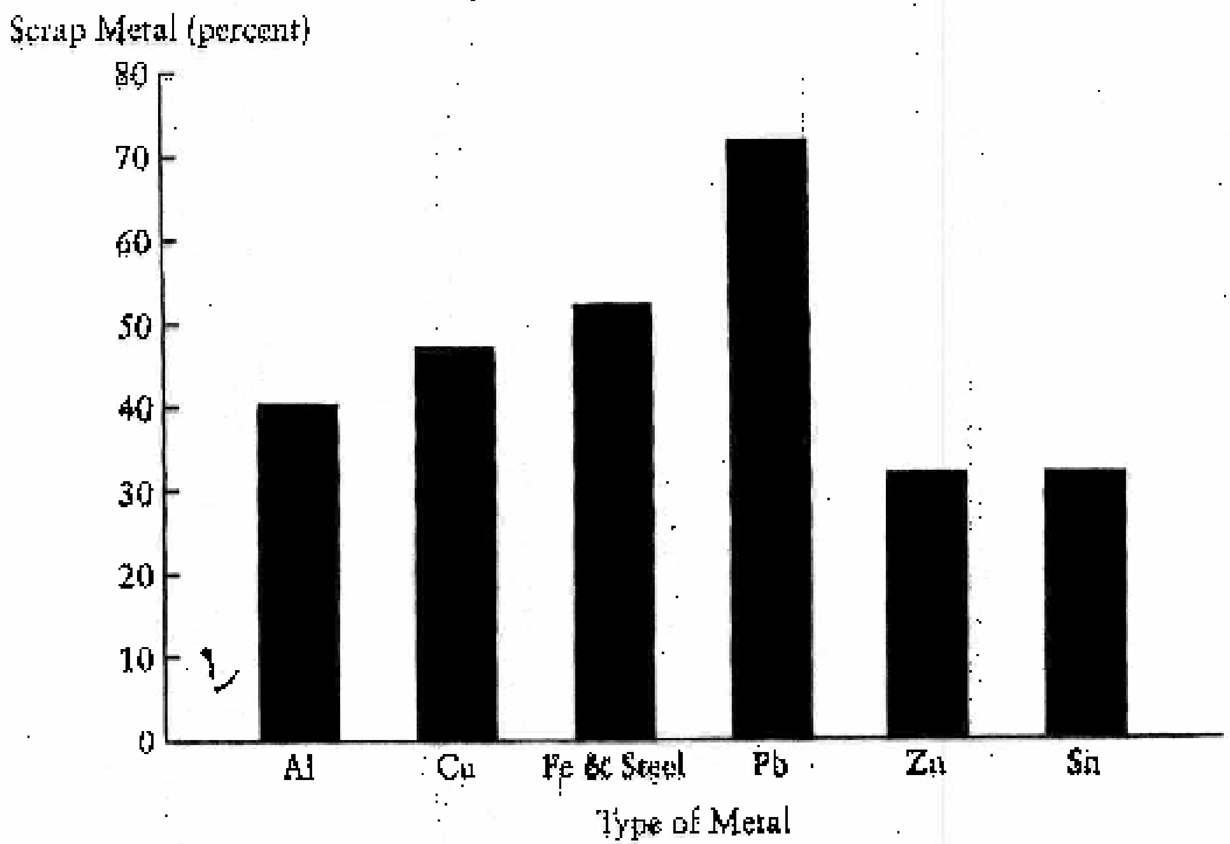


FIGURE 12-12 *Scrap Metal as a Percentage of Total U.S. Consumption*

Source: Adapted from Carol Hodges, "Mineral Resources, Environmental Issues, and Land Uses." Reprinted from *Science* 268 (June 2, 1995), p. 1307.

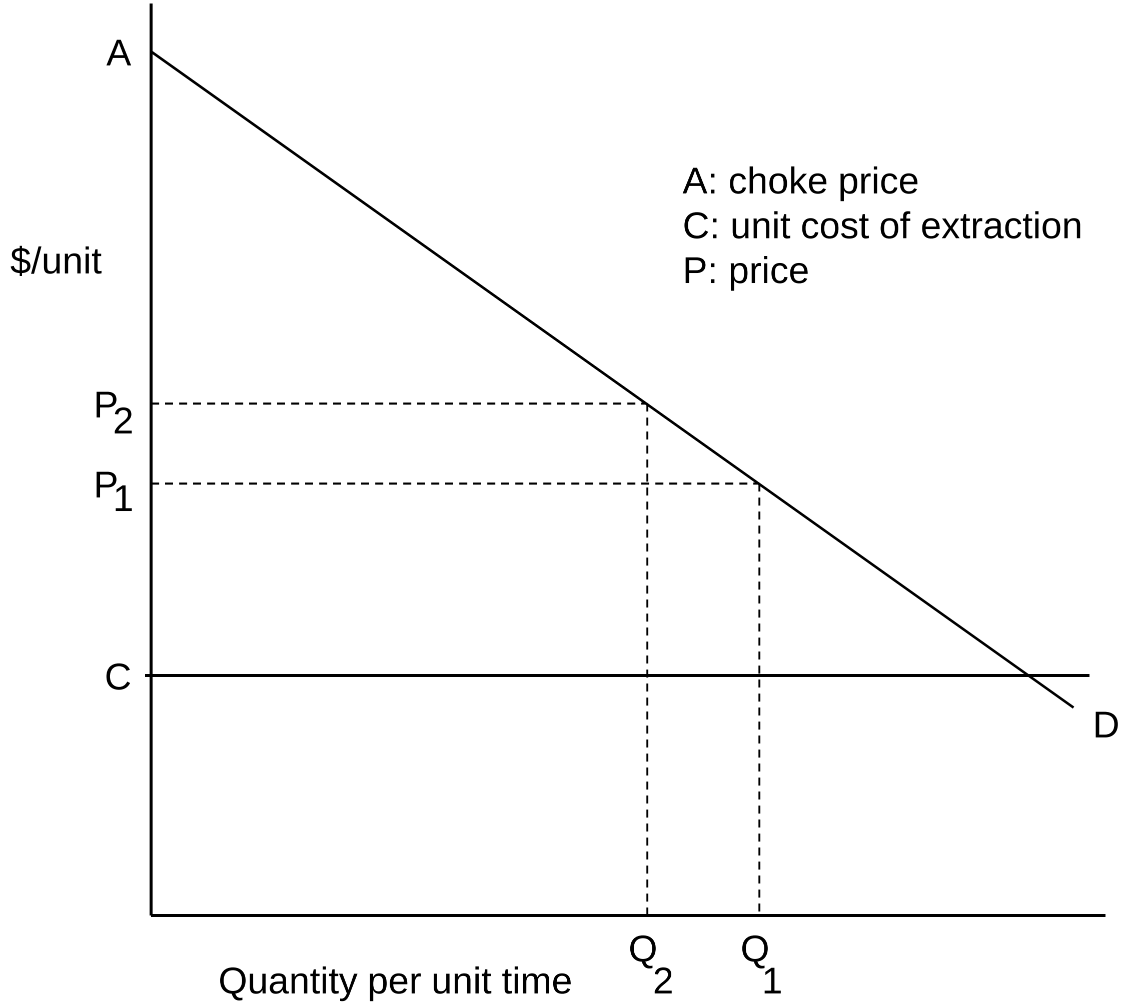
Exploration and Development

- Large share (2/3 in US) of total expenditure by petroleum industry.
- Long lead times: revenue may not be realized for decades after exploration expenditures are made.
- Expected future growth rates in demand are key factor.
- Current and future interest rates also matter;
- Factors in 2007-2009 gyrations in oil prices.
- Security of property rights also matters (evidence later)

Hotelling Rule for Competitive Market

1. Notation

P_t	price of extracted mineral in year *t*.
C	unit extraction cost (assumed constant).
r	interest rate (assumed constant).
A	choke price; price at which quantity demanded goes to zero.
T	date when exhaustion occurs, i.e., year last unit is consumed.
$P_t - C$	value of a unit of the mineral in the ground.
R	Size of initial reserve.



Demand curve for nonrenewable resource

2. Conditions for Equilibrium

(i) $\dfrac{(P_t - C)}{(1+r)^t}$ is equal in all periods.

(Production in any period yields same present value profit per unit.)

This implies $P_t - C = (P_0 - C)\cdot(1+r)^t$

(ii) $P_T = A$. (Last unit sold sells at choke price.)

3. Explanation of conditions

Condition (i):

Consider one unit of the mineral in the ground.

PV profit from selling is $P_0 - C$ in year 0, $\frac{(P_1 - C)}{(1+r)}$ in year 1, $\frac{(P_2 - C)}{(1+r)^2}$ in year 2, etc.

If positive amounts are sold for consumption in all periods, PV profit must be the same in all periods. Therefore:

$\frac{(P_t - C)}{(1+r)^t} = P_0 - C$ for $t = 1,2,3,...$, or

$$P_t - C = (P_0 - C) \cdot (1+r)^t$$

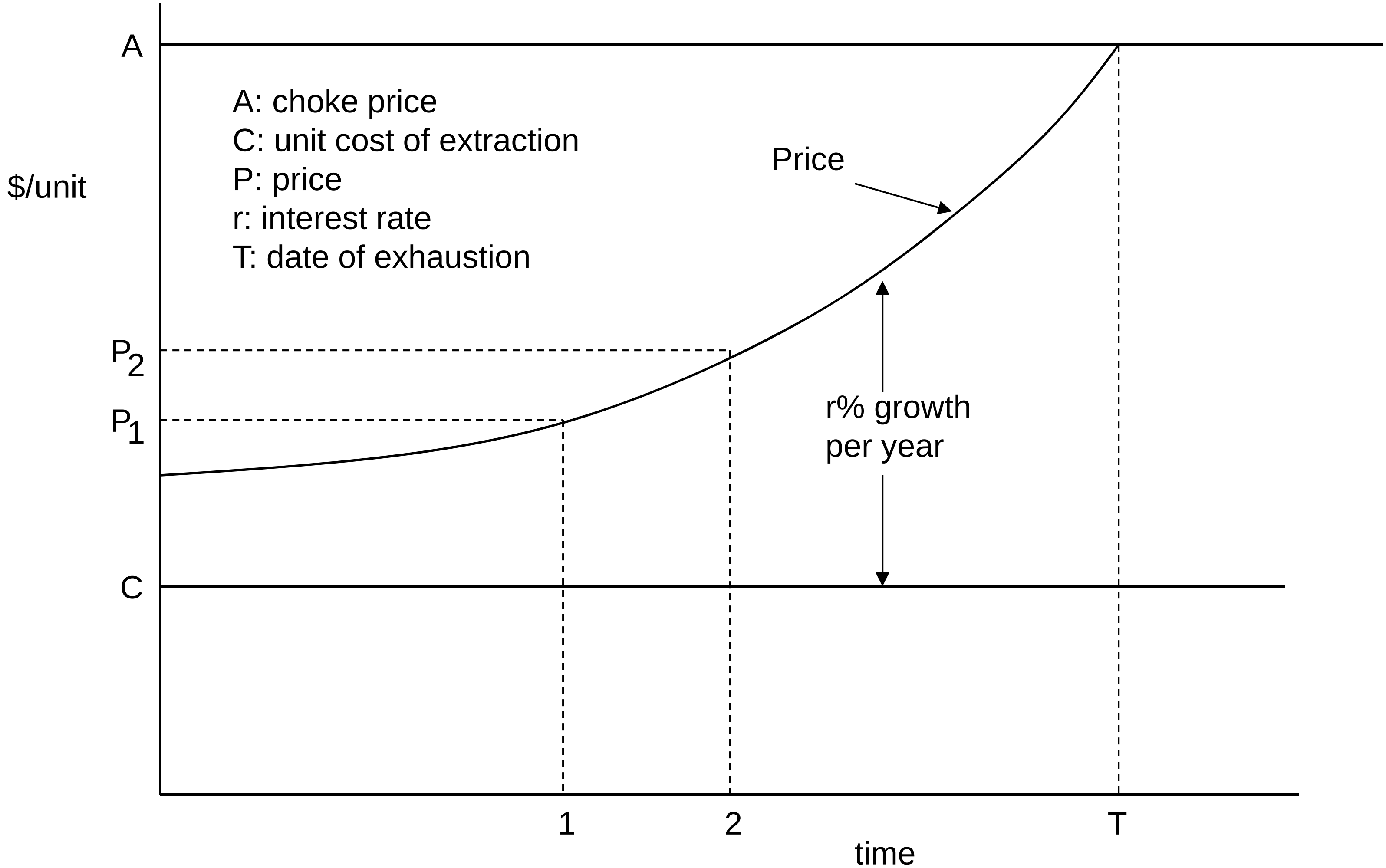
In words, price minus marginal cost increases over time at the rate of interest.

3. Explanation of conditions (cont.)

Condition (ii):

If the last unit sold at a price below A, any mineral owner who anticipated this would have earned a capital gain exceeding r% per year by withholding a unit of the resource until all others had exhausted their deposits, and then selling it at price A in the next instant. This cannot occur in equilibrium.

If the price rose to A before all deposits were exhausted, then those holding deposits at that point would earn a zero rate of return on them. This cannot occur in equilibrium.



Competitive equilibrium: time path for price

Nonrenewable Resources Sample Problem

Demand: $Q_t = 100 - P_t$ (Q is in tons, P is in \$/ton).

Cost: C = 10

Interest rate: r = .10

Reserve: R = 153 tons.

Questions: During how many periods does extraction take place?
What is price in initial period?

(Assume exactly 1 unit is sold in period T.)

Solution:

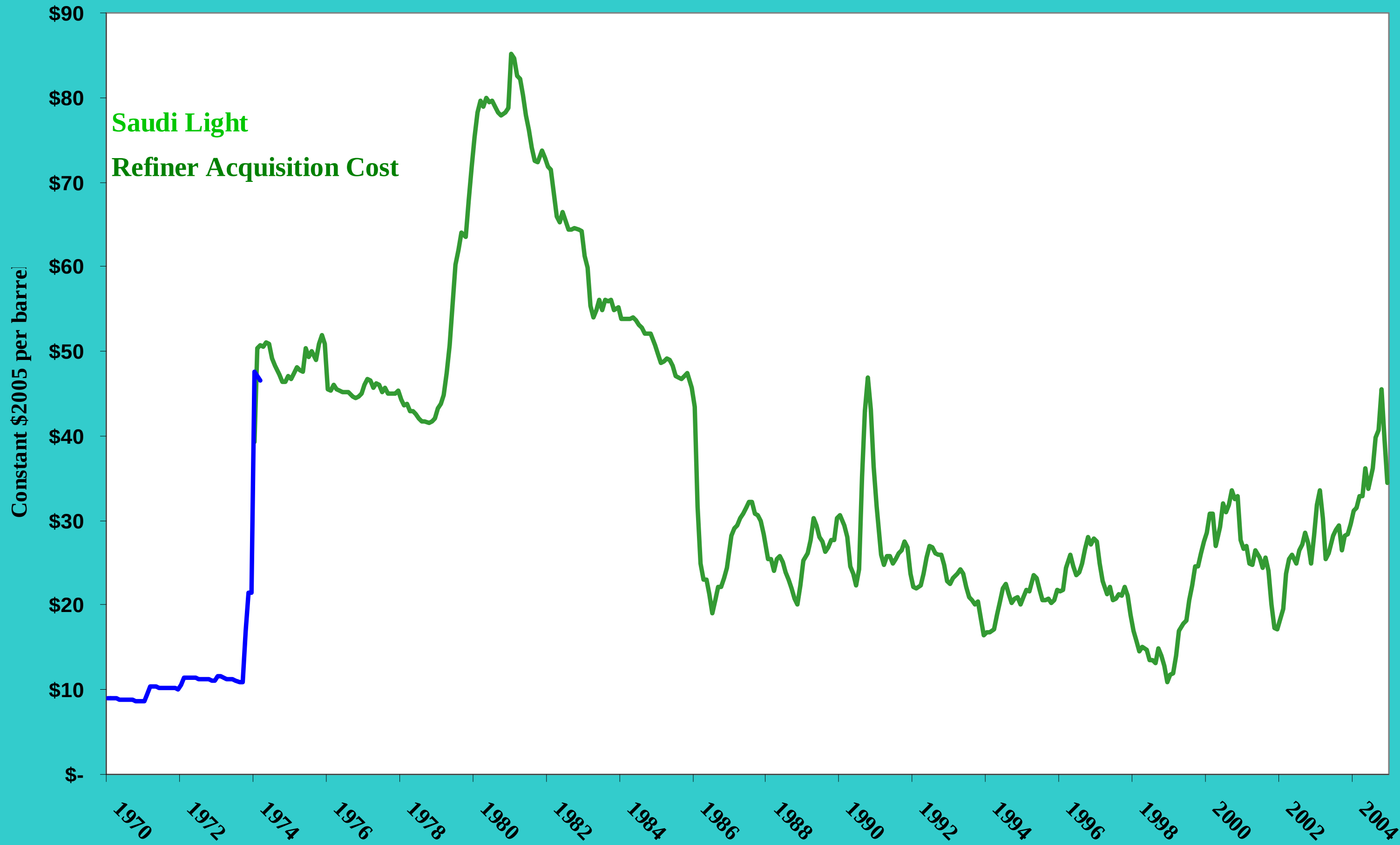
year	P_t	P_t - C	Q_t	Sum(Q_t)
T	99	89	1	1
T-1	91	81	9	10
T-2	84	74	16	26
T-3	77	67	23	49
T-4	71	61	29	78
T-5	65	55	35	113
T-6	60	50	40	153

T-6 is initial year of extraction; price is $60. Extraction occurs over 7 years.

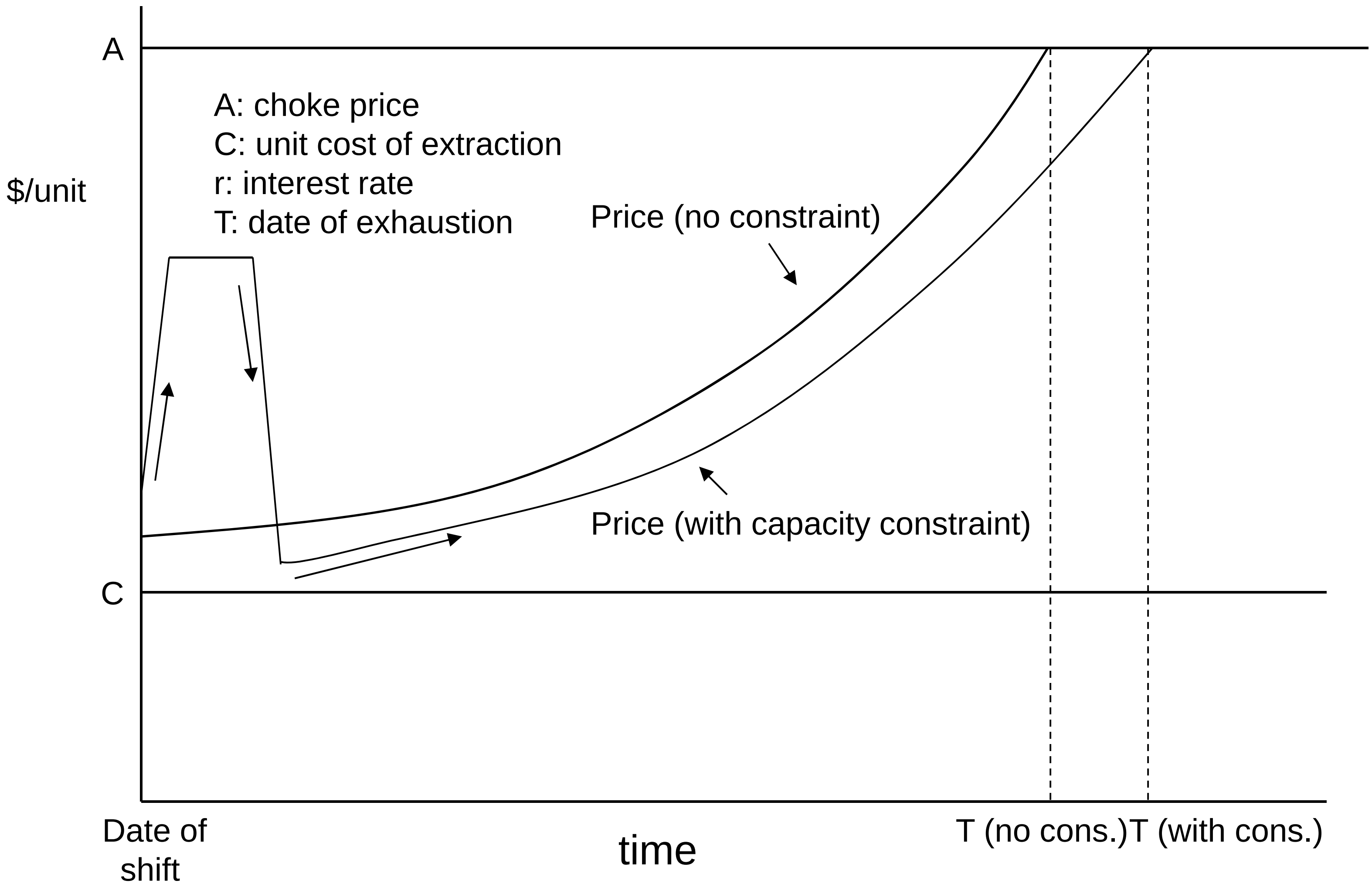
Note: $(P_{T-1} - C) = (P_T - C)/(1 + r)$; $(P_{T-2} - C) = (P_T - C)/(1 + r)^2$; etc.

Real World Oil Prices, 1970-2005

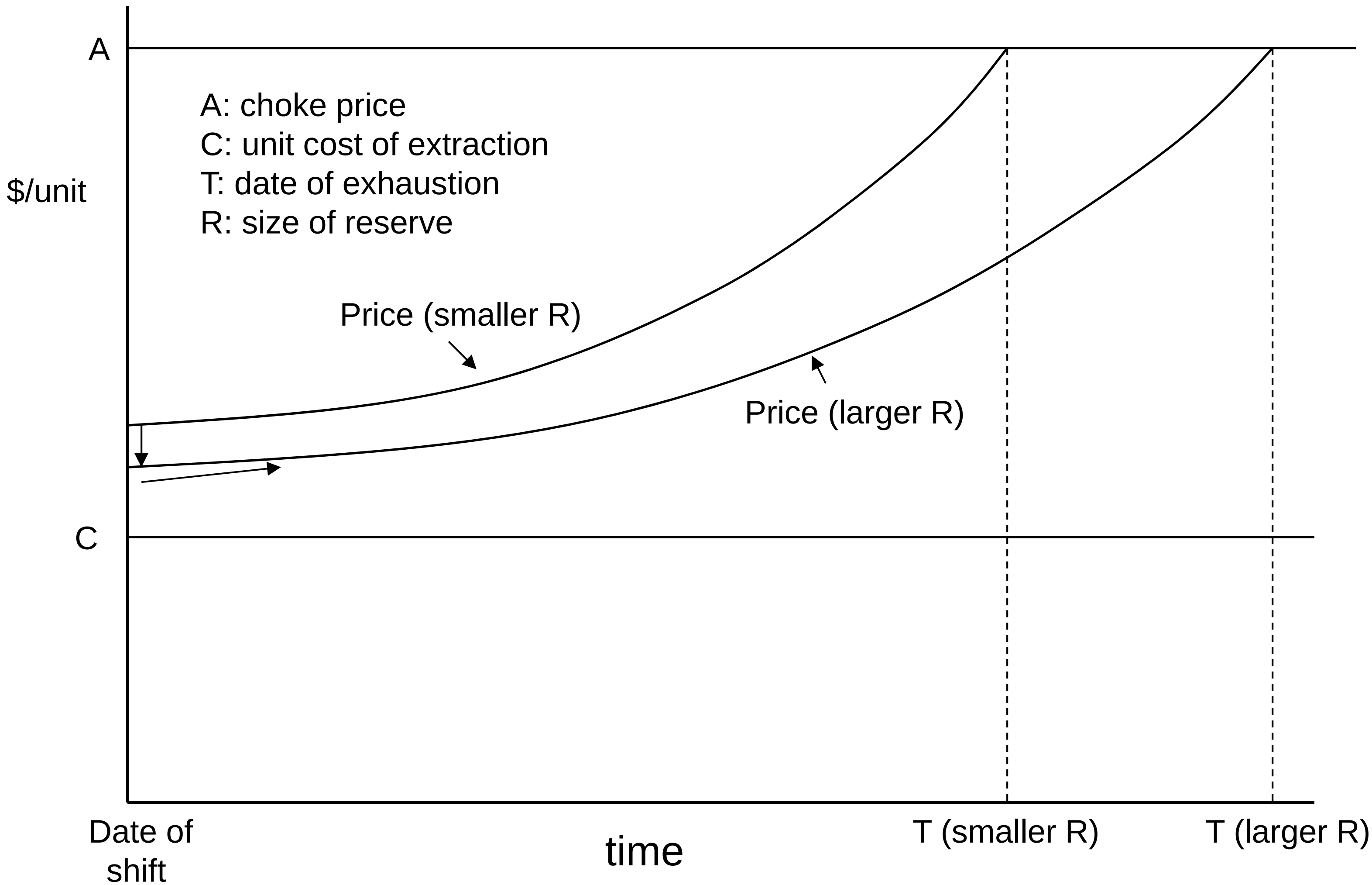
(Prices adjusted by CPI for all Urban Consumers, 2005)



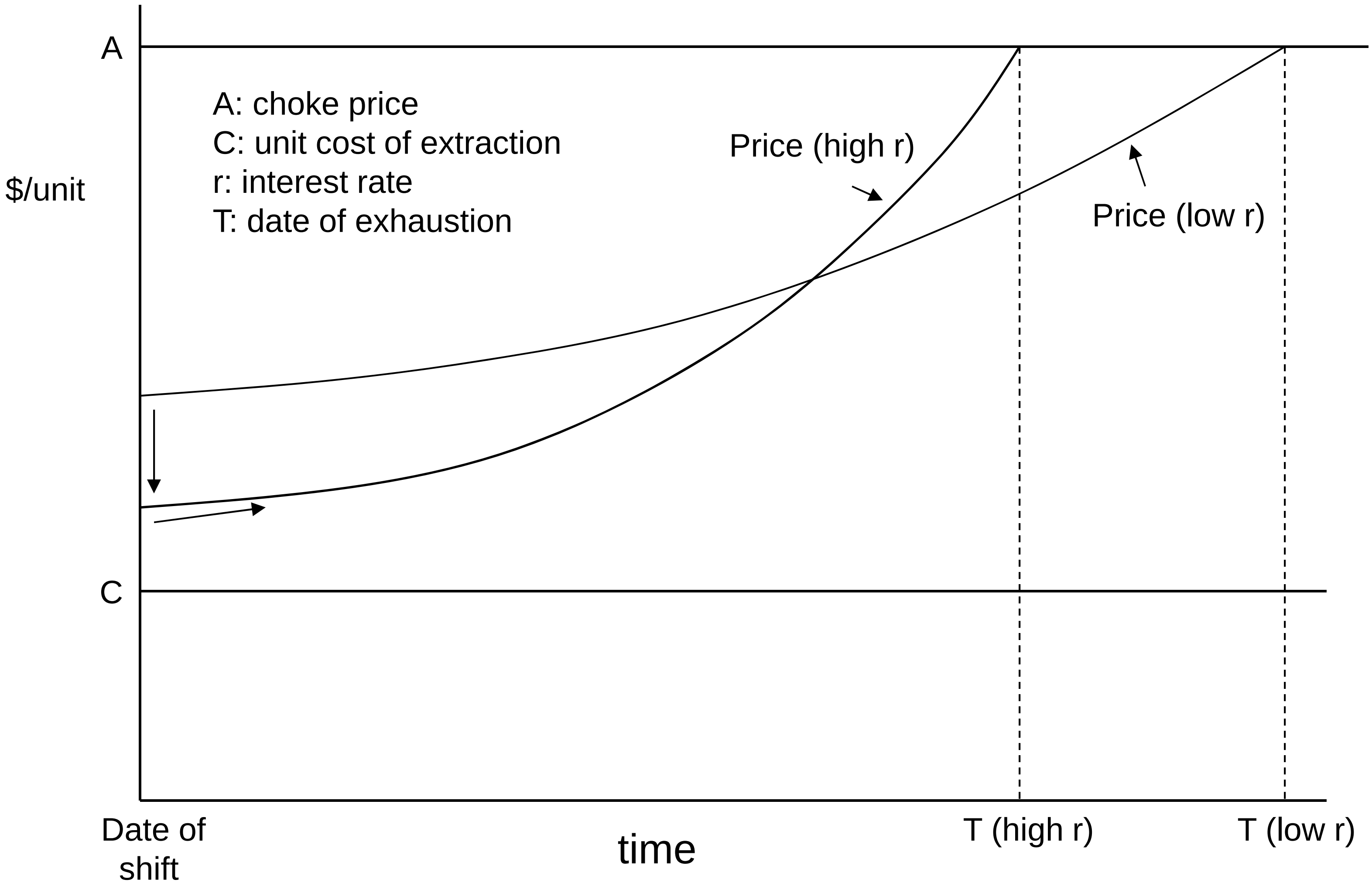
Source: EIA



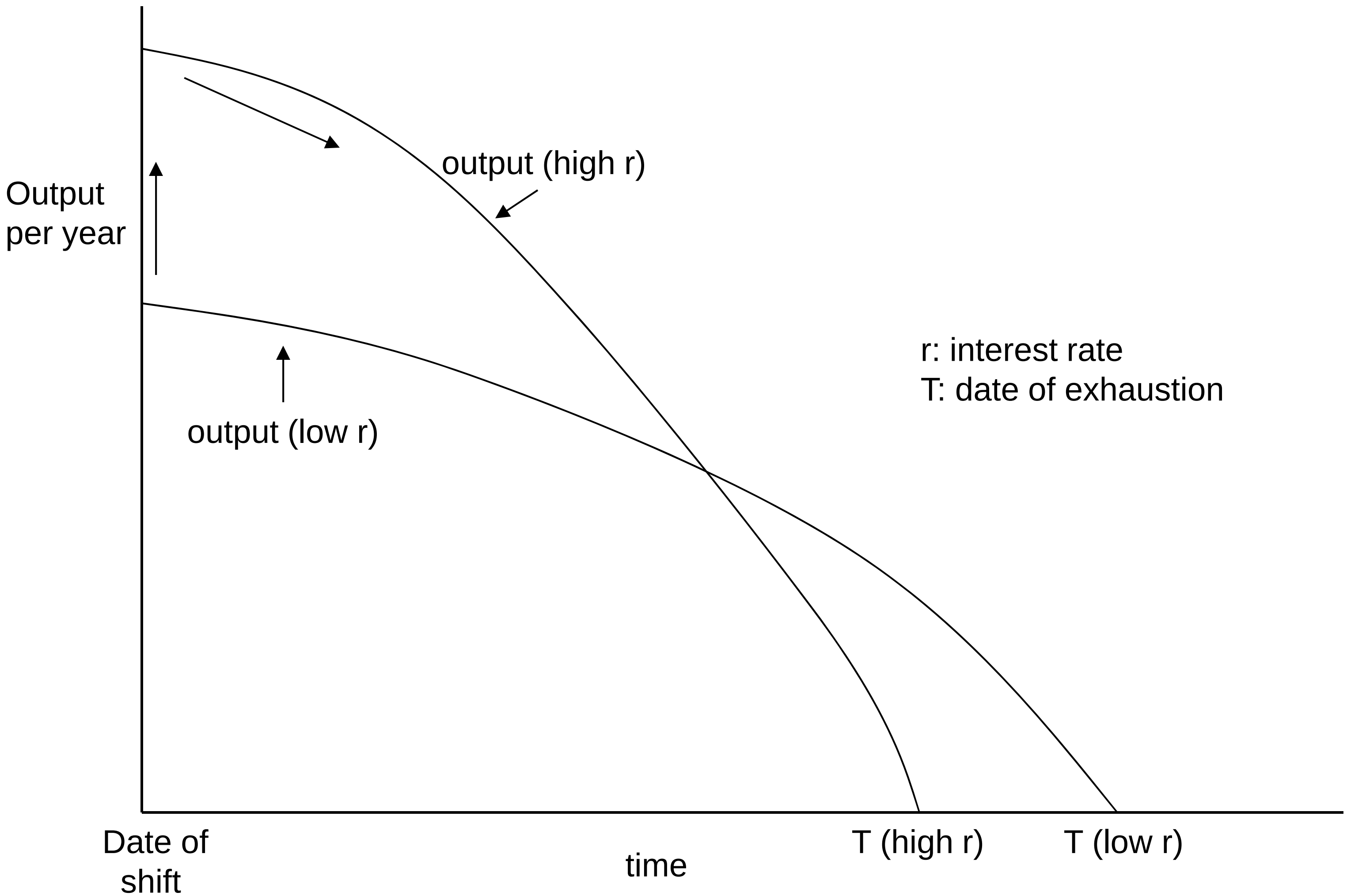
Effect of temporary extraction capacity constraint on time path for price



Effect of increase in size of reserve on time path for price

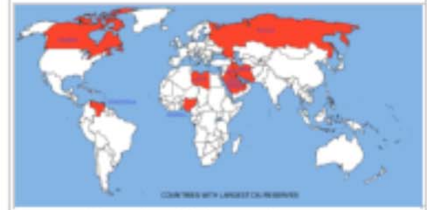


Effect of increased interest rate on time path for price



Effect of increased interest rate on time path of output

Estimated reserves in order



Countries with largest oil reserves

The amount of oil in any particular oil field involves a degree of uncertainty until the last barrel of oil is produced and the last oil well is abandoned. The following estimates are the best that could be obtained using publicly available data, and the confidence in them varies greatly from country to country. Estimates in developed countries are generally much more accurate than those for undeveloped countries. For instance, reserves estimates in the United States are considered highly accurate, while those in Iraq are highly uncertain. In many countries (particularly OPEC producers) the estimates may involve a great deal of political influence. The raw data underlying reserves estimates is considered a state secret in some countries, so independent assessments of their reserves cannot be made.

Summary of Reserve Data as of 2007

Country	Reserves [1]		Production [2]		Reserve life [3]
	10^9 bbl	10^9 m^3	10^6 bbl/d	10^3 m^3/d	years
Saudi Arabia	260	41	8.8	1,400	81
Canada	179	28.5	2.7	430	182
Iran	136	21.6	3.9	620	74
Iraq	115	18.3	3.7	590	101
Kuwait	99	15.7	2.5	400	108
United Arab Emirates	97	15.4	2.5	400	107
Venezuela	80	13	2.4	380	91
Russia	60	9.5	9.5	1,510	17
Libya	41.5	6.60	1.8	290	63
Nigeria	36.2	5.76	2.3	370	43
United States	21	3.3	4.9	780	12
Mexico	12	1.9	3.2	510	10

Notes:

1 Claimed or estimated reserves in billions (10^9) of barrels (converted to billions of cubic metres). (Source: Oil & Gas Journal, January, 2007)

2 Production rate in millions (10^6) of barrels per day (converted to thousands of cubic metres per day) (Source: US Energy Information Authority, September, 2007)

3 Reserve life in years, calculated as reserves / annual production. (from above)

Hotelling Rule for a Monopoly

1. New Notation

MR_t marginal revenue from sales in *t*.

T_M year when last unit is consumed with monopoly.

2. Conditions for Equilibrium

(i) $\dfrac{MR_t - C}{(1+r)^t}$ is equal in all periods. (Production in any period yields the same present value marginal profit.) This implies

$$(MR_t - C) = (MR_0 - C)\cdot(1+r)^t$$

(ii) $P_{T_M} = A$.

3. Explanation of Conditions

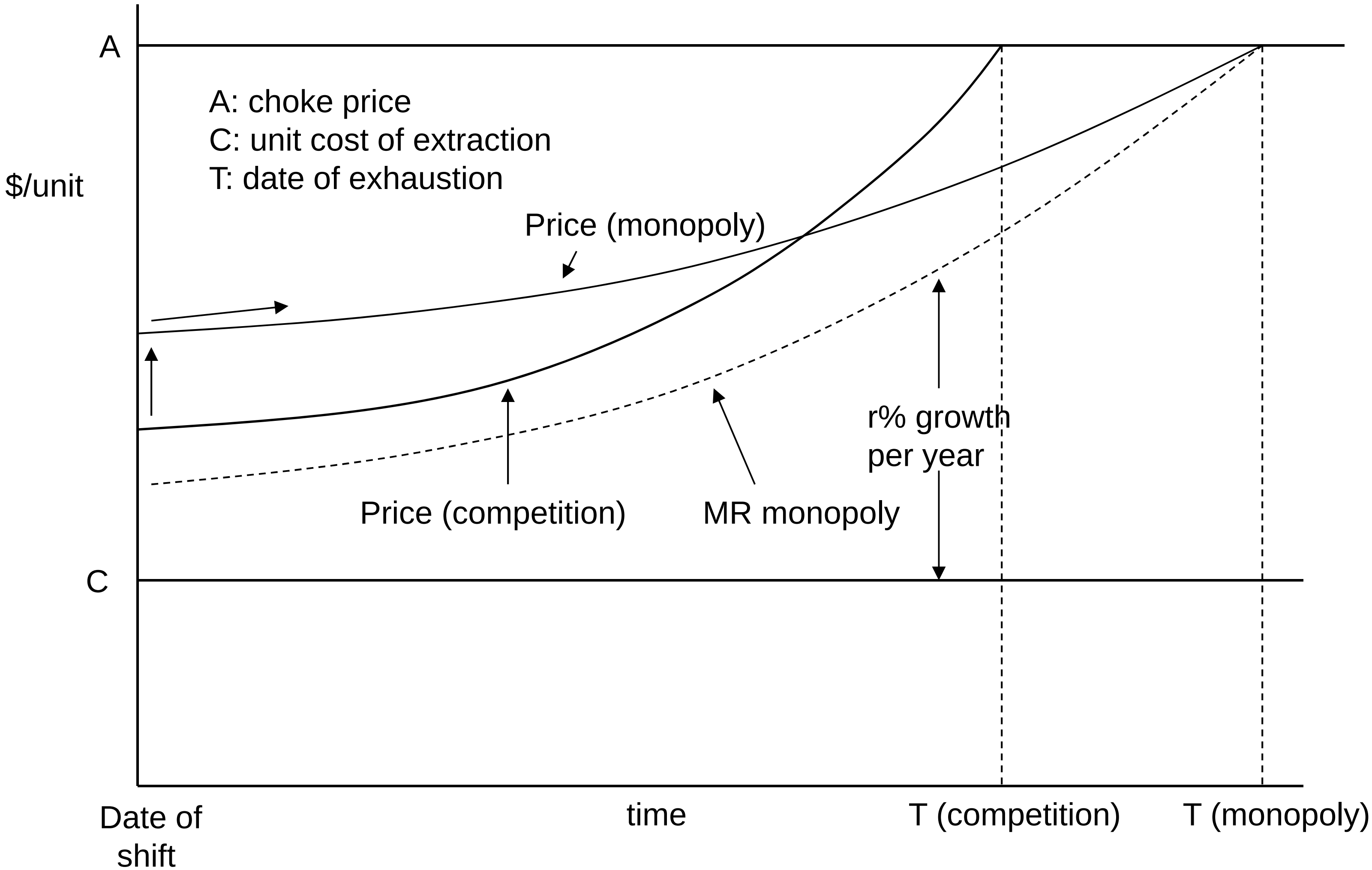
Condition (i):

PV profit from selling one unit of the mineral is $MR_0 - C$ in year 0, $\frac{MR_1 - C}{(1+r)}$ in year 1, $\frac{MR_2 - C}{(1+r)^2}$ in year 2, etc. In equilibrium the monopolist is indifferent between selling that unit in the present or in any future period, so the PV profit must be the same in all periods. This implies

$$MR_t - C = (MR_0 - C) \cdot (1+r)^t \text{ for } t = 1,2,3,...$$

Condition (ii):

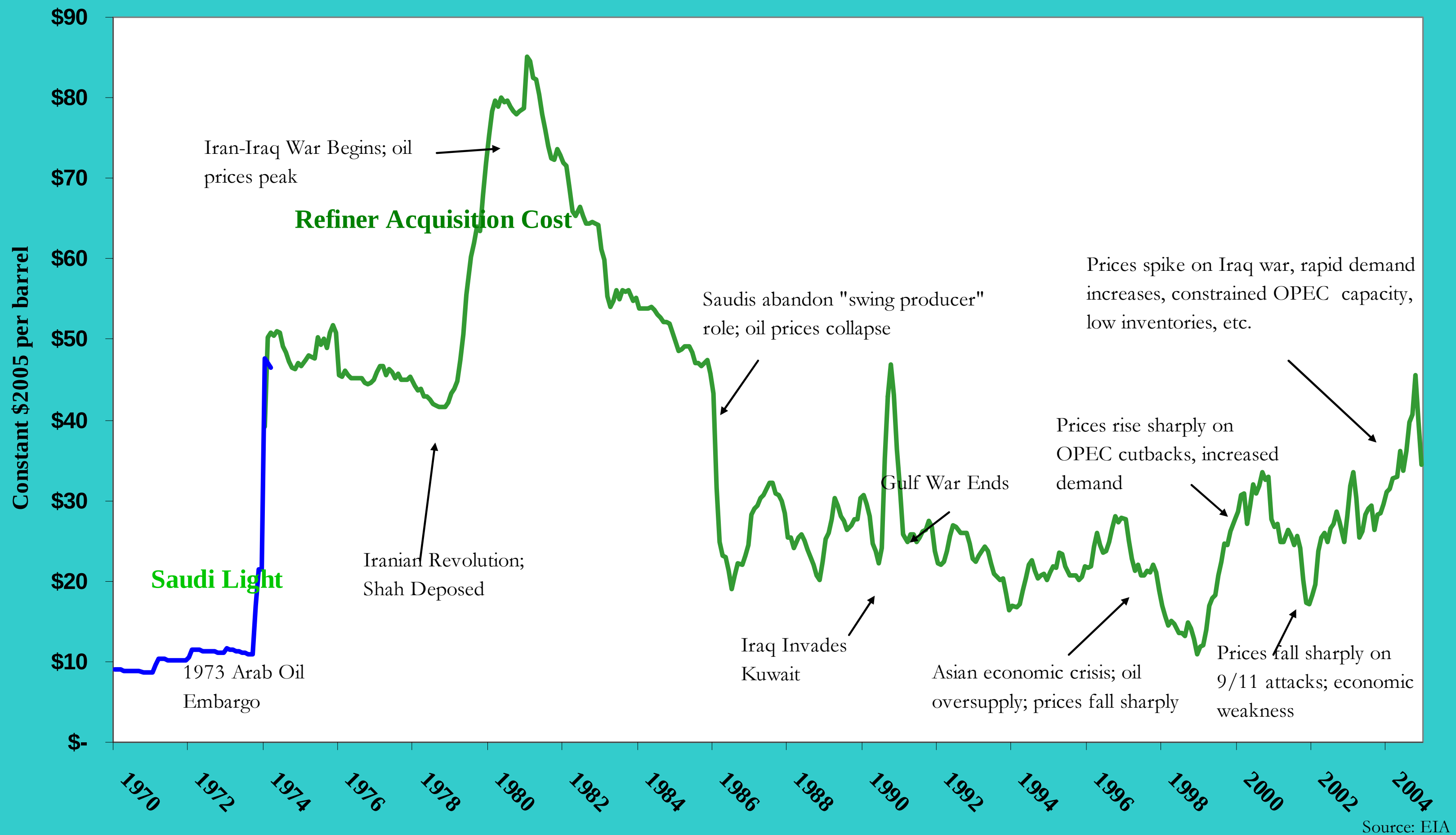
Same rationale as for competitive case.

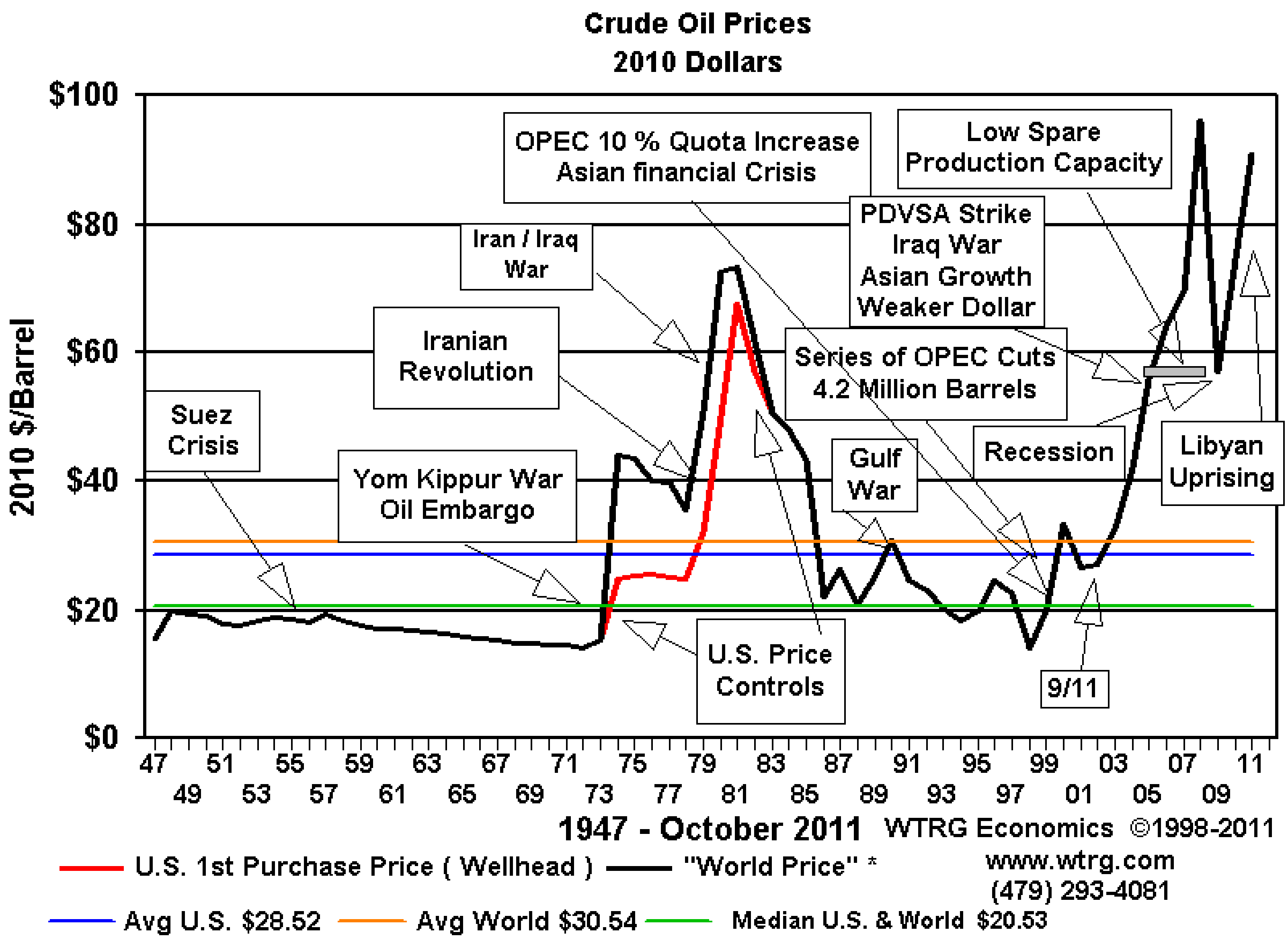


Effect of monopolization (vs. competition) on time path for price

Major Events and Real World Oil Prices, 1970-2005

(Prices adjusted by CPI for all Urban Consumers, 2005)




Crude Oil Prices
2010 Dollars
$100
$80
$60
$40
$20
$0
2010 $/Barrel
OPEC 10 % Quota Increase
Asian financial Crisis
Low Spare
Production Capacity
PDVSA Strike
Iraq War
Asian Growth
Weaker Dollar
Iran / Iraq
War
Iranian
Revolution
Series of OPEC Cuts
4.2 Million Barrels
Suez
Crisis
Yom Kippur War
Oil Embargo
Gulf
War
Recession
Libyan
Uprising
U.S. Price
Controls
9/11
47 49 51 53 55 57 59 61 63 65 67 69 71 73 75 77 79 81 83 85 87 89 91 93 95 97 99 01 03 05 07 09 11
1947 - October 2011
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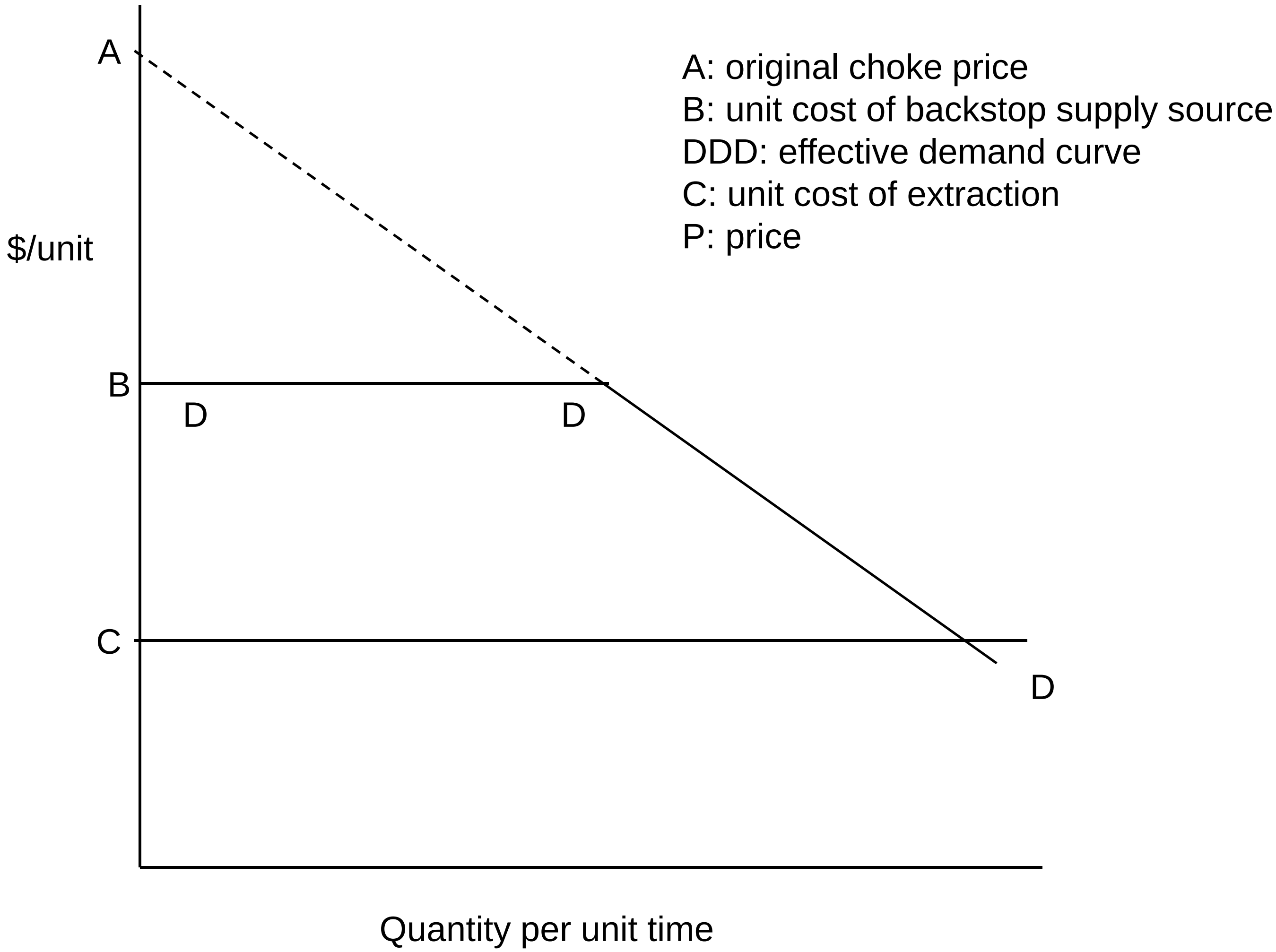
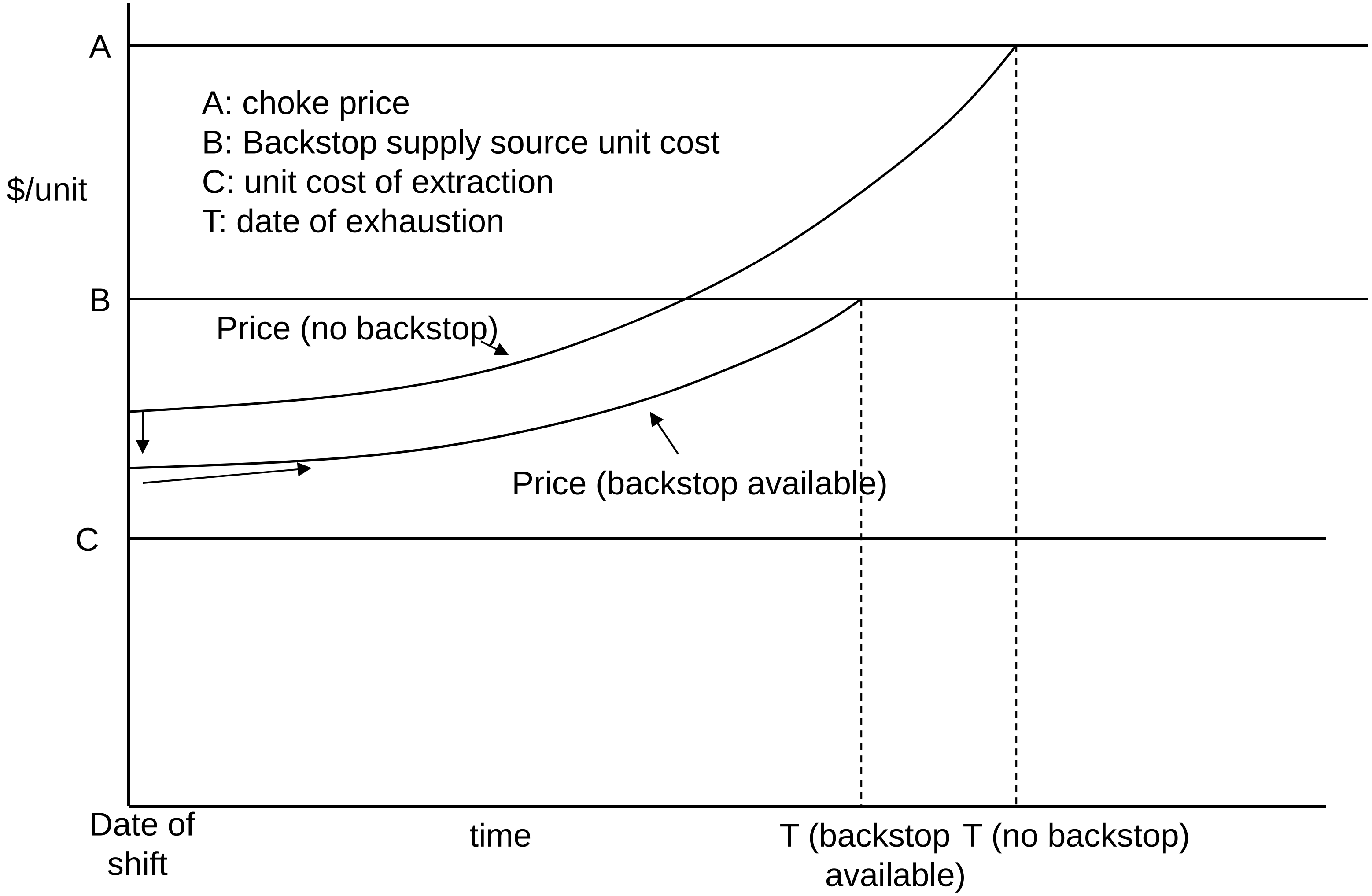
U.S. 1st Purchase Price (Wellhead)
"World Price" *
Avg U.S. $28.52
Avg World $30.54
Median U.S. & World $20.53



Effect of backstop supply source on demand for resource



Effect of introducing backstop supply source on time path for price

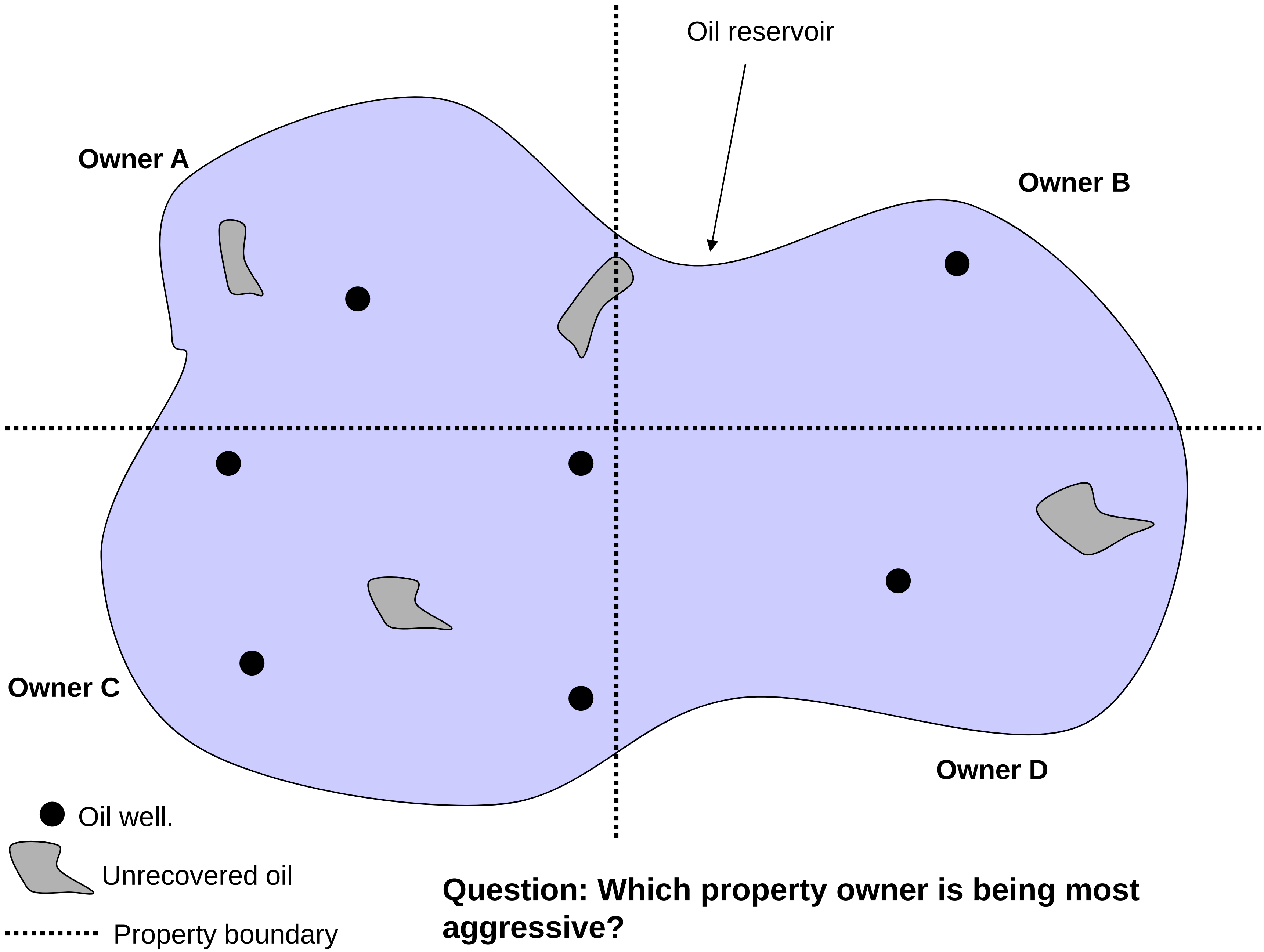
Common pool oil resources

Normal opportunity cost of leaving oil in the ground 1 year is foregone interest on profit, ‘r’ times value in ground

Suppose any barrel left unextracted for 1 year has a 20% chance of being extracted by your neighbor.

Then you will discount future profits from it at r+20%.

Predict more rapid extraction; also physical waste due to less oil recovered.



Question: Which property owner is being most aggressive?

Owner C

Photos

Mitigating environmental impacts of offshore production

- Aesthetic impacts of offshore production

- Spills from offshore production

Photos

Bargaining approaches to mitigating environmental impacts

Plains Exploration (PXP) proposal

Drill new wells from Platform Irene to extract oil under state waters

- Possibly extract 200 mm bbls.

In return, PXP promised to

- Shut down Irene in 2022
- Shut down 3 more platforms
- Shut down 2 oil processing plants
- Transfer 3,900 acres to the trust for public lands
- Give $1.5 to SB Co., to support mass transit
- Operate ‘carbon neutral’

Photos

Bargaining approaches to mitigating environmental impacts

PXP project outcome:

- Project denied by State Lands Comm.
- Fight led by former Lt. Gov. Garamendi.
- Unlikely this will be approved, following BP accident and spill in Gulf of Mexico.

ANWR and gasoline prices

- Basic economics: ANWR would increase petroleum supply.
- At $80/bbl., ANWR reserve ~7.3 billion bbl. (1 bbl. = 42 gal.)
- Worldwide reserve = 156,700 million tons, or ~1.1 trillion bbl.
- ANWR would increase worldwide LR supply by 0.6847% (two-thirds of one percent.)

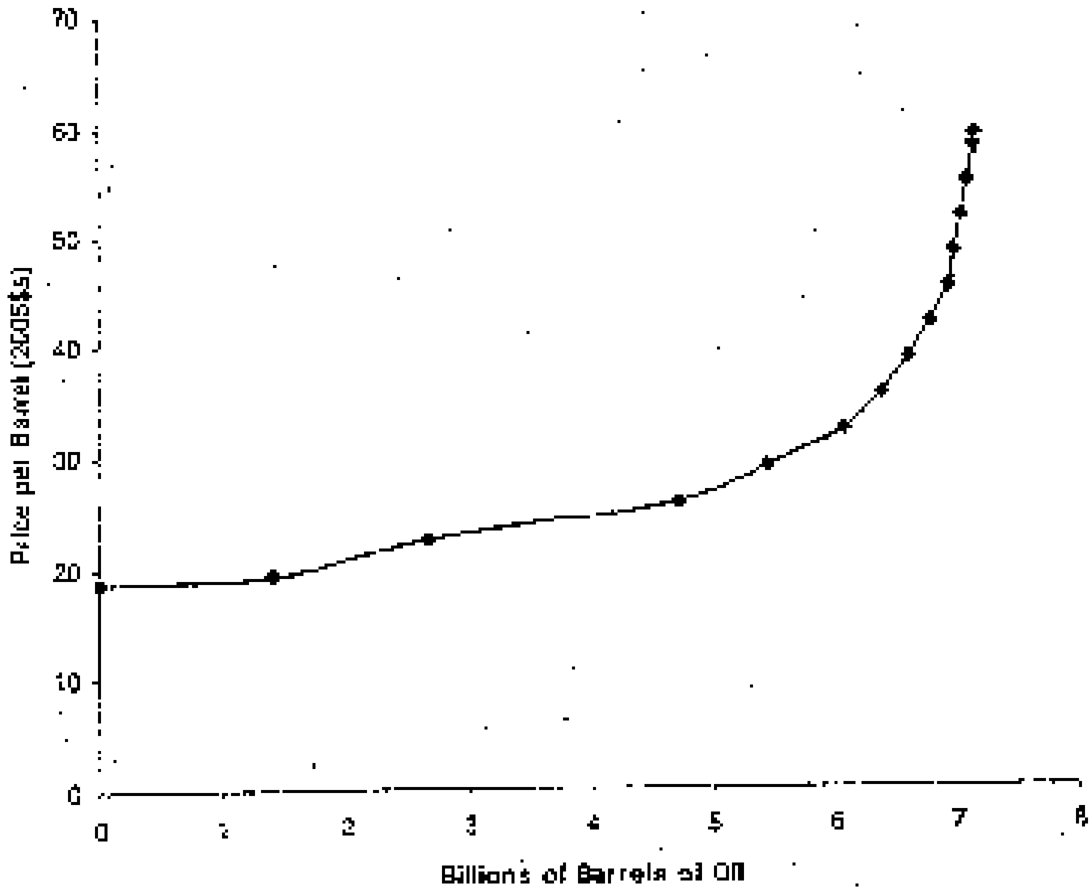


Figure 1: Mean scenario for ANWR's Economically Recoverable Oil at Different Prices (Source: Attanasi, 2005)

To determine effect on price, estimate effect on consumption:

- On average, world consumption would rise by 0.6847%.
- To estimate price change, use price elasticity of demand:

$$\text{Price elasticity} = \frac{\%\Delta Q}{\%\Delta P} = -0.25$$

- Implied price effect: $\%\Delta P = \frac{\%\Delta Q}{-0.25} = \frac{.006847}{-0.25} = -.0274$
- Implied price reduction for crude oil is -2.74%, or $.052 per gallon.
- This is the estimated effect on gasoline prices, $.052/gal.

Ownership Risk

- Confiscation events: loss of claim due to corrupt courts, seizure of assets by dictatorial government, arbitrary taxation, change in government regime.
- By holding $1 million asset for one year, owner foregoes potential interest, *r*% times value of asset;
- If asset owner faces *q*% probability that asset will be confiscated during the year, the future return from investment will be discounted by (*r*+*q*)%.
- Prediction: effect of greater ownership risk on investment and natural resource use is similar to higher interest rate.

Application to oil exploration:

- Example: 20% chance of confiscation.
- Owner discounts future returns from investment at r + 20% per year.
- Effect on exploration investments: Reduction.

Effect on production, once a reserve is found:

- Example: 20% chance reserve is confiscated.
- First effect: Owner discounts future profit at r + 20%.
  Incentive to produce rapidly.
- Second effect: Cost of extraction capital (wells, pipelines, processing equipt.) increased. Causes high extraction cost, C, which slows extraction.
- Which effect dominates?

Empirical strategy and results **(Bohn and Deacon Tables 4, 5)**

- Estimate link from political instability to capital investment; form 'security index'.
- Oil exploration model: wells drilled, by country and year.
  Result: 1 s.d. change in ownership security reduces drilling by 68%.
- Oil production model: log output / reserve, by country and year.
  Result: Greater security leads to more rapid production.
  1 s.d. change in security reduces production by 28%.

TABLE 4—DRILLING MODEL

	Log(wells/year)	
Dependent variable	Coefficient	*t*-statistic
Ownership security	0.1377	(8.82)
Geologic abundance (fixed effect)	5.2052	(11.74)
Log(price)	0.6380	(6.36)
OPEC 1974–1985	−0.4594	(−2.56)
Log(API gravity)	−1.4822	(−5.70)
Log(depth)	−1.0770	(−7.53)
Log(land area)	0.7585	(21.30)
Year	−0.0226	(2.95)
Constant	50.7324	(3.41)
N	632	
R^2 adjusted	0.54	

Notes: Data sources are *Oil and Gas Journal Energy Database* (1993) for drilling rates and *Oil and Gas Journal* (various issues) for gravity and well-depth information. The sample used for estimation excludes communist countries, because their data on production and reserves appear unreliable. Available data do not separate each country's onshore and offshore operations, so countries with offshore production exceeding 25 percent of total output were excluded, because onshore and offshore operating costs are very different. Data on gravity are incomplete. The variable used is the average API (American Petroleum Institute) gravity for the country's top-ten-producing onshore fields as of 1970, or a year close to 1970. Gravity is a chemical attribute of a country's petroleum, so it typically will not vary widely over time. Average depth is recorded as the average depth of each country's onshore oil in 1970.

TABLE 5—OIL-PRODUCTION MODEL

	Log(output/reserve)	
Dependent variable	Coefficient	*t*-statistic
Ownership security	0.0647	(9.12)
Log(price)	0.1129	(2.01)
OPEC dummies (1974–1985)		
Algeria	−0.2370	(−1.20)
Ecuador	0.4542	(2.35)
Indonesia	−0.2124	(−1.11)
Iran	−0.7128	(−3.66)
Iraq	−0.9357	(−4.92)
Saudi Arabia	−0.8157	(−4.08)
Log(API gravity)	0.0375	(0.27)
Log(depth)	−0.1640	(−2.06)
Year	−0.0052	(−1.19)
Constant	7.5388	(0.88)
N	636	
R^2 adjusted	0.22	

Notes: Communist countries and countries with more than 25 percent of production from offshore reservoirs were excluded for reasons explained earlier. A production minimum of 1,000 barrels per day was imposed for inclusion in the sample, since smaller output levels might indicate experimental operations. Israel and Egypt were excluded be-

Further research topics

- Natural resource ‘curse’
- Climate change from fossil fuel use and appropriate resource policy:

  Taxing emissions.

  Quotas with cap and trade.

  Subsidies for alternative energy?
- How will rapid growth in China, India and other developing countries affect fossil fuel use?

  Effects on carbon emissions.

  Politically feasible strategies for curbing emissions.