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Crude Oil Supply Curves

by

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CRUDE OIL SUPPLY CURVES

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In recent years there have been many reports of improved methods in oil production. But improvements do not add themselves up to measure changes in industry supply and cost. One hears that "high-tech leads to uptick in U.S. petroleum supply[1]" If true, this would be welcome; but that does not make it true.

The cost and price of any mineral are constantly pushed in two opposing directions. Depletion pushes the supply curve toward the left, while growing knowledge pushes it rightward. Depletion does not result from a limited mineral stock, the "economic portion" of hydrocarbons in-ground. The "economic" portion itself changes. Moreover, the concept of a limited stock is not only illogical but superfluous. All we need assume is that the owners of mineral deposits are rational. They use cheaper sources before dearer ones. If knowledge did not change, they would forever go from good ore to bad, from bad to worse. Costs and prices would rise over time.

One still reads that mineral costs and prices must eventually rise: while supply curves may initially shift rightward with discoveries, they must after a time go leftward because of cumulative

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[1] Resources For The Future, *Resources*, Fall 1997. See also DOE-EIA, *Performance Profiles of Major Energy Producers 1996* (1997), Chapter 3, especially Tables 14, 19, 21. The reported "finding cost per barrel of oil equivalent" is an illogical mix of oil and gas. It is also impossibly high for the 1980s, and improbably high for the 1990s, because it much exceeds the market *value* of developed reserves. The changing bias builds in a strong spurious decline. The industry rule of thumb is that value is about one-third of wellhead price. See Adelman & Watkins, "The Value of United States Oil and Gas Reserves", *Advances in the Economics of Energy and Resources,* vol. 10 (1997), pp. 131-184.

depletion.[2] In fact, U-shaped price trajectories for "exhaustible" minerals are rare or unknown. The U-shaped curves apparently found by Slade[3] resulted from the Great Depression, about midway in the period covered. The apparently rising price series all declined just after the date at which the sample stopped.[4]

Over the long run, for nearly all minerals, knowledge has overcome depletion. Costs and prices have declined. But this need not hold for all minerals at all times and places. Nor must past trends continue. We need to see what has actually happened.

The nature of a supply curve

The array of all sources of supply, e.g. all reservoirs, from lowest to highest cost, is a first approximation to a supply curve. But in competitive equilibrium, each individual source expands current output to where its short run marginal cost is equated to the price. In other words, marginal cost sums up both cost and demand. A "demand surge" will only raise prices if the demand shift overbears any supply shift.

Figure 1 shows the supply curve for all non-OPEC producers, excluding the USA and the Former Soviet Union (FSU). For the whole group, the supply curve goes from the origin (0,0) through the observed point (P, Q). Assuming price equals marginal cost, diminishing returns require an upward slope. The curve is summed up in the slope coefficient b. Thus if $P = bQ$, then $b = P/Q$. It seems more realistic to assume that marginal cost P rises at an increasing rate, as in the exponential $P = e^{bQ} - 1$. Then $b = \ln(P+1)/Q$. We use this form hereafter. Using another form would make little difference to the conclusions drawn below.

The coefficient b is purely ordinal, and registers shifts over time in a given supply curve. A higher b indicates a steeper slope, therefore a leftward shift. A lower b indicates a lower slope and a rightward shift. The long run is captured in a succession of short terms. The coefficient fluctuates in the short term, as higher or lower demand draws output to a higher or lower percent of capacity. Moreover, there may be temporary bottlenecks or surpluses of scarce factors, hence changes in factor prices. Over time, these short-run variations offset one another, and we see the effect of changes in installed capacity at higher or lower investment costs.

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[2] For a good recent example, see Elin Berg et al, "Gains from cartelisation in the oil market", *Energy Policy*, vol. 25, November 1997, page 1078. Cost is assumed as "an exponentially increasing function of cumulative production." It depends on "initial reserves" and in their view the increase can be only partly offset by a one- percent reduction due to technological advance.

[3] Margaret Slade, "Trends in Natural-Resource Commodity Prices", *Journal of Environmental Economics and Management,* vol. 9 (1982), pp. 122-137

[4] M. A. Adelman, *The Economics of Petroleum Supply* (MIT Press 1993), p. 233

Figure 1: Supply Curves, Non-OPEC, Excl USA, FSU
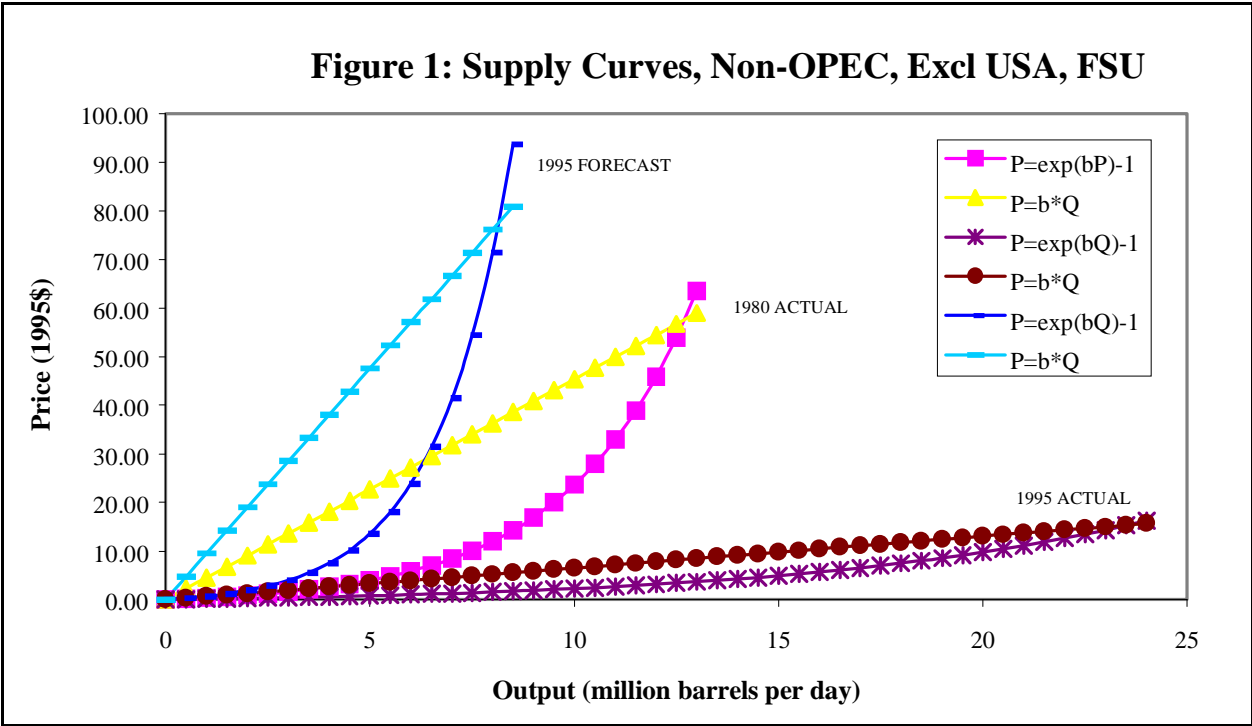
Competition and supply curves

In a non-competitive market, the supply curve does not exist because producers do not equate marginal cost to price. Hence the method is not valid. The most usual case is an imperfectly collusive group, which suppresses lower-cost capacity to make room for higher-cost capacity. OPEC has been the outstanding example of this effect, which has also mildly distorted the USA.

Figure 2 shows massive rightward movement of the supply curve, at a declining rate, in the USA ex-Alaska in 1918-1972, and a leftward movement thereafter. Data imperfections are serious in both periods. After 1935, there was "market demand prorationing", which made less economic sources produce at the expense of more economic.[5] Its importance dwindled after about 1960. But over the whole 1935-1970 period, the true coefficient was lower than the calculated.

During 1974-1981, prices in the USA were deranged by controls and entitlements. The average price was only the mean of several official price tiers. The higher the expected cost, the higher was the allowed price. Thus higher cost output was favored, and lower cost output was repressed. Moreover, entry to the higher-price tiers was worth paying for. Accordingly, there was great inflation of factor demand and factor prices, especially because more exotic and expensive

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[5] *Ibid.,* chapter 2. I estimated in 1986 (*ibid*, p. 155) that the U.S. industry would shrink because of rising investment requirements.

types of oil (and natural gas) were favored the most. The surge in the coefficient was almost accomplished by about 1981, when P is again fully meaningful.

Figure 2: Short Run Supply Coefficients for USA ex-Alaska 1918-1997
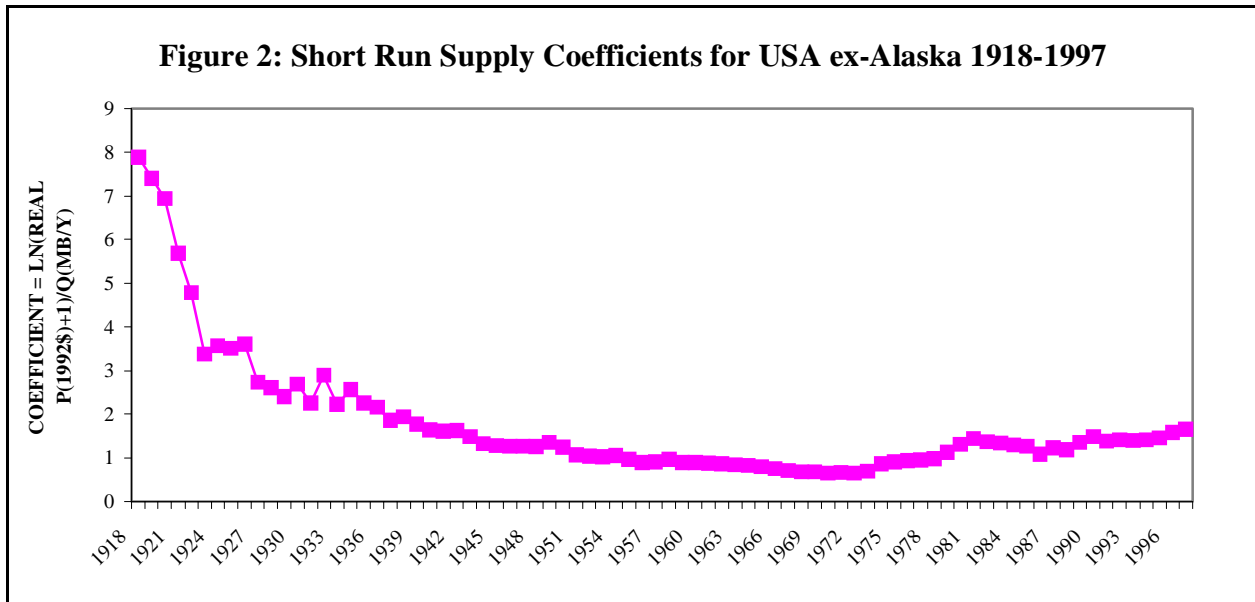
As of the mid-1990s, the coefficient is much higher than it was before 1972, but its current rate of increase is quite slow. Moreover, the rising price trend after 1995 has now (February 1998) been reversed, and US output is stable or even rising.[6] As usual, the current coefficient is dimly seen. The domestic oil industry is shrinking, but it is not about to disappear.[7]
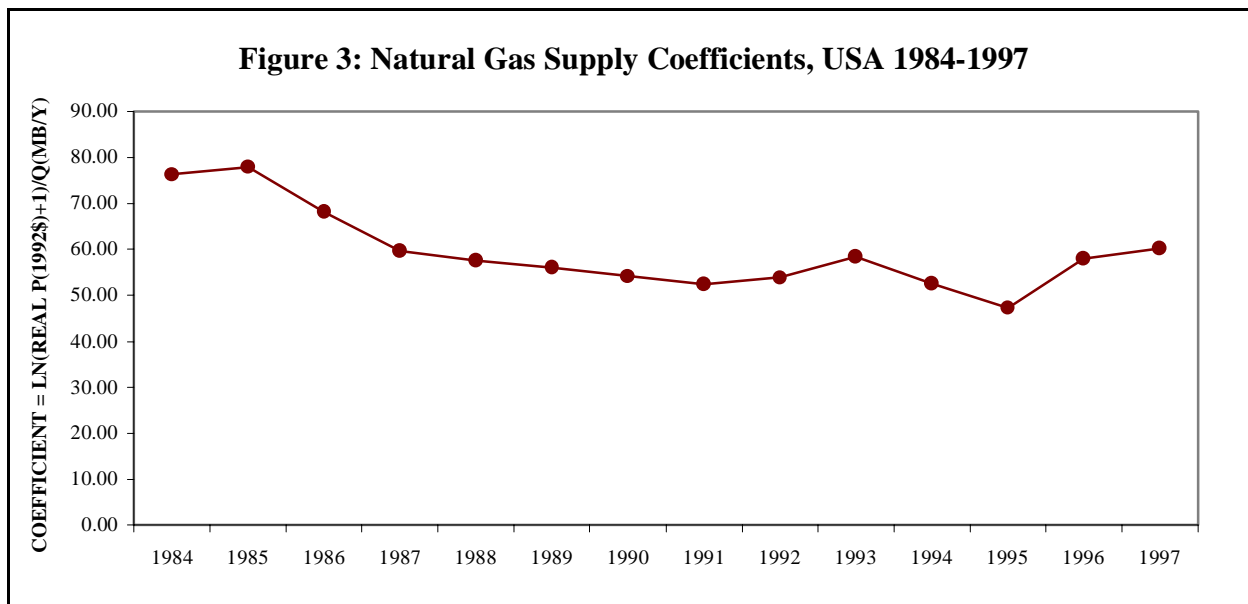
For natural gas, there is no meaningful price earlier than 1984. Previously, the "average wellhead price" was unrelated to current marginal cost because it was not a current price. It was merely the total of all payments received for deliveries during the year, divided by the total amounts delivered, as set by contract, irrespective of the year when the contract was made. Thus the average "price" included bargains made 20 years earlier, and the average age of the units delivered was in the neighborhood of nine years. Field price regulation, which became effective around 1960, and did not end until the early 1980s, made distortion much worse.[8]

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[6] Comparing January 1997 with January 1998:

Price (WTI, $/brl)	19.80	16.60
Output (mbd)	6.3	6.5
Coefficient	.482	.441

[7] Cf. M. A. Adelman, "Finding and Developing Costs in the United States, 1945-1986", *Advances in the Economics of Energy and Resources,* ed. J. R. Moroney (JAI Press 1992), pp. 11-58

[8]Deregulation nominally began in 1978, but the 1979-80 price explosion, with reversal beginning in 1981, made gas prices for a time higher than competing fuels, to which demand was diverted. Only then did prices and sales approach a competitive balance.

Figure 3: Natural Gas Supply Coefficients, USA 1984-1997

COEFFICIENT = LN(REAL P(1992$)+1)/Q(MB/Y)

(y-axis: 0.00 to 90.00; x-axis: years 1984–1997)

Since 1984, at least, the coefficient for natural gas has if anything tended to decrease. If so, technology has outrun gas depletion, and the supply curve has shifted to the right. This divergence between oil and gas is confirmed by reserve increments related to expenditures.[9] Whatever the reason, the divergence shows that to lump oil and gas together as "oil equivalents" makes no sense. Year to year changes in "finding cost per barrel of oil equivalent" are further distorted as the oil-gas mix keeps changing.[10]

Knowledge outruns depletion (1): OPEC 1945-1970

For many years, eight large multinational oil companies controlled the market outside the USA. They restricted their total output to the amount demanded at current prices. Under competition, they would have expanded output enough to force a lower world price. They reluctantly began doing this after World War II. (The U.S. responded by restricting imports to maintain the price). But the companies never allocated output to keep less efficient units in operation. Hence the coefficient is valid through 1970. Afterward, the host governments took charge, and raised world prices even as their production stagnated or declined. The price was above the USA level, until about 1981.[11]

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[9] Cf. M. A. Adelman, *The Genie out of the Bottle: World Oil Since 1970* (Cambridge: MIT Press 1995), ch. 2

[10] See DOE-EIA, *op. cit.,* n. 1 above.

[11] For details of calculation, see Adelman (1995), *op. cit.,* chapter 2, n. 9.

**Figure 4: OPEC Supply Coefficients, 1947-1970**
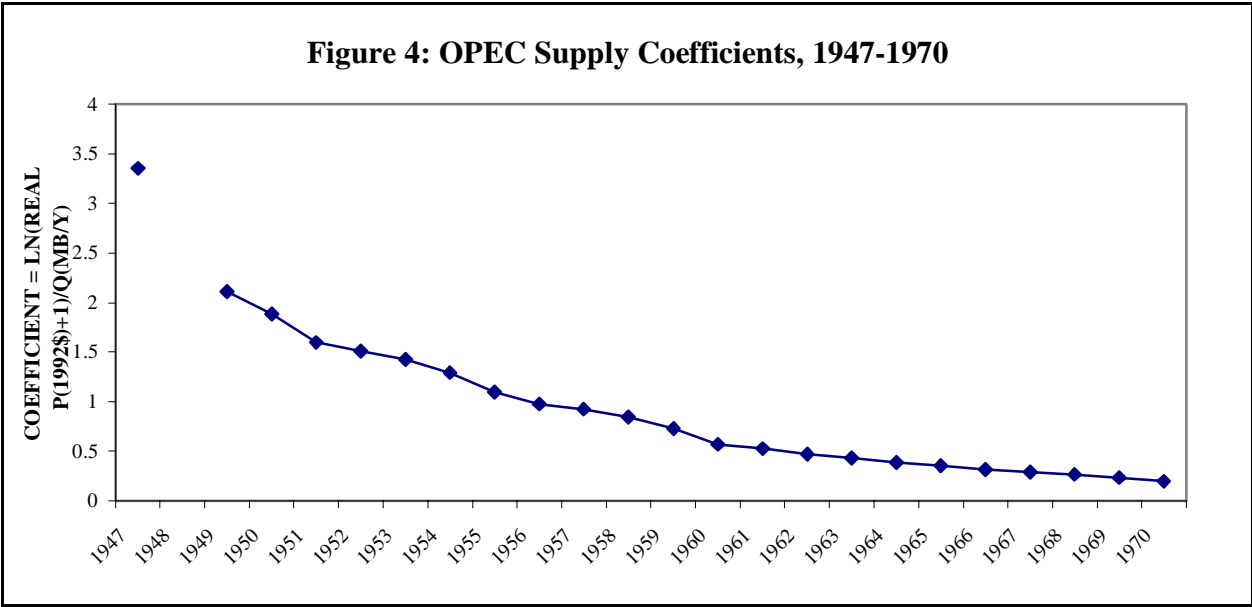
The 1947-1970 productivity increase reflected, among other things, external economies of scale: the installation of service and supply facilities in new areas. Some economists later wrote that the cost level was "unsustainable", and that prices had to increase after 1970 because of "limited reserves".[12] There was no basis for this. In 1966, I had published a simulation of the supply price, to show that even assuming zero new-field discoveries (and accelerating output growth) reserve growth in old fields would keep supply prices *below* 1970 market prices for at least another 20 years. The simulation was accepted as essentially accurate in the industry press.[13] It was later updated in a book. Reserve expansion was of course much greater than assumed. In the 27 years after 1970, OPEC used up 240 billion barrels of reserves, but added 627 billion.

Knowledge outruns depletion (2): non-OPEC 1970-1997

Finally, Figure 5 gives each year's value for the curve in Figure 1. It shows the annual supply coefficient for total non-OPEC outside the USA and the Former Soviet Union. There was an increase in 1970-1974, and in 1979-1981, when marginal cost chased after the rapidly rising price, as producers pushed existing capacity to the limit. But as new investment came on line, the supply curve moved strongly to the right. The coefficient declined in every individual country, except for some small ones.

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[12] Dermot Gately, "A Ten-Year Retrospective: OPEC and the World Oil Market", in *Journal of Economic Literature*, vol. 23 (1984), pp. 1100-14; see also Book Review, ibid, vol. 35 (1997), pp. 183-184.
[13] Adelman, (1993) *op. cit.,* chapter 3 [1966 pub.]

Figure 5: Non-OPEC (excl USA, FSU) Supply Coefficients, 1970-1997
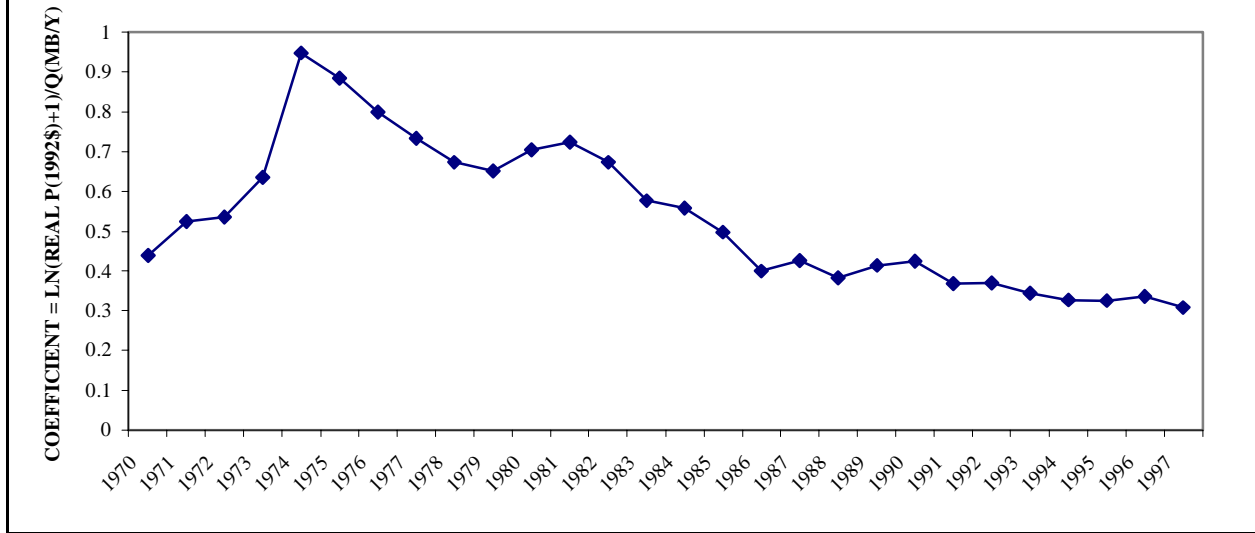
Referring back to Figure 1: the "predicted" (P, Q) starts with the actual 1980 (P, Q), then gives the result of a 3 percent annual price increase and output decrease. Taken together they imply a supply function rotating to the left. In fact, there was rapid rotation to the right. As prices rose exuberantly, non-OPEC output stagnated; when prices fell sharply, output expanded.[14]

Resolving the paradox gives us a hint of future change. Practically every non-OPEC country has been an under-achiever because tax codes and regulations have kept investment below the level that would maximize profits and government revenues. The price control was a wake-up call to stop dreaming and start reforming. If, as is likely but not inevitable, each country moves slowly toward its production possibilities curve, then even assuming no change in that curve, the observed function will keep shifting rightward.

We should of course test with an independent body of evidence: the investment needed to install a unit of additional reserves/capacity. But relevant data to prove or disprove any hypothesis are few and decreasing.[15]

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[14] Adelman (1995), *op. cit*., pp. 150-154

[15] Marie N. Fagan, "Resource Depletion and Technical Change: Effects on U.S. Crude Oil Finding Costs from 1977 to 1994", *The Energy Journal*, vol. 18, No. 4, pp. 91-105, makes an important contribution, but uses as dependent variable the illusory "finding cost". See footnote 1 above. Offshore "finding costs" are said to decline from an impossible $33.76 in 1981 (implied wellhead price over $102) to an improbably high $6.09 in 1994 (implied $18.27, when the U.S. average crude oil price was $13.19). The decline is spurious. But meaningful data might produce similar results, though I do not think so.