CEEPR Center for Energy and Environmental Policy Research

World Oil:
Market or Mayhem?

by

James L. Smith

08-015 September 2008

A Joint Center of the Department of Economics,
MIT Energy Initiative, and Sloan School of Management

World Oil: Market or Mayhem?

James L. Smith[*]

September 20, 2008

The world oil market is regarded by many as a puzzle. Why are oil prices so volatile? What is OPEC and what does OPEC do? Where are oil prices headed in the long run? Is "peak oil" a genuine concern? Why did oil prices spike in the summer of 2008, and what role did speculators play? Any attempt to answer these questions must be informed and disciplined by economics. Such is the purpose of this essay: to illuminate recent developments in the world oil market from the perspective of economic theory.

[*]Department of Finance, Southern Methodist University, Dallas, TX 75275

I am grateful to Morris Adelman, Larry DeBrock, Dwight Lee, and John Parsons, who provided comments on an earlier draft. The author bears full responsibility for all remaining errors.

World Oil: Market or Mayhem?

Introduction

The oil market has often excited and sometimes perplexed its many participants and observers. A list of the presently baffled would include investors, merchants, politicians, regulators, economists, analysts, and just plain folks. This is not so hard to fathom. We have moved beyond oil's golden era, that hundred-year stretch between 1874 and 1973 when the real price was relatively stable and mostly stayed within the range from $10 to $20 per barrel.[1] That epoch has ended and been replaced by something entirely different, something that to many observers looks like chaos.

The old regime began to crumble in 1973, when certain politically-motivated major producing nations declared an embargo on oil exports to the U.S. That spooked the market and caused prices to triple from $15.42 to $48.92 within one year. Later in the decade, political and military strife in the Middle East again rattled the market and caused a further doubling, although prices eventually fell back to earth with a loud thud, bottoming out at $27.22 per barrel in April 1986. Recent developments seem even more remarkable. After skidding to a low of $17 per barrel in 1998 in the wake of the Asian financial crisis, oil stabilized around $30 during 2000-2004, but then began a breathtaking ascent that surpassed $140 by July, 2008. Everyone repeats the same question: What next?

Because the world oil market is, ultimately, subject to the forces of supply and demand, and because most participants are motivated to some extent by profit, it is not unreasonable to believe that application of basic economic principles may help to

[1] All prices in this section are stated in terms of 2007 US dollars, as reported by BP (2008).

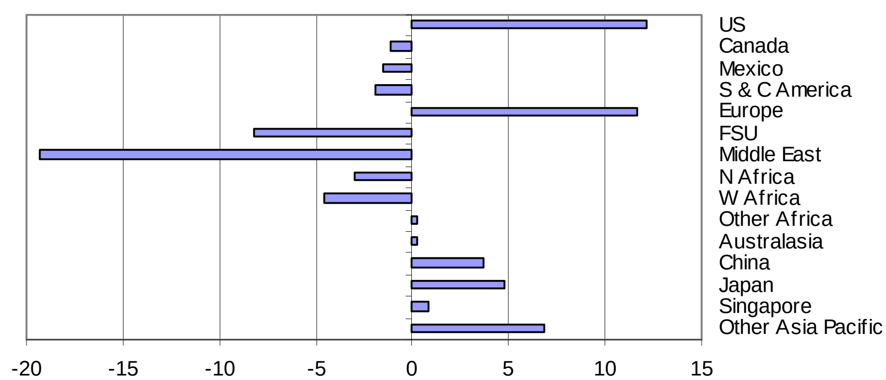
organize the data, concentrate thought, and strengthen our understanding of these events. However modest it may seem, such is the purpose of this essay: to see whether economic theory can help to illuminate recent developments in the world oil market. Taking the next step (what next?) represents a higher aspiration, but one that still must be as amenable to economic analysis as to other forms of punditry. Keep in mind, however, that whereas economics may help to clarify certain aspects of the petroleum story, economists have not the power to eliminate uncertainty regarding exogenous events. It should be enough to satisfy most readers if, by taking an economic perspective, we are able to distinguish sources of fundamental uncertainty regarding the future of world oil from the fog that descends from confused thought.

Some Background

It is no exaggeration to say that a unique combination of economic circumstances and policy issues surrounds oil. A short list would include the prominent role and unusual longevity of a major cartel (OPEC); nagging doubts about the sustainability of the natural resource base and concerns about "peak oil;" extremely high price volatility compared to other commodities; the absolute size and scope of the oil industry and its historical link to industrialization, economic growth, and the global distribution of wealth; the substantial volumes of petroleum-related CO_2 emissions that place oil near the epicenter of the global warming debate; plus a host of tricky geopolitical issues that reflect the uneven distribution of oil deposits around the globe.

The oil industry is both large and international, which means nearly all nations are significantly impacted by market developments. At least fifty countries produce substantial volumes of oil, and two-thirds of total production is exported.[2] Countries of the Middle East, the Former Soviet Union, and Africa account for the bulk of exports, whereas the U.S., Europe, China, and Japan account for nearly all of the imports, as recorded in Figure 1. There are many grades of crude oil, but they all compete in a highly integrated world marketplace with price differentials that reflect the relative desirability of grades. It costs only a dollar or two to shift a barrel from Europe to the U.S., or from the Middle East to the Far East, so arbitrageurs are active and keep relative prices in line.

Figure 1: 2006 Net Oil Imports, by Region
(Crude Oil & Refined Products, Million Barrels per Day)

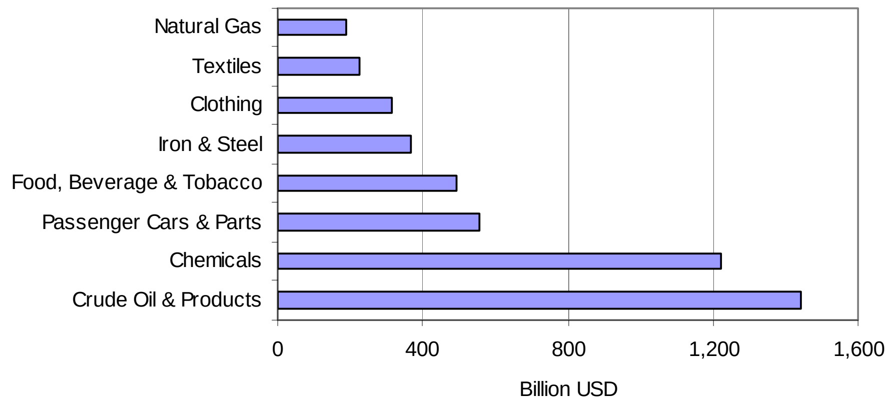


For many years, oil exports (crude oil plus refined products) have been the leading commodity in world trade—lately comprising 13% of total commodity trade by value, some $4 billion per day.[3] In comparison, automobile exports amount to only about one-third as much, and iron and steel even less. Chemicals are the only category that comes close, at five-sixths the value of oil (see Figure 2). These statistics are for 2006, the most recent year available. Since then, the relative value of oil exports has increased.

---

[2] Oil production, imports, and exports are from BP (2008).
[3] All trade statistics reported here are derived from UN (2006).

Figure 2: Global Imports, 2006



It is also true that the world oil market has undergone fundamental change during our lifetime, and that adherence to old conceptions has tended to confuse the analysis and taint public discourse. Although contradicted by facts, the historical presumption that world oil is dominated by a handful of private corporations (the so-called "Seven Sisters") who manipulate the market has been slow to die. In 1969, before a wave of nationalizations reshaped the industry, the eight largest oil companies produced 89% of the world's oil; today, those same companies account for only 12% of production.[4] Perhaps more significantly, they now control only 3% of the world's remaining proved oil reserves. Production is still highly concentrated, but market power has passed into new hands. "Big Oil" now consists of the state-owned companies of the major exporting nations, who account for about 50% of global output, control 70% of recoverable reserves, and operate under sovereign power beyond the reach of anti-trust or regulatory authorities. Some of these national oil companies are affiliated with OPEC, some are not.

[4] The original eight included Esso, BP, Shell, Gulf, Texaco, SoCal, Mobil, and CFP. With the exception of CFP, these were the "Seven Sisters." Through various mergers and consolidation, the eight have been reduced to five, now know as the "super majors": ExxonMobil, BP, Shell, Chevron, and Total. The 1969 shares are from Adelman (1972); current shares are from *Petroleum Intelligence Weekly* (2007).

In these few pages we cannot provide a comprehensive review of the world oil market. Fortunately, excellent and more detailed analyses are available.[5] Our goal is to examine just a few key questions that have sparked recent controversy and debate:

- Why are oil prices so volatile?
- What is OPEC and what does OPEC do?
- What is the equilibrium price of oil?
- Is "peak oil" a genuine concern?
- Why did oil prices spike in 2008, and what role (if any) did speculators play?

Any attempt to answers these questions must be informed and disciplined by economics. No amount of political theory, geology, or engineering can substitute for the basic principles of supply and demand—no matter how hard some people may try.

Oil Price Volatility

Volatility is a composite measure of the *size* and *frequency* of price movements. It is convenient to think of price changes in terms of percentages. If we denote by x the percentage change from one year to the next, i.e., $x_t = (p_t - p_{t-1})/p_{t-1}$, it follows that $x_t \approx \ln(1+x_t) = \ln(p_t/p_{t-1})$, which is the usual formula by which the relative price change (or "return" as it is called in the finance literature) is computed. Annual volatility is simply the standard deviation of annual returns over a series of years:

$$v \;=\; \left[\sum_{t=1}^{n} \left(x_t - \bar{x} \right)^2 / n \right]^{1/2}$$

[5] Adelman (1972) produced the first comprehensive study of the modern oil market, albeit just before OPEC took center stage. Important and more recent works include Adelman (1993, 1995, and 2002), Adelman and Watkins (2008), Bentzen (2007), Chapman and Khanna (2006), Chen and Chen (2007), Elekdag, et. al. (2008), Griffin and Xiong (1997), Hartschorn (1993), IEA (2005), Kaufman, et. al. (2004), Killian et. al. (2007), Nordhaus (2007), Parra (2004), Smith (2005), and Weiner (2006).

Intuitively, volatility represents the range of movement (percentage up or down) that could reasonably be expected to occur during the year. If we assume that returns follow a normal distribution, this can be made more precise: the chance of a fluctuation beyond one standard deviation (i.e., the stated volatility) over the course of a year is determined (from the z-table) to be roughly 1-in-3.

The volatility of crude oil prices is high: 31% when measured using annual returns over the "modern" era, 1974-2007.[6] Regnier (2007), who provides volatility estimates for many products, finds that oil is more volatile than 95% of all products sold in the U.S. Moreover, oil is more volatile now than before; having averaged only 20% during the previous century (1874-1973).[7] Natural gas—which is traded in separate markets not subject to manipulation by OPEC or fears of reaching peak production—exhibits even greater volatility than oil, 41% measured over the 1995-2008 interval.[8]

What creates high volatility, for both oil and gas, is the inelasticity of demand and supply, plus the substantial lead times required to efficiently alter the stock of fuel-consuming equipment, or to augment the productive capacity of oil and gas fields. Volatility provides incentives for holding large inventories, but since inventories are costly, they cannot fully offset the rigidity of demand and supply. Empirical estimates of the price elasticity of demand for crude oil vary by place, time, and statistical technique. Estimates of -0.05 (short-run) and -0.35 (long-run) are typical, with several years required to complete the adjustment to a permanent price change.[9]

---

[6] Author's calculation based on the annual oil price data in BP (2008).
[7] Author's calculation based on the annual oil price data in BP (2008).
[8] Author's calculation based on monthly Nymex futures prices, as reported by the U.S. Energy Information Administration. Oil and gas are not perfectly substitutable, and their prices are therefore imperfectly correlated. The simple correlation has averaged 85% since 1995.
[9] See, for example, Gately and Huntington (2002), Cooper (2003), and EIA (2003).

Income elasticities of demand for crude oil appear to vary significantly by level of income, with near proportional growth in oil demand in many developing countries ($\varepsilon_I \approx 1.00$), but much slower growth in the industrialized world ($\varepsilon_I \approx 0.50$).[10] It follows that future growth of demand for oil, and therefore the equilibrium price level, hinges on economic growth rates in China, India, etc.

It is more difficult to produce current and reliable estimates of the elasticity of crude oil supply, due in part to confounding effects of resource depletion and technical innovation, but there is consensus that the supply of conventional oil is inelastic. The U.S. Energy Information Administration uses elasticities of 0.02 (short-run) and 0.10 (long-run) for most regions in its international oil supply model.[11] At current price levels, unconventional oil resources are becoming an effective substitute for conventional oil, and therefore helping to make supply more elastic, at least in the long-run.[12]

Despite the rigidity and lags, there would be no volatility absent shocks to crude oil demand and supply. Shocks, which are indeed plentiful, trigger price adjustments that restore balance between supply and demand. Weather-related shocks affect demand and often disrupt supplies. Political disruptions, and threats (real or imagined) of military incursions and terrorist action also have an impact. These factors are compounded by the bumpy path of economic growth and occasionally by unexpected technical breakthroughs or breakdowns—which produce a continual series of price corrections that are magnified to the extent that both supply and demand are inelastic.

---

[10] Gately and Huntington (2002).
[11] Personal communication from George Butler, EIA, and Table Omsecon2.b04 of the EIA's International Energy Module documentation, National Energy Modelling System, 2003.
[12] Unconventional oil consists of alternative hydrocarbon resources (e.g., shale) that require different technologies for their exploitation).

Consider, for example, BP's forced closure (due to corrosion problems) of the Alaskan Prudhoe Bay field (the largest oil field in the United States), which unexpectedly removed 400,000 barrels per day (0.47%) of total world supply for an indefinite period in 2006. If the entire adjustment to restore equilibrium were to have come from the demand side, and given a short-run elasticity of -0.05, then the price would have jumped by some 9.4% (=-0.0047/0.05). In fact, the price rose by just 3% (from $74.78 to $77.05 per barrel) during the first trading session after the closure.[13] The difference confirms the importance of inventory adjustments and induced production increases elsewhere in offsetting the impact of supply disruptions.

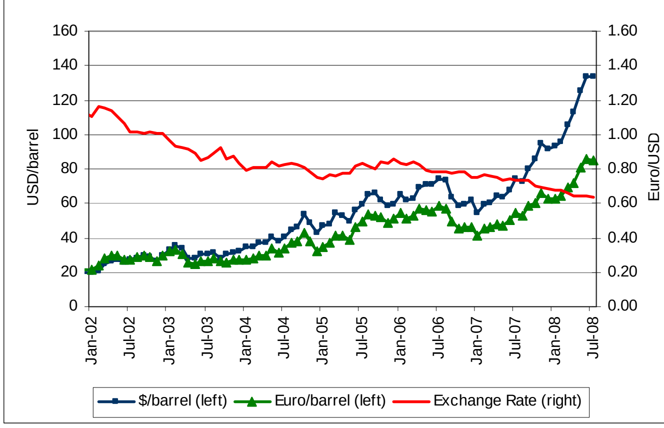
The demand for crude oil is a derived demand that stems from the demand for gasoline, jet fuel, heating oil, etc. The lack of good substitutes creates inelastic demand for motor fuels, and therefore contributes to the inelasticity of demand for crude oil. So too does the proclivity of many developing nations to subsidize the retail price of refined petroleum products. Millions of consumers in China, India, Thailand, Malaysia, Sri Lanka, Taiwan, Venezuela, etc. enjoyed subsidies which shielded them from part of the steep increase in the price of crude oil that occurred during 2006-2008.[14] The impact of price caps and subsidies is to reduce the elasticity of demand for crude oil. Ironically, large excise taxes levied on consumption of refined products in Europe and elsewhere have much the same effect: the pass-through of increased crude oil cost is dampened in percentage terms by the presence of the tax, and the elasticity of demand for crude oil is reduced—at least if the tax remains fixed. The demand response would be diminished further if proposals (floated during the recent U.S. Presidential campaign) to reduce

[13] The closure was announced early on Monday, August 7. We compute the impact using spot prices of WTI on Friday, August 4 and Monday, August 7, as reported by the EIA.
[14] *The Economist* (2008a).

motor fuel taxes to relieve consumers of the burden created by higher crude oil costs were adopted.

Because crude oil is priced in US dollars, a weaker dollar makes oil cheaper for most of the world's consumers. If care is not taken with the data, currency fluctuations may obscure the true elasticity of demand, especially when exchange rates move with the price of oil, as they have done lately (see Figure 3). Consider, for example, that the price of oil rose by 11% in dollar terms (from $64.99 to 72.36) between August 2005 and August 2007. However, because the Euro rose in value over this period (from $1.2195 to $1.3682), the effective price of oil to European consumers actually *fell* by 1% (from €53.29 to €52.89).[15] Likewise, when the dollar price of oil fell 22% from its peak between July 3 and August 15, 2008, the value of the Euro also fell (from $1.5708 to $1.4695), so the effective price reduction was only 17% from the European perspective. In recently years, currency fluctuations have dampened oil price movements for most consumers outside the U.S. Their muted reaction to changes in the quoted price of oil does not mean they are less sensitive to changes in the price of oil.

Figure 3: A Weaker Dollar Cushions the Rise in Oil (monthly data)



[15] These are spot prices for WTI, as reported by the EIA. Exchange rate are from the US Federal Reserve Board of Governors historical data base.

OPEC

It is impossible to discuss the world oil market without mentioning the influence of OPEC, a cartel that includes eleven of the fifteen largest oil-exporting countries in the world.[16] This cartel, which controls 70% of global oil reserves, is actively managed by its members who meet regularly to "coordinate their oil production policies in order to help stabilize the oil market and to help oil producers achieve a reasonable rate of return on their investments."[17] In other words, OPEC's goal is to set the price.[18]

Because much has been written elsewhere about OPEC, we restrict our focus to the two major pieces of OPEC's strategy for "stabilizing" prices: (1) shutting in existing production capacity, and (2) limiting the growth of new capacity. OPEC has mostly failed at the former, but succeeded at the latter. Perhaps surprisingly, consumers have suffered from OPEC's failure as well as its success. Mismanagement of shut-in capacity has contributed significantly to the volatility of prices, as in 1997 when OPEC famously mistimed quota adjustments just before the Asian financial crisis. Limiting the growth of new capacity, on the other hand, has definitely driven up the average price level. OPEC has created both instability and higher prices.

At first glance, OPEC's track record for withholding production appears successful (see Figure 4). After gaining control of production in 1973, OPEC recorded a quick success by threatening an embargo and cutting output. Shut-in capacity nearly

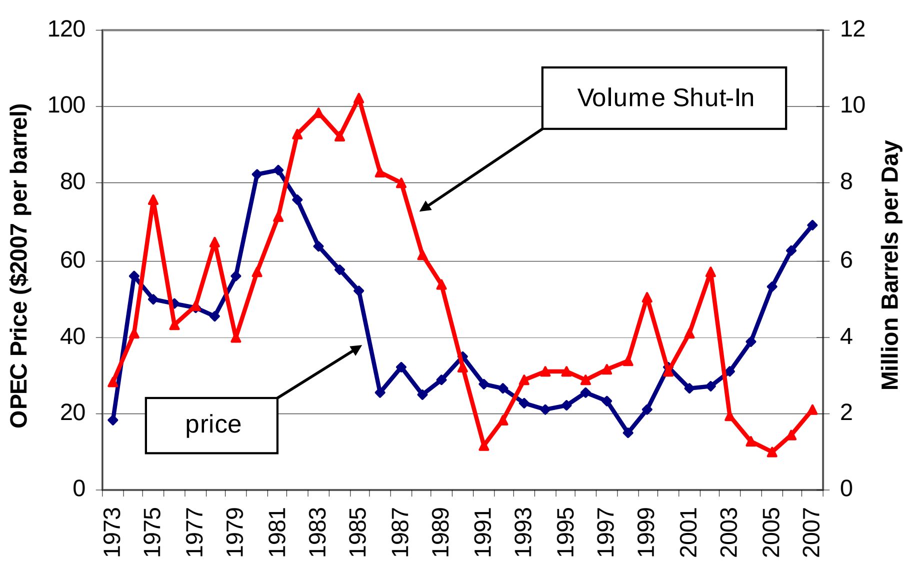
[16] These eleven include (listed by decreasing export volume): Saudi Arabia, UAE, Iran, Kuwait, Venezuela, Nigeria, Algeria, Libya, Iraq, Angola, and Qatar. Export volumes (2006) are from the EIA database: http://tonto.eia.doe.gov/country/index.cfm. OPEC's twelfth member, Ecuador, produces and exports relatively little crude oil. Indonesia, formerly a prominent member of OPEC, announced its intention to suspend membership during 2008 since its production has declined and it is no longer a net exporter of oil.

[17] For more of OPEC's own statement of intents and purposes, see http://www.opec.org/aboutus/.

[18] Smith (2005) showed that monthly output changes by OPEC members are synchronized to an extent that is inconsistent with non-collusive behavior.

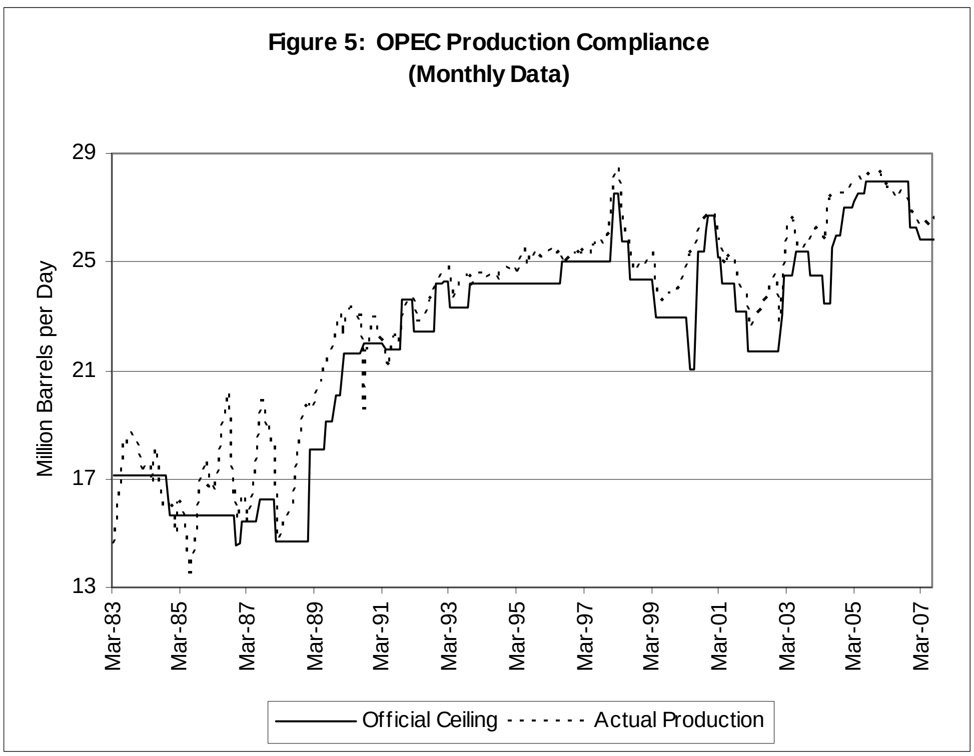
tripled between 1973 and 1975—and the real price of oil nearly tripled as well.[19] That action was not sustained, however, and prices began to retreat. Since that early episode, there has been no comparable demonstration of OPEC's ability to hold production off the market. The period from 1979 to 1983 (the only other time that prices and shut-in capacity both rose sharply) might seem to qualify, but those events were not the purposeful result of OPEC's strategy. Rather, they were caused by the Iranian revolution and the outbreak of war between Iran and Iraq, which disrupted operations and kept nearly 6 mmb/d off the market.[20] Readers with a sense of history will recognize that much of the cartel's "shut-in capacity" has resulted involuntarily from extraneous developments. One does not refer to war, international sanctions, labor strife, or sabotage as serendipitous events—but these have all delivered important, unsought benefits to OPEC.

Figure 4: OPEC: Shut-In Capacity



[19] Estimated excess production capacity of OPEC members is available from EIA (2008b, Table 3c).
[20] War-related disruptions shut in roughly 15% of OPEC's production capacity.

OPEC's struggle with excess production capacity is reflected in the members' lack of compliance with assigned production quotas, which is consistent with economists' understanding of the free-rider problem. Since the quota system was adopted in 1983, total OPEC production has exceeded the ceiling by 4% on average, but on numerous occasions the excess has run to 15% or more (see Figure 5).[21] In general, full compliance has been achieved only during episodes, like the present, when members have not had enough installed capacity to exceed their quotas; i.e., when it has been physically impossible to cheat on their production limits.



Price-fixing, according to Professor Adelman, is like singing and mountain climbing: easier to go up than come down."[22] OPEC has learned this lesson the hard

[21] Quota data are from OPEC (2008a). Actual production figures are from EIA (2008a). In both cases, volumes of lease condensate and natural gas liquids, which are produced in conjunction with oil but not subject to the quotas, have been excluded.
[22] Adelman (2002, p. 187).

way and therefore adopted a conservative approach towards formation of new capacity, knowing that once it is built it is likely to used, whether or not to the cartel's advantage. Better that demand outrun supply than supply outrun demand because the latter exposes OPEC's weakness: managing excess capacity.

OPEC's crude oil production capacity (33 mmb/d) is virtually unchanged from 1973, although the volume of proved reserves (i.e., known deposits that could have been tapped to expand capacity) doubled over that span.[23] OPEC's installed capacity is sufficient to extract just 1.5% of its proved reserves per year, which is another way of measuring the low intensity of development. On the other hand, non-OPEC producers, working mostly in less prolific and more expensive petroleum provinces, have increased their production capacity by 69% since 1973, and installed sufficient facilities to extract 5.6% of their proved reserves each year.[24] OPEC accounted for only 10% of the petroleum industry's upstream capital investment during the past decade, although it produced nearly half of global output.[25] By holding back, OPEC has effectively allowed secular growth in demand to absorb and eliminate its surplus capacity, although ceding market share to non-OPEC producers in the process. It appears that the risk of expanding low-cost capacity within OPEC exceeded the perceived harm from expansion of high-cost capacity outside the cartel.

OPEC has recently initiated numerous projects to tap their under-developed reserves and finally expand capacity. $40 billion per year is budgeted for this going

---

[23] Production capacity data are estimates from EIA. Proved reserves are from BP (2008).
[24] BP (2008). To ensure comparability with OPEC's conventional crude oil reserves, we have excluded Canadian tar sands reserves from this calculation.
[25] Investment figures are OPEC estimates, reported by Sandrea (2006). Production share is based on BP (2008).

forward.[26] The significance of that effort, however, can only be seen in perspective. In 2007, the five largest international oil companies (the super-majors), who collectively own just 3% of global oil reserves, spent about $75 billion to develop new production capacity.[27] OPEC, with about twenty times the reserves, spends only about half as much in absolute terms. OPEC restraint is also reflected in the upstream plowback rate: in 2007, the super-majors reinvested 25% of their *gross production revenues* to expand capacity, whereas OPEC members are investing only about 6% of their *net export revenues* on such projects.[28]

The Equilibrium Price of Oil

Various models of the world oil market have been advanced in the attempt to identify the equilibrium price of oil.[29] They tend to have complex structures that are disaggregated by geographic region, industrial sector, and they usually incorporate various hypotheses regarding the behavior of OPEC members. A basic insight can be obtained with less complication from a very simple model that regards Saudi Arabia as a Stackelberg leader—a producer who anticipates the reaction of consumers and all other (price-taking) producers, and who sets its own output (and price) accordingly. In such a model, the residual demand for Saudi oil is given by:

$$Q_{SA}^{D}(P) = Q_{W}^{D}(P) - Q_{ROW}^{S}(P)$$

where superscripts designate demand and supply and subscripts denote the disaggregation

[26] $160 billion is expected to be spent on upstream projects within OPEC between 2008 and 2012, according to OPEC (2008b, p. 5).
[27] Investment expenditures as reported in corporate annual reports.
[28] Gross production revenue as reported in corporate annual reports. OPEC members export three-fourths of their gross crude oil production. The U.S. EIA estimates OPEC net oil export revenues on a monthly basis (http://www.eia.doe.gov/emeu/cabs/OPEC_Revenues/Factsheet.html).
[29] For example, Eckbo (1976), Horn (2004), Gately (2007), and Al-Qahtani, et. al. (2008).

of world (W) demand into the portion available to Saudi Arabia (SA) after allowing for oil produced by the rest of the world (ROW). After differentiating with respect to price (P) and some manipulation, we can infer the elasticity of demand for Saudi crude oil:

$$\varepsilon_{SA}^{D} = \frac{\varepsilon_{W}^{D}}{\sigma} - \frac{\varepsilon_{ROW}^{S} \times (1-\sigma)}{\sigma},$$

where σ represents Saudi market share. If the Saudis are maximizing profits, we expect $MR_{SA} = MC_{SA}$, but since $MR = P(1+1/\varepsilon)$, the marginal cost of Saudi production would then be $P(1+1/\varepsilon_{SA}^{D})$.

Using the estimated parameter values introduced earlier (and subject to the many oversimplifications of this model), we can test whether the current price of $115 per barrel (as this is being written) satisfies the requirements for equilibrium. We let $\varepsilon_{W}^{D} = -0.35$, $\varepsilon_{ROW}^{S} = +0.10$, and $\sigma = 12\%$ (which is the Saudis' current market share). Thus, $\varepsilon_{SA}^{D} = -3.65$, and since P = $115 we have MR_{SA} = $83.49 per barrel. The International Energy Agency (and most other analysts) estimate the marginal cost of Saudi oil to be much lower, in the range of $5 to $15 per barrel,[30] which implies that the Saudis would benefit by reducing price and increasing production. Reduce price by how much? Our simplified model does not provide an answer, but Al-Qhatani, et. al. (2008) have built a more detailed and realistic model of this type, using data provided by Aramco (the Saudi national oil company) and other sources, and found the optimal Saudi price under a range of assumptions regarding market structure to be $40 per barrel or less.[31]

[30] IEA (2005), Adelman and Watkins (2008).

[31] The calculations of Al-Qhatani, et. al. are calibrated to 2004 data. Subsequent changes in costs and capacities would cause the results to vary, but not in dramatic fashion.

What this type of static, one-period analysis leaves out is the impact of depletion on future production and profits. Because Saudi oil reserves are limited, what is produced today cannot be produced tomorrow. Thus, to maximize the present value of the profit stream, it is necessary to schedule production such that the present value of marginal revenue from current and future outputs are the same.

If we assume the relevant discount rate is 10%, we can test the price by comparing production twenty years ahead with production today.[32] Marginal revenue today is $83.49, so if it does not rise to at least $561.70 in twenty years time,[33] the Saudis would profit by shifting production to the present. Since $MR \leq P$ (always), this means current Saudi production could only be optimal (in the profit-maximizing sense) if the real price of oil were also expected to reach at least $561.70 per barrel within twenty years. Given the wide array of alternative energy resources available at substantially lower cost, this seems doubtful.[34]

This simple exercise strongly suggests that oil is overpriced at present, at least from the Saudi perspective. Put differently, at this price level, the Saudis will run out of customers before they run out of oil. By reducing price, they can avoid this. Although our analysis is oversimplified, more detailed and realistic analyses of the inter-temporal optimization problem facing Saudi Arabia come to essentially the same conclusion. See, for example, Horn (2004) and Gately (2007).

Readers may ask where burgeoning Chinese demand for oil fits into this picture. The quick answer is to say that many alternative energy sources will be made available at

[32] Adelman (1993, p. 461) estimates the real discount rate of OPEC producers to be even higher than 10%, which strengthens our argument.
[33] $\$561.70 = 83.49 \times 1.10^{20}$
[34] IEA (2005, Figure ES-1, p. 17), and Aguilera, et. al. (2008).

costs below the equivalent of \$561 per barrel to satisfy that demand—and that the high price of oil will itself cool the torrid pace of growth. There is something to be learned, however, by considering in more detail the economic process by which a free market manages the depletion of a fixed resource against growing demand. This type of question was first considered by Hotelling (1931), but for ease of exposition we present a simplified version of Hotelling's analysis, as formulated by Herfindahl (1967).

There are two conditions that an inter-temporal equilibrium must meet. First, total consumption must not exceed the fixed amount of supply. Second, the net price of the resource ("mineral rent") must grow at the risk-adjusted discount rate, else there would be incentives for producers to reschedule production:

$$\sum_{t=0}^{T} Q_t^D(P_t) = \bar{S}$$

$$P_{t+1} - C = (1+r)\times(P_t - C) \quad \textit{for } t = 0, \ldots, T-1;$$

where $Q_t^D(P)$ is demand in period *t*, $\bar{S}$ the fixed amount of supply, C the (constant) cost of production, *r* the discount rate, and *T* represents the date at which the fixed supply will be exhausted.[35] If there is an alternative ("backstop") resource that provides the same services, but available in unlimited quantities at higher cost, B, then the market price must reach that level at the moment of exhaustion: $P_T = B$.

Once the form of the demand function is specified, the equilibrium can be solved numerically with nothing more than a spreadsheet. We assume a fixed elasticity and constant growth over time:

[35] Since the cost is constant through time, it is implied that the forces of depletion and technical progress negate each other. The model can be enriched, but this simple form serves our purpose well enough.

$$Q_t^D(P) \quad = \quad K \times P_t^{\varepsilon} \times (1+g)^t ,$$

where K is a scaling factor. To illustrate the impact of underlying economic parameters on depletion and prices, we specify three scenarios, as outlined in Table 1. The "Base Case" is calibrated to resemble, at least in broad outline, the world oil market as of year 2004. The elasticity and growth rate of oil demand are similar to the historical rate for OECD countries. The cost of the resource is $20 per unit, and if priced at cost, calculated demand shows there would be enough supply to last for twenty-three years.

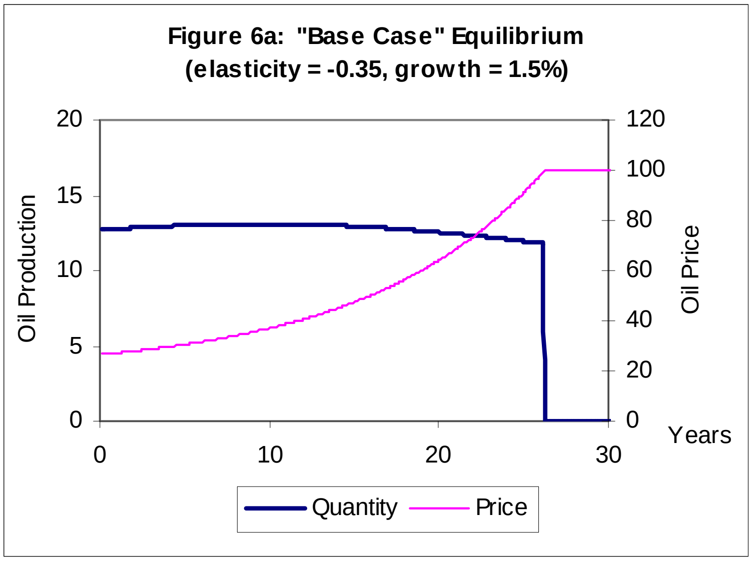
Table 1: Economic Scenarios

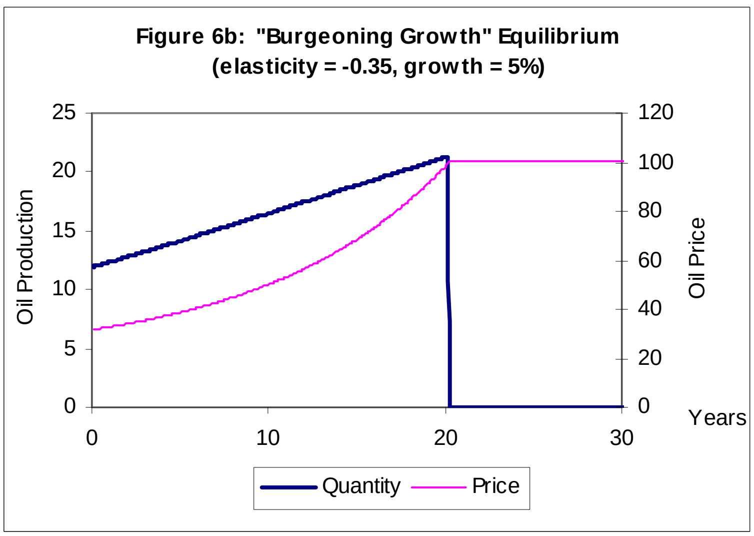
Parameter	Base Case	Burgeoning Growth	Resource Disappointment	High Growth	Low Growth
Supply	400	400	300	400	400
Elasticity of Demand	-0.35	-0.35	-0.35	-0.35	-0.35
Growth Rate	1.50%	5.00%	1.50%	2.75%	0.50%
Cost	20	20	20	20	20
Discount Rate	10%	10%	10%	10%	10%
Demand Intercept	20	20	20	20	20
Backstop Cost	$100	$100	$100	$100	$100

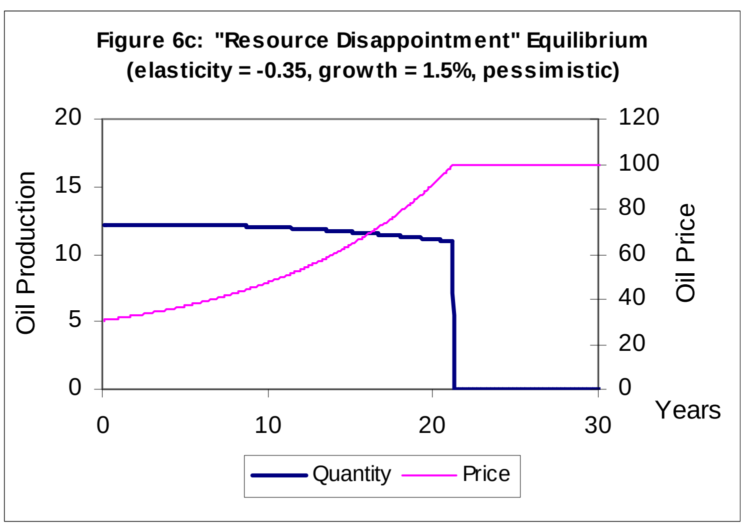
Because of depletion, however, the market would not price this resource at cost. The equilibrium price trajectory starts at $26.61 and rises to $100 (the backstop level) over a period of roughly twenty-seven years, as shown in Figure 6a. Production slowly rises, then falls until the resource is finally exhausted and replaced by the backstop.

The second scenario ("Burgeoning Growth") allows us to gauge the market's reaction to a sudden change in the expected growth in demand. Compared to the Base Case, the only difference is that the economic growth rate is summarily increased to 5%, which is roughly the rate of growth in demand for oil from the developing nations outside OECD. If at time zero (let it be 2004), the old growth outlook were replaced with this new information, the market would adjust to ensure that exhaustion does not occur before

Figure 6: The Price Impact of Demand/Supply Surprises







the backstop has become economical. Despite this sudden surge in anticipated growth, however, the initial price (in 2004) rises only modestly (see Figure 6b), from $26.61 to $31.71 (19%). Something more than the sudden realization of Chinese growth prospects, something quite extraordinary in fact, would be required to produce a doubling or tripling of the initial price under these presumed parameters.

Might that extraordinary factor lie on the supply side? Since certain observers have recently contended that a portion of Saudi Arabia's reported oil reserves are illusory,[36] we must consider that possibility. The third scenario ("Resource Disappointment") is provided to gauge the market impact of the sudden loss of a substantial portion of perceived supply—one-fourth of the entire remaining resource base in this case. How would the market react to such news? As in the case of a sudden perceived change in demand, the market reaction to the disappearance of reserves is modest (see Figure 6c), prices rising by only 15% (from $26.61 to $30.64).

Although our model of equilibrium price adjustments is highly stylized, it reveals something very genuine about the market process: adjustments to new information are spread across time, rather than being concentrated at the moment of "Eureka!" Immediate and dramatic change is costly, costlier in fact than pushing off to the future much of the adjustment that will eventually be required. We are therefore left in search of a different explanation for what has occurred lately in the world oil market.

The Portents of Peak Oil

In 1956, M. King Hubbert advanced a novel approach to forecast the date at which oil production would enter an inexorable decline. The method is based on the

[36] See Simmons (2005) for a pessimistic view of Saudi Arabian reserves that has triggered much debate. The main issues in dispute are summarized by King (2008).

logistic curve. Many economists are familiar with the use of logistic curves to model the impact of prices and other incentives on consumer choice. Hubbert's idea was that, in the case of oil production, prices and other incentives were superfluous; it was all a matter of time. The resulting model of production behaves like a ballistic missile, first rising, then falling of its own accord. The method is entirely empirical, with no theoretical grounding in either geology, engineering, or economics. Hubbert himself refereed to the technique as an "extrapolation."[37]

The so-called "Hubbert curve" might have been forgotten altogether but for the fact that Hubbert's 1956 prediction (reproduced here as Figure 7) that U.S. oil production would peak around 1970 was famously borne out. It should also be noted (but usually is not) that the predicted volume of oil to be produced at the peak was 37% too low, and that Hubbert's predictions regarding coal and natural gas ran badly amiss.[38] Extensive

Figure 7: Hubbert's Curve

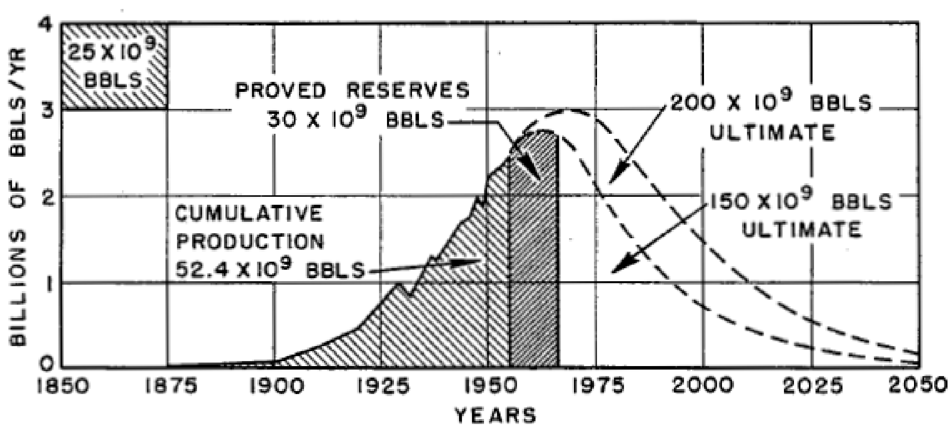


Figure 21 – Ultimate United States crude-oil production based on assumed initial reserves of 150 and 200 billion barrels.

[37] Hubbert (1956, p. 21).

[38] Hubbert predicted that U.S. oil production would peak at 3 billion barrels per year; actual production in 1970 was 4.1 billion barrels. Hubbert predicted that U.S. gas production would peak at 14 trillion cubic feet per year in 1973; actual production was 20 trillion cubic feet in 2007. Hubbert predicted that global coal production will peak in 2150 at about 6.4 billion metric tonnes; actual production reached that level in 2007 and is still growing rapidly. Actual production data are from the EIA.

testing by Brandt (2007) and Nehring (2007a-c), who applied this technique to many petroleum basins around the world, indicates that the Hubbert curve is a very poor predictor of the time shape of petroleum extraction, that it finds peaks that do not exist, and misses peaks that do.

Despite its poor track record in predicting actual behavior, the Hubbert curve has become influential in certain quarters, and is now widely applied to predict that global oil production will soon peak (with cataclysmic effects according to some analysts) if corrective actions are not taken. Consider, for example, this warning from the introduction to the well known "Hirsch Report," a study of peak oil commissioned by the U.S. Department of Energy:[39]

> "The peaking of world oil production presents the U.S. and the world with an unprecedented risk management problem. As peaking is approached, liquid fuel prices and price volatility will increase dramatically, and, without timely mitigation, the economic, social, and political costs will be unprecedented."

Even if one does believe that oil production will peak in a given year, it is quite another thing to assume that catastrophic effects will necessarily follow. The timing of the peak and the nature of its aftermath are not pre-determined by geology; they are endogenous manifestations of the inter-temporal allocation of resources as determined by market forces. We demonstrate below that peaking may signal either scarcity or relative surplus, rapidly rising prices or constant prices, the near termination of production or its mere beginning. In other words, the phenomenon of peaking in a market-based economy is an ambiguous indicator of anything of fundamental importance to the economy. Therefore, efforts to date the peak should be of little interest to policymakers or the

---

[39] Hirsch, et. al. (2005, p. 4).

public debate. On the other hand, shouting "fire" in a crowded theater has predictable results, whether or not fire exists—so economists can hardly afford to ignore the fuss.

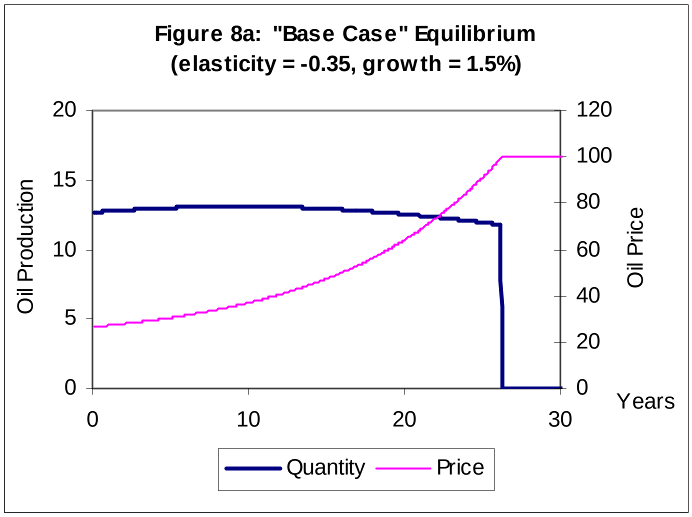
Therefore, we revisit the economic model of equilibrium depletion considered in the previous section. Beside the Base Case scenario, we now place two more: High Growth and Low Growth, which differ only with respect to the underlying rate of economic growth (see Table 1). Although the change in "fundamentals" is quite small—well within the range of recent experience—the implications of peak oil change profoundly. In the Base Case, where income grows at 1.5% annually, the peak arrives once 36% of the resource has been extracted, leaving 64% available to sustain future growth (see Figure 8a). Beyond the peak, prices rise moderately. Subject to "High Growth," where income grows at 2.75%, the peak is delayed entirely—production collapses at the very end (Figure 8b). This result is not due to oversight and does not signal a problem. It is, rather, the market's determination of the extraction path that maximizes social welfare.[40] And with arrival of the peak in the High Growth scenario, prices *cease their ascent*. Compare that to the "Low Growth" scenario, where income grows at 0.5%, in which case the peak arrives *immediately* and production is all downhill (Figure 8c). In that case, 100% of the resource remains to be exploited after the peak arrives.

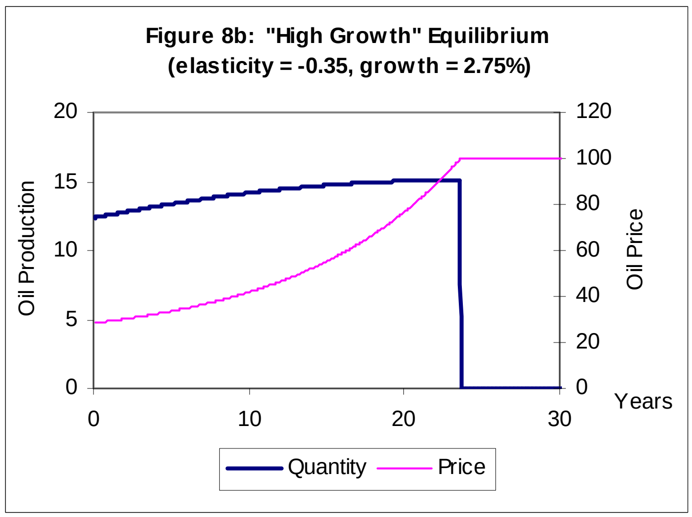
The purpose of these simple exercises is not to predict the future, but to place the discussion of peak oil in the context of a market economy where it belongs. Admittedly, the model is rudimentary and quite mechanistic; the price elasticity of demand is the only parameter that moderates the rate of depletion. But this limitation means that a more

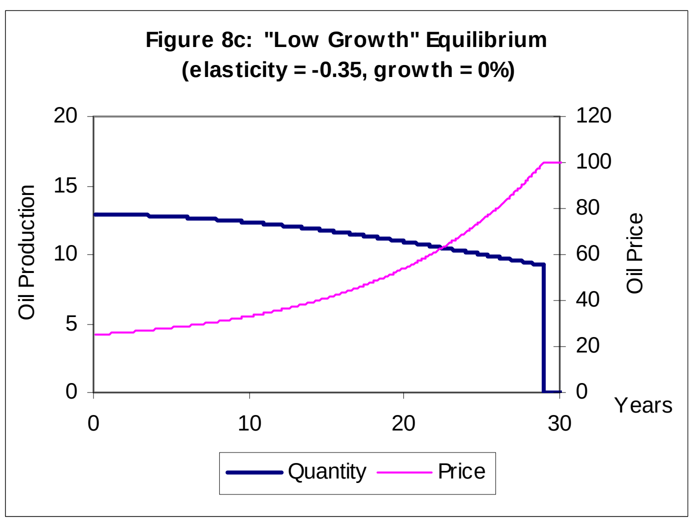
---

[40] Our focus here is on the impact of resource depletion, therefore we ignore the possibility that externalities or other forms of market failure could warrant government intervention.

Figure 8: Predicted Onset and Aftermath of "Peak" Production



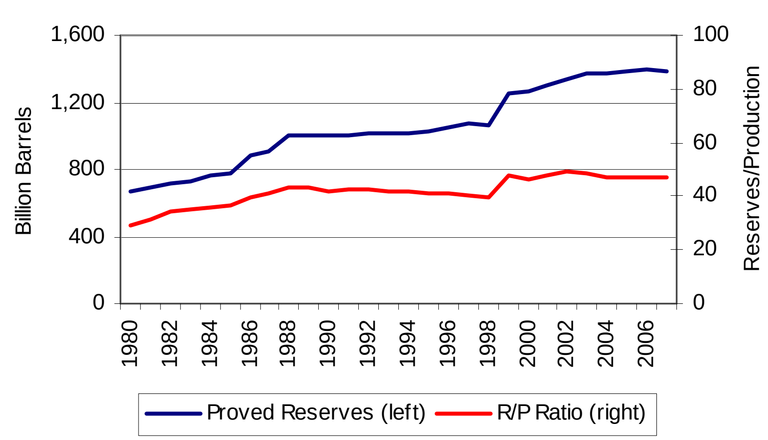




realistic analysis that includes such factors as (a) feedbacks from price to exploration and discovery of new deposits, (b) technical innovation, (c) endogenously determined economic growth rates, and/or (d) incentives for developing unconventional substitutes for crude oil will only guarantee that the ambiguity of the peaking phenomenon is so much the worse. The tournament among analysts who attempt to date the peak has provided some amusing results, but it is a sideshow, not the main event.

The crucial fact is that while oil is constantly being "used up" the world is not "running out" of oil. Indeed, Adelman and Watkins (2008) make a strong case that the depletable resource paradigm is not empirically relevant. Since its inception, the oil industry has endeavored to replace every barrel extracted from the earth by investing in new projects to find and develop additional resources, so far with great success. Despite our having consumed almost 700 billion barrels of crude oil during the past quarter-century, the volume of remaining proved reserves available to support future production has doubled since 1980 and now stands at an all-time high (see Figure 9). The stock of proved reserves has grown even faster than production, which means that the "reserves to production ratio" has grown, and that we now extract a smaller fraction of remaining

Figure 9: Global Proved Reserves of Crude Oil



reserves each year than previously. The implication is undeniable: increasing physical scarcity, the currency of the peak oil club, can not have triggered oil's recent ascent.

Spikes and Speculators

Soaring prices have triggered drastic proposals to curb speculative trading in the oil markets. Various restrictions have been proposed by elected officials, who may be seeking political cover rather than substantive change, but similar ideas have bubbled up from more surprising quarters—including industry insiders.[41] Before settling on a particular solution to the problem of speculation, however, we should examine two central questions: What should be the role of speculators in a market economy? What has been the impact of speculators in the oil market?

Most economists regard the first question as being fairly easy. Ordinarily, freedom to speculate (i.e., to buy or sell an asset because its price is expected to change) is fundamental to the efficient operation and stability of markets. Limiting speculation impairs the flow of information needed to maintain equilibrium and achieve allocative efficiency. Markets that are subject to the greatest fundamental volatility in supply and demand stand to benefit *most* from the activities of speculators. Speculation is not price manipulation, but is sometimes used to exploit efforts to manipulate prices by other means. In such cases, it is the manipulation of prices that is objectionable (and usually illegal), not speculation, per se.

The second question is difficult because it is impossible to actually measure the extent of speculation. Most analyses focus on the futures market and distinguish

[41] See, for example, Talley and Meyer (2008).

"commercial" and "non-commercial" traders.[42] Commercial traders are companies whose business is naturally exposed to the risk of oil price fluctuations, like oil producers, refiners, the airlines, etc. These companies can hedge their risks by taking certain positions in the futures market, which stabilizes cash flow and does not constitute speculation. On the other hand, non-commercial traders (e.g., banks, pensions, and hedge funds) are companies who lack natural exposure to oil price movements, have no incentive to hedge, and whose positions should be counted as speculation. In theory.

In practice, many commercial traders speculate (which has spawned the term "hedgulator") and many non-commercial traders hedge.[43] Simply counting the volume of open interest held by each category reveals very little about the extent of "speculation."

The problem goes deeper, of course, because what reformers really want to identify (and eliminate) is "destabilizing speculation," which refers to speculators who buy (or sell) when the price is already too high (or low). The impracticality of this "reform" is revealed by the fact that, for every transaction involving a destabilizing speculator, there must be either a hedger or a stabilizing speculator on the other side. By construction, the two are always equal. To eliminate destabilizing speculation would require eliminating intermediaries, hedgers, and the futures market altogether.

Is it possible that price fixing, rather than speculation per se, has elevated oil prices to unprecedented levels? With respect to OPEC, this has already been answered: OPEC does engage in price fixing. Oil prices would be lower today if OPEC had not

---

[42] See, for example, US CFTC (2008).

[43] Commercial traders tend to speculate, rather than hedge, when they hold particularly strong views about future market movements. Many non-commercial traders are financial intermediaries who provide risk management services to commercial traders. By so doing, the intermediaries acquire natural exposure to price risk, some of which may be laid off by hedging in the futures market. Other intermediaries are categorized as non-commercial traders even though they have acquired substantial petroleum operations of their own. See Davis (2008).

previously restricted investment in new capacity. On the other hand, major OPEC producers, like Saudi Arabia, must by now feel that prices have gotten too high—placing future demand for their long-lived deposits in jeopardy.[44]

In fact, there is no evidence of price fixing on the part of anyone else, which includes both speculators and the "super-major" oil companies. It would be a daunting proposition to fix the price of the single largest commodity in world trade, something a cartel might attempt if it controlled 70% of world reserves, but not something that small fry could achieve. Relative to the size of the world oil market, hedge funds and the "super-major" oil companies are indeed small fry. To succeed at price fixing, one of two things would be required: (1) accumulating large private inventories that are diverted from the commercial supply chain; or (2) shutting in a significant portion of global oil production. Neither phenomenon has been observed.[45]

Conclusion

Although we argue that the world oil market operates subject to the familiar laws of supply and demand and is therefore amenable to economic analysis, we can not say what will come next. The fundamental determinants of price will continue to be highly volatile, and demand and supply will remain inelastic. The range of plausible prices is therefore broad, especially in the short-run.

Having declined to make a specific prediction, however, we would not rule out the possibility that soaring oil prices were triggered by an unwarranted perception of scarcity, and possibly accelerated by elastic expectations and overtrading in the manner

[44] For a discussion of Saudi concern over high prices, see Mouawad (2008) and *The Economist* (2008b).
[45] Commercial stocks of petroleum in the U.S. and OECD were essentially unchanged between 2003 and 2008, while global oil production increased. Source: EIA *Short Term Energy Outlook*, August 2008, Table 3a.

of many previous commodity bubbles. Although it is to be hoped that freely functioning markets would never exhibit such instability, it is not an uncommon result—as Charles Kindleberger's survey of historical manias amply demonstrates.[46]

Explanations for bubbles may range from animal spirits and herd mentality to more rational factors like differential information.[47] In the particular case of a depletable resource, however, there is a specific dynamic to the equilibrium that might threaten stability, as Robert Solow pointed out in his 1974 Presidential Address to the AEA.[48] Inter-temporal allocation imposes two conditions (stock and flow) on the equilibrium: (1) the net price must rise at the rate of interest, and (2) the price level must be just high enough to extinguish demand when the resource is finally exhausted. If for any reason the price begins to rise too rapidly, and producers extrapolate that to the future, they may be tempted by capital gains to shut-in production and withhold current supply. That reaction would create additional upward pressure on the current price and push the market farther away from equilibrium. Concrete evidence of the glut that would inevitably result arrives only in the long run. In the short run elastic expectations could produce a bubble.

Even if this view of the market is correct, which seems likely, we still lack a definite answer to the inevitable question: "what next?" As Professor Kindleberger would remind us: "The period of distress may be drawn out over weeks, months, even years, or it may be concentrated into a few days."[49] In other words: some bubbles pop, but others just peter out.

---

[46] Kindleberger (2000).
[47] See Blanchard and Watson (1982), who discuss the scope for "rational bubbles."
[48] Solow (1974, pp. 6-7).
[49] Kindleberger (2000, p. 91).

Bibliography

Adelman, M.A. 1972. *The World Petroleum Market.* Baltimore: Johns Hopkins University Press.

Adelman, M.A. 1993. *The Economics of Petroleum Supply*. Cambridge: The MIT Press.

Adelman, M.A. 1995. *The Genie out of the Bottle*. Cambridge: The MIT Press.

Adelman, M.A. 2002. "World Oil Production and Prices: 1947-2000." *Quarterly Review of Economics and Finance*, 42(2): 169-191.

Adelman, M.A., and G. Campbell Watkins. 2008. "Reserve Prices and Mineral Resource Theory." *The Energy Journal*, Special Issue to Acknowledge the Contribution of Campbell Watkins to Energy Economics, 1-16.

Aguilera, Roberto F., Roderick. G. Eggert, C. C. Gustavo Lagos, and John. E. Tilton. Forthcoming. "Depletion and the Future Availability of Petroleum Resources." *The Energy Journal.*

Al-Qahtani, Ayed, Edward Balistreri and Carol Dahl. 2008. "A Model for the Global Oil Market: Optimal Oil Production Levels for Saudi Arabia." Paper presented at the IAEE Annual Conference, Istanbul.

Blanchard, Olivier and Mark W. Watson. 1982. "Bubbles, Rational Expectations and Financial Markets." In *Crises in the Economic and Financial Structure*, ed. Paul Wachtel, 295-315. Lexington: D.C. Heath.

Bentzen, Jan. 2007. "Does OPEC Influence Crude Oil Prices? Testing for Co-movements and Causality Between Regional Crude Oil Prices." *Applied Economics*, 39(11): 1375-85.

BP, p.l.c. 2008. *BP Statistical Review of World Energy.*

Brandt, Adam R. 2007. "Testing Hubbert." *Energy Policy*, 35(5): 3074-3088.

Chapman, Duane, and Neha Khanna. 2006. "The Persian Gulf, Global Oil Resources, and International Security." *Contemporary Economic Policy*, 24(4): 507-519.

Chen, Shui-Sheng, and Hung-Chyn Chen. 2007. "Oil Prices and Real Exchange Rates." *Energy Economics*, 29(3): 390-404.

Cooper, John. 2003. "Price Elasticity of Demand for Crude Oil: Estimates for 23 Countries." *OPEC Review,* 27: 1-8.

Davis, Ann. 2008. "Speculator' in Oil Market is Key Player in Real Sector." *Wall Street Journal.* August 20, C1.

Eckbo, Paul. 1976. *The Future of World Oil*. Cambridge, MA: Ballinger.

Elekdag, Selim, Rene Lalonde, Douglas Laxton, Dirk Muir, and Paolo Pesenti. 2008. "Oil Price Movements and the Global Economy: A Model-Based Assessment." *IMF Staff Papers,* 55(2): 297-311.

Gately, Dermot. 2007. "What Export Levels Should We Expect from OPEC?" *The Energy Journal*, 28(2): 151-174.

Gately, Dermot, and Hillard Huntington. 2002. "The Asymmetric Effects of Changes in Price and Income on Energy and Oil Demand." *The Energy Journal*, 23(1): 19-37.

Griffin, James, and Weiwen Xiong. 1997. "The Incentive to Cheat: An Empirical Analysis of OPEC." *Journal of Law and Economics*, 40(2): 289-316.

Hartshorn, Jack E. 1993. *Oil Trade: Politics and Prospects.* Melbourne: Cambridge University Press.

Herfindahl, Orris C. 1967. "Depletion and Economic Theory." In *Extractive Resources and Taxation,* ed. Mason Gaffney, 63-90. Madison: University of Wisconsin Press.

Hirsch, Robert L., Roger Bezdek, and Robert Wendling. 2005. "Peaking of World Oil Production: Impacts, Mitigation, & Risk Management." Report presented to the U. S. Department of Energy, Washington, DC.

Horn, Manfred. 2004. "OPEC's Optimal Crude Oil Price." *Energy Policy*, 32(2), 269-280.

Hotelling, Harold. 1931. "The Economics of Exhaustible Resources." *Journal of Political Economy*, 39(2): 137-175.

M. K. Hubbert, M. King. 1956. "Nuclear Energy and the Fossil Fuels." Shell Development Company Exploration and Research Division, Publication 95.

International Energy Agency. 2005. *Resources to Reserves: Oil & Gas Technologies for the Energy Markets of the Future*, Paris: IEA.

Kaufmann, Robert K., Stephane Dees, Pavlos Karadeloglou, and Marcelo Sanchez. 2004. "Does OPEC Matter? An Econometric Analysis of Oil Prices." *The Energy Journal* 25(4): 67-90.

Killian, Lutz, Alessandro Rebucci, and Nikola Spatafora. 2007. "Oil Shocks and External Balances," International Monetary Fund Working Paper 07-110.

Kindleberger, Charles P. 2000. *Manias, Panics, and Crashes: A History of Financial Crises*. New York: Wiley.

King, Neil Jr. 2008. "Global Oil-Supply Worries Fuel Debate in Saudi Arabia." *Wall Street Journal.* June 27, p. A1.

Mouawad, Jad. 2008. "Plan Would Lift Saudi Oil Output to Highest Ever." *The New York Times.* June 14, p. A1.

Nehring, Richard. 2006. "Two Basins Show Hubbert's Method Underestimates Future Oil Production." *Oil and Gas Journal*, 104(13): 37-44.

Nehring, Richard. 2006. "How Hubbert Method Fails to Predict Oil Production in the Permian Basin." *Oil and Gas Journal*, 104(15): 30-35.

Nehring, Richard. 2006. "Post-Hubbert Challenge is to Find New Methods to Predict Production, EUR." *Oil and Gas Journal*, 104(16): 43-51.

Nordhaus, William. 2007. "Who's Afraid of a Big Bad Oil Shock?" *Brookings Papers on Economic Activity*, 2: 219-38.

OPEC Secretariat. 2008a. *Annual Statistical Bulletin, 2007.* Vienna.

OPEC Secretariat. 2008b. *World Oil Outlook, 2008.* Vienna.

Parra, Francisco. 2004. *Oil Politics: A Modern History of Petroleum*. London: I. B. Taurus.

*Petroleum Intelligence Weekly***.** 2007. "PIW Ranks the World's Top Oil Companies," Special Supplement, XLVI(49), December 3.

Regnier, Eva. 2007. "Oil and Energy Price Volatility." *Energy Economics*, 29(3): 405-427.

Sandrea, Ivan. 2006. "Global E&P Capex and Liquid Capacity Trends, and Medium Term Outlook." Paper presented at AAPG International Prospect & Property Expo, London.

Simmons, Matthew R. 2005. *Twilight in the Desert: The Coming Saudi Oil Shock and the World Economy.* Hoboken: John Wiley & Sons, Inc.

Solow, Robert M. 1974. "The Economics of Resources or the Resources of Economics." *American Economic Review*, 64(2): 1-14.

Smallman, Adam, and Spencer Swartz. 2007. "Saudi Arabia May Push for Increase in OPEC Output." *Wall Street Journal Online,* November 12. http://online.wsj.com/article_print/SB11948556545528989.

Smith, James L. 2005. "Inscrutable OPEC: Behavioral Tests of the Cartel Hypothesis." *The Energy Journal*, 26(1): 51-82.

Talley, Ian, and Gregory Meyer. 2008. "Oil Speculation Draws Scrutiny; House Panel Told Curbs on Trading Could Ease Prices." *Wall Street Journal*. June 24, A4.

The Economist. 2008. "Crude Measures: Not Everyone is Paying Higher Prices for Oil." May 29, 75.

The Economist. 2008. "The Puzzle of Oil Production: Why the Saudis are Worried About the High Price of Crude." June 19, 59.

United Nations. 2006. Commodity Trade Statistics Database. http://comtrade.un.org/pb/ (accessed July 31, 2008).

U. S. Commodity Futures Trading Commission. 2008. Inter-agency Task Force. "Interim Report on Crude Oil," July.

U.S. Energy Information Administration. 2003. National Energy Modelling System, International Energy Module documentation, table Omsecon2.b04.

U.S. Energy Information Administration. 2008a. *International Petroleum Monthly*, various issues.

U.S. Energy Information Administration. 2008b. *Short-Term Energy Outlook*, various issues.

Weiner, Robert. 2006. "Do Crises Tear the Fabric of Oil Trade?" Resources for the Future Discussion Paper 06-16.