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Oil and the World Economy

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The recent stupendous rise in the price of crude oil has led economists to propose many different reasons for this phenomenon. The fact that oil is a commodity traded on worldwide markets and used by every country in the world makes it difficult to assess these claims quantitatively and scientifically. This paper proposes seven separate, but interrelated, reasons for the rise in the value of crude oil and evaluates each of these quantitatively using a variety of methods and data sets. These include (1) rising costs and peak oil, (2) rising world demand, (3) increased speculation and spot storage, (4) increased hedging of US dollar assets, (5) greater assertiveness of OPEC and multinational corporations, (6) higher geopolitical risk premiums, and (7) increased additions to global strategic petroleum reserves. It is found that the world has roughly 45 years of oil remaining using Hotelling's Rule to estimate the time to exhaustion of the current known reserves. In addition, it is shown that about 40% of the current high price of oil is due to increased demand,

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another 10-20% is due to increased geopolitical risk, and the residual 40-50% is due to increased speculation and preemptive storage of oil. It is projected that with oil reserves reaching satisfactory levels, the price of oil should revert back to levels slightly below $100 per barrel during the remainder of 2008 and during 2009.

Key words: oil, speculation, geopolitical risk, OPEC, peak oil, strategic petroleum, reserves

I. Introduction:

Once again oil is the focus of attention around the world. It has always been an engaging subject on which to speculate, but events of the past few years have made it a matter of vital concern to everyone. The oil crises of the late 1970s and early 1980's have provided useful backdrops to our experience today. We have grudgingly come to recognize that oil is a central element to the grand economic and social organization of the world. It is an essential substance in our lives and has unfortunately proven an object worth fighting for. Of course, oil has often been the crux of major conflicts around the world including the ongoing civil conflict in Nigeria, the first and (possibly) second Iraq war, the Iran-Iraq war, recent fighting between Russia and Georgia, and some would even say the Japanese attack on Pearl Harbor[1]. Oil continues to surround numerous smaller territorial disputes such as the sovereignty of the Spratly Islands, Diaoyutai Island, Iranian claims on Bahrain and the UAE, as well as

[1] See Yergin (1993) for a discussion of the linkage of oil with the war with Japan.

claims of Bahrain on Qatar[2].

Beyond the fact that oil has been a powerful catalyst in raising and intensifying territorial disputes and international conflicts, it has also become an integral part of the controversy surrounding alleged man-made global warming. That is, many environmental groups have found an unlikely ally in higher oil prices; an ally which helps in the push for a concerted policy shift to safer energy sources. These environmental groups oppose expanded drilling for oil in areas such as the continental shelves and wildlife preserves, despite the fact that greater drilling is the logical market response to higher oil prices. Rising prices for oil have intensified the debate over the environment in recent years.

Oil has been suspected of producing higher inflation, either through changes in inflationary expectations or via secular monetary accommodations of the adverse supply shocks. Moreover, the obvious change in relative prices attendant to oil shocks result in changes in resource demands depending on the substitutability or complementary of the other factors of production with oil. This was a major issue in the first two oil shocks, but has yet to be a significant issue in recent times.

Finally, the rise in the value of oil has once again altered the flow of funds in international trade and finance, with all the attendant changes in global power that this entails. Large sums of real income have been

[2] See Metz (1993) on the various territorial conflicts around the Gulf. Even though oil has made the Spratly Islands a subject of dispute, high oil prices have encouraged cooperation The Spratly Islands are currently being explored for oil in a joint effort by the Philippine National Oil Co., China National Offshore Oil Corp. and Vietnam Oil and Gas Corp. For more on this see Dow Jones Newswires (2008).

transferred from the set of oil consuming economies to the set of oil producing economies; principally in the Middle East, but also in Russia and Venezuela. These petrol dollars form the foundation of sovereign wealth funds that have made investments throughout the world, helping to fund fiscal deficits in the US and allowing the rescue of certain high profile financial firms that are in distress due to the US subprime mortgage debacle. Along with this is the fact that enormous sums of money are flowing daily into regions that are among the least stable in the world politically, fueling regional tensions, arms races, and belligerent behavior reminiscent of the Cold War. Both Russia and Venezuela have taken particularly hard stances vis-a-vis the US, largely due to the increased wealth they have enjoyed accompanying the rise in the price of fossil fuels.

With the dramatic rise in the price of oil have come numerous explanations for this rise.[3] These putative explanations seek to throw light on the issue of whether the rise is due to any one specific combination of reasons. Naturally, such information is essential if one is to craft a policy response to the rise in oil prices. However, even if one adopts a laissez-faire attitude towards the oil price rise, there remains the important issue of determining whether or not the rise is permanent. Many

[3] Hamilton (2008) has provided a reasonably solid discussion of oil -- first of the time series properties of the price of oil and then of certain econometric studies of oil and gasoline. However, his paper does not move the discussion much outside of the experience of the US, except to argue probable income and price elasticities and the growth of China and India. Since oil is determined on the world market, there is very little that one can definitively draw from his work. His research is indicative of the whole genre which fails to look at the problem globally and comprehensively. This is due to a general lack of high frequency global data on real output, as well as secular structural change.

industries and consumer purchases depend on oil. As such, their investment plans likewise depend on the likelihood that cheap oil will be available in the future. It follows that research oriented towards discovering the nature of the recent oil price rise is of great practical value.[4]

This paper surveys and quantitatively evaluates the various reasons put forward for the recent dramatic rise in the price of oil. Oil is a commodity and therefore its value is determined by the market -- whether a free market or a controlled market. But, this superficial appeal to supply and demand, while true, is nevertheless glib and begs the real question people are asking. Investors, consumers, and policymakers are interested in specificity. They wish to know exactly what is driving changes in supply and demand, and most importantly which of these factors is the predominant forcing agent for the enormous changes in oil's value recently.

A short list of possible causes (not in any particular order) for the rapid rise in the price of oil include: (1) reduced supply and increased costs due to exhaustion of the resource, also called peak oil; (2) increased demand due to growth of the world economy, especially in China and India; (3) increased speculation and spot storage by oil producers and oil users; (4) rising risk premiums due to increased tensions in the Middle East; (5) increased assertiveness of multinational oil companies, OPEC and the rise of Russia; (6) increased hedging of US dollar denominated

[4] Barsky and Kilian (2004) and Hall(2005) have surveyed the issue on how oil affects the macroeconomy. By contrast, we are interested here in how that the state of the economy and the geopolitical landscape affects the price of oil.

assets in very large funds, including pension funds and sovereign wealth funds; and finally (7) substantial additions to various strategic petroleum reserves (SPR) among the countries of the world. It should be clear from this that each of these factors have an effect on the price of oil and some will be singularly important on one occasion while others will be more important on other occasions. However, it will still be instructive to judge each of these factors on average using reasonably objective criteria over the past to see which is most important and whether there has been substantial structural change in the past few years.[5]

Due to the large number of factors involved, there are an equally large number of results to report.

First, we find it unlikely that we have entered a period of peak oil, where rising costs are ensuring that oil is becoming critically scarce. The world easily has 30-40 years of proven oil reserves at current depletion rates. We use a framework of Hotelling to estimate the time to depletion

[5] Each factor above has been discussed to varying extent elsewhere in the literature using a variety of methodologies. The classic reference for peak oil is Hubbert (1956). More recently Koonin (2008) has offered a series of lectures at Berkeley and MIT that indicate the earth has at least 40 years of crude oil left at current consumption rates. Greene, et al. (2003) have made estimates of depletion and transition out to 2050. For the effect of demand on oil, recent testimony by Bernanke (2008) and a series of investigators in Diwan, Gheit, and Newsome (2008) have asserted a significant role for demand recently. OPEC leaders have made it clear that they believe that speculation lies at the root of the recent price rise, see Democratic Party Committee (2008) for a collection of statements by oil and financial experts, including OPEC leaders. OPEC itself has been the subject of scrutiny, such as Kaufman, et al (2004) and Horn (2004). The measurement of risk premiums in oil have been concentrated in excess volatility studies such as in Luis (2000), Luis (2001), and Jalali-Naini(2006). However, war in the Middle East has generated some work at assessing the geopolitical risk in oil, such as in Alkadiri and Fareed (2003). On the recent behavior of sovereign funds see Sender (2008).

of oil and find this time to be slightly under 46 years. Naturally, faster consumption can reduce this time, but new reserves, added drilling, better identification and extraction technology can balance these negatives. In addition, the hybridization of consumption can potentially reduce demand in such a way that the peak oil effect is mitigated for a very long time. The whole notion of peak oil is thus seen to depend on how consumption and substitute energy resources are developed over time.

We also show in the paper that oil production growth, being closely related to world real income growth, is an important factor in determining the movement in prices. We estimate here that a rise of 4% in world income will increase the quantity needed of oil by 2%. This is more or less a technical relation and not demand elasticity *per se*. The association is surprisingly stable over a number of years and with different data sets – underscoring both its utility and robustness. A disequilibrium residual in this technical relation (e.g. world real income growing faster than world oil production) can explain up to 40% of the recent variation in spot oil prices. The ex post forecasting power of this relation is also reasonably high. We find it encouraging that the relation is also reasonably stable. Nevertheless, there remains a full 60% of the recent variation in the price of oil unaccounted for by "excessive" growth in world income.

Speculation in oil futures by itself cannot generate a long run movement in spot oil prices unless there is concomitant storage of spot output. It is of course impossible to make precise estimates of how much oil is being held back in the ground or in storage facilities throughout the world by producers, consumers, and speculators. However, very precise weekly data on US storage of oil (*excluding* the SPR) are readily available. We find in this paper that the data are consistent with the hypothesis that from 2004 US oil storage was being used in a speculative manner rather than as a buffer stock, as was its nature prior to 2004. Even so, these changes in the nature of US storage (from buffer stock to speculation) cannot explain very much of the variation in oil prices recently. They are significant statistically, but are not significant in terms of their economic impact. Storage due to government strategic petroleum reserves is a different matter though.

We find mixed evidence that changes in the value of the dollar (against the British pound and Japanese yen) have an effect on changes in the price of oil. Annual data appears to indicate that the effect has strengthened considerably (nearly 40 times as large) after 2001. Much of this is probably related to portfolio adjustment among central banks and private funds involving the purchase of gold and commodities as a hedge against depreciation of the US dollar.

There is no clear evidence that risk premiums due to Middle East tensions are significant *over an extended period of time*, although this is admittedly very hard to quantify. A timeline dummy was created that included many significant Middle Eastern events and was included in regressions on the growth of the price of oil over time. It was seen to be insignificant. Indeed, many periods of tension saw declines in the price of oil rather than increases. Middle East tensions should first impact on the futures markets, which in turn affect the spot markets. However, if these events cannot generate sufficient motivation to force investors to willingly store oil, then it will not be possible for the futures price to affect the spot price for any length of time. We also experiment with data we collect from a specific Google search attempting to measure geopolitical risk. We are successful at estimating a geopolitical risk premium corresponding to approximately 10-15% of oil's price. Commercial data (e.g., the popular IRCG data) aimed at trying to assess Persian Gulf geopolitical risk is uniformly unsuccessful at deriving this risk premium, since changes in the measure are too slow moving.[6]

Our analysis shows that OPEC has only had spotty success with generating a high degree of coordination among its members. There is no evidence that OPEC as a whole is purposively restricting production to suit its intertemporal preferences for revenues. Some observers have asserted that leaving oil in the ground to appreciate is the direct result of Fed engineered low interest rates. However, production has not be significantly reduced and the movement in prices seems to be well beyond that consistent with lower interest rates.

Finally, global strategic petroleum reserves are increasing with substantial additions being made not only in China and India, but smaller countries such as Taiwan and South Korea. Increases in the strategic petroleum reserves are no doubt supporting the extraordinary rise in spot and futures prices, thus validating the views of higher oil prices in the

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[6] ICRG data is produced and disseminated by The PRS Group and involves numerous metrics. The data is sold commercially, indicating that not only is there a market for the data, but that the product has proven practical value. Nevertheless, the analyses we have done using a single series of ICRG "external conflict" data for Iran (at a cost of roughly 80 USD) does not have sufficient variation to allow a clear identification of a geopolitical risk premium tied to possible hot conflict in the Persian Gulf.

future. This factor along with increased use of futures for speculation and hedging has allowed the spot price for oil to remain high despite the rather small changes in economic fundamentals. This is what is referred to by some as the "financialization of oil".

The outline of the paper is as follows. First, a short history of oil is presented and is linked to the seminal work of Hotelling which describes how the price of a nonrenewable resource such as oil will evolve in both competitive and noncompetitive markets.[7] The well known Hotelling's Rule is then evaluated using a long time series on oil prices. Oil is compared with other commodities as a check. In addition, numerous stylized facts concerning oil are presented, including a simple but effective estimate of the number of years left to exhaust the world's projected oil reserves -- estimates consistent with Koonin and others. Second, each factor contributing to the increase in the price of oil is examined quantitatively. In so doing, a large number of data sets are introduced, some having over 5000 daily observations, while others having fewer than 30 annual observations. Indeed, there are a wide variety of data sets involving frequencies at daily, weekly, monthly and annual periods which are used in the paper. Some cross sectional data sets on countries and regions will be used also. Third, a general synthesis of the empirical evidence is made and a set of conclusions are presented.

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[7] Nearly all research on exhaustible resources begins with the classic work of Hotelling (1931). Unfortunately, most empirical works make only passing reference to Hotelling's Rule and then proceed to ignore much of the paper. Seldom is there any concerted effort to apply the paper to actual data. We will follow Kleykamp (2008b) in showing that Hotelling's framework can be applied on a limited basis to help estimate the length of time till exhaustion of the resource.

II. A Short History and Some Important Stylized Facts A Tranquil Land?

It is natural for most people to associate oil with the Middle East and OPEC in particular, but historically this is not at all true. Prior to the 1950's most oil was produced in the US. The history of oil can be roughly broken into four periods. [8] First, there was a highly disaggregated period in the US prior to the 1860s, with many producers and oil products going mainly to industry and home heating purposes. Second, there was a period in the US during 1868-1899 where aggregation and consolidation took place culminating in the breakup of the Standard Oil Trust which controlled 90% of the oil flows in the US. Third, was the period of 1900-1950 with the US in the predominant producer position both domestically and internationally, sharing production somewhat with the English and Dutch – this was the period involving the so–called pejorative "Seven Sisters".[9] The advent of motor cars caused a rapid increase in the scale of oil companies. Fourth, we have the period of expropriation of oil fields from Western interests and the nationalization of oil beginning in the 1960's in numerous countries throughout the world, along with the gradual decline of American production in favor of the Middle East. This period also saw the aggressive rise of the OPEC cartel. It is also the period we find ourselves in today.

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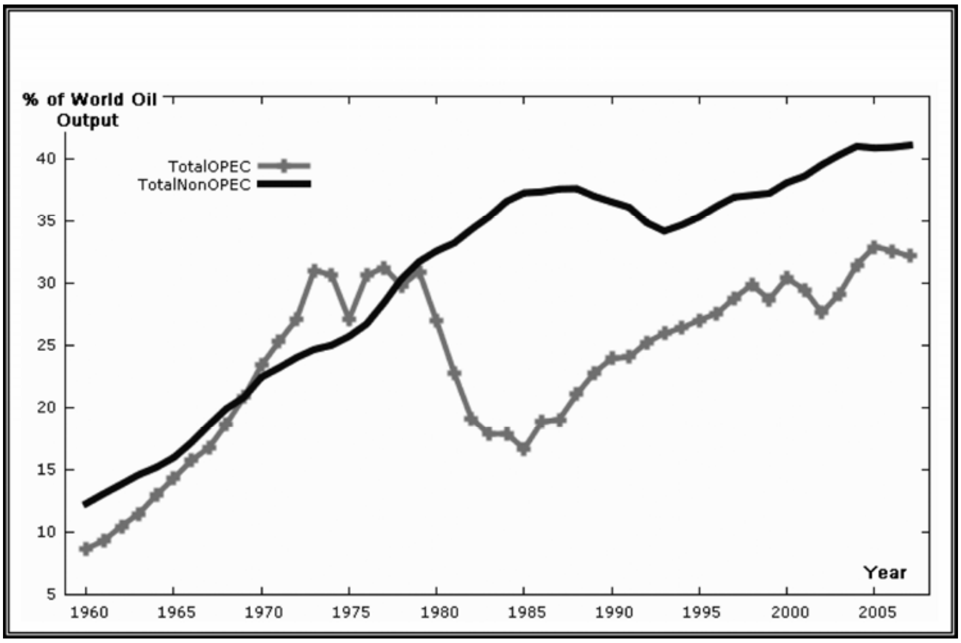
[8] A clear reference to pre-1960's oil production is *The International Petroleum Cartel,* Staff Report to the Federal Trade Commission, released through Subcommittee on Monopoly of Select Committee on Small Business, U.S. Senate, 83d Cong., (Washington, DC, 1952)

[9] The generic term "Seven Sisters" refers to over 20 different subjects. It is being used here specifically to refer to the original international oil cartel involving the US, British, and Dutch corporate ancestors of Exxon, Mobil, Royal Dutch Shell, BP, Gulf, and Texaco, some of which have been further merged. For more on this early history see Sampson (1975) and Yergin (1991).

Figure 1: OPEC and NON-OPEC Oil Production



Source: Energy Information Agency http://www.eia.doe.gov/emeu/aer/txt/ptb1105.html

Figure 1 shows that growth in OPEC production was faster than that of Non-OPEC producers from 1960 – 1973. From 1976 up to 1995, OPEC became much more politically aggressive and restricted production; thus keeping the total world production rate of oil at about a steady 60 million barrels.[10] Since 1995 it has allowed production to grow roughly in line with Non-OPEC producers, although it is clear that for some periods there was an absolute reduction in output not reflected in the

[10] This 60 million barrels per day figure is arrived at by adding together OPEC production and Non-OPEC production. OPEC must judge its own output goals by considering world production, not simply its own production, if it is to be an effective international cartel.

Non-OPEC group of nations. This was no doubt due to disruptions owing to the war in Iraq.

According to Hotelling, *nominal* spot prices of nonrenewable resources in competitive markets should grow at the same rate as the prevailing nominal rate of interest or rate of return on alternative assets or capital. Monopolization of the industry would result in a slower growth, in general, since output is normally reduced under monopoly. This means that we should see growth in nominal oil prices at rates above the prevailing nominal rate of return when there are monopolistic elements in the market. Historically, oil has not precisely followed Hotelling's Rule, but it is nevertheless instructive to see how much of a departure there has been from this Rule.

Siegel has estimated the average total nominal return (assuming reinvestment of all dividends, etc.) on US common stocks from 1946-1997 at 5.4%. For roughly the same period, the nominal price of oil rose 3.99%.[11] The nominal interest rate on AAA bonds in the US from 1949-1969 as given in Friedman and Schwartz (1982) was 3.95%, while oil's price for the same period grew only 0.9%. As shown in Table 1, oil's price grew at 6.24% from 1958 to 2006. At the same time, Moody's AAA rated corporate bonds were yielding a nominal 7.7% Clearly, the price of oil is growing too slowly in the past for Hotelling's Rule to strictly hold.

However, Hotelling's Rule may still be useful to us. If instead we take

[11] See Siegel (1999) for a clear discussion of average rates of return in the US over the last 100 years.

the first 6 months of 2008 the average price of oil was equal to $110.94, which when combined with 1958 oil in Table 1 gives an average geometric growth in oil's value over the period 1958-2008 of 7.48%.[12] The corresponding average in the nominal AAA Moody's interest rate is approximately equal to 7.66%. Thus, including the rapid rise of oil up to $110/barrel, in 2008, produces numbers which are ***on average*** reasonably consistent with Hotelling's Rule. The subsequent rise in the value of oil to over $140/barrel is excessive as judged by Hotelling's Rule. Such a high price would have occurred after a period of four years (or 2012) if the value of oil continued to grow at Hotelling's 7.66%. It follows that there is strong evidence that oil would move back and stabilize at about $110/barrel before continuing to grow at say 7.5%.

We should point out that at times a higher interest rate (in the US) can be associated with increased profitability and expansion of the US economy relative to other countries. Such a rise in the interest rate will thus have the effect of strengthening the US dollar making it less desirable to hold petroleum in a portfolio as opposed to say US corporate stock. Hotelling, and those who followed him, did not consider this effect in their research, since their analyses was generally micro-based and did not consider that exhaustible resources may be located overseas. This exchange rate effect certainly weakens Hotelling's Rule. There are other macro-based considerations, as well. For example, changes in the price of oil can have an effect on nominal interest rates by affecting inflationary

12 The geometric average annual growth rate of X_t between two periods separated by T years, which we are using here, is defined as $g = 100\% \cdot [(\frac{X_T}{X_0})^{1/T} - 1]$. Note that this is very sensitive to which two years are chosen, unlike a simple arithmetic average.

expectations. To the extent that this occurs, higher nominal interest rates would be associated with higher oil prices in addition to the effect set out in the traditional Hotelling's Rule. Some analysts attempt to avoid this by converting the nominal price of oil to a real price. However, this assumes that there IS a price level which can be applied. If we note that oil is traded internationally, there is no particular price index that can be used. One has to resort to a world price index for which there is only scant annual data. Hamilton and others simply avoid this issue by deflating oil by the US price index. No reason is given for this. Superficially, a real price of oil is what we are interested in. However, it is not clear how one computes a real price for everyone in the world at the same time.

Table 1: Growth in Price of Selected Minerals

Resource	Average Value (1958)	Average Value (2006)	Average % Growth
Copper	$665/ton	$6,939/ton	4.80%
Gold	$1,120,000/ton	$19,500,000/ton	5.88%
Silver	$29,300/ton	$373,000/ton	5.22%
Zinc	$251/ton	$3,500/ton	5.41%
Tungsten	$3,400/ton	$37,000/ton	4.89%
Tin	$2,120/ton	$12,500/ton	3.61%
Nickel	$1,630/ton	$24,200/ton	5.54%
Manganese	$121/ton	$800/ton	3.85%
Oil	$3/barrel	$62/barrel	6.24%

Source: Historical Statistics for Mineral and Material Commodities in the United States,

http://minerals.usgs.gov/ds/2005/140/#data

Table 1 allows a clear comparison of the growth rates of nominal values of various non-renewable resources with the growth in the value of oil. Clearly oil has generated a bigger return than any other mineral.

We can use Hotelling's framework to estimate the time remaining till depletion or complete exhaustion of global oil reserves.

The exposition below follows Hotelling in assuming constant marginal and average costs of extraction, so that maximizing profit is equivalent to establishing a price consistent with inter-temporal arbitrage.[13]

Hotelling correctly notes that through arbitrage the competitive price (minus a constant average cost) for oil is

$$P(t) = P(0)e^{rt}$$

where r is the nominal rate of interest ***applicable for the time unit t***. Next, assume that the demand for oil quite reasonably follows

$$Q(t) = e^{\beta_2 t}\{\beta_o - \beta_1 P(t)\}$$

[13] Clearly the assumption of constant average (and thus marginal) costs is annoying. In addition, there is good reason to believe that the costs of discovery and extraction of oil are falling. The Economist magazine made a now famous prediction in 1999 that oil prices might fall to as low as $5/barrel in the near future based largely on the idea that technology was improving so much it would become extremely cheap to find and extract oil. Needless to say, they were wrong in this prediction, but their views on the movement of costs were not altogether unreasonable, see The Economist (1999).

Note that this formulation assumes that the short and long run price elasticity of demand does not change over time. Clearly as time progresses, the demand elasticity should increase. Thus, this estimation method biases it results towards a smaller estimate of the time remaining to exhaust the resource. Following Hotelling, suppose that oil is exhausted at time t = T. This means that Q(T) = 0, which implies

$$P(T) = \frac{\beta_o}{\beta_1}$$

Plugging P(T) into P(t) above we can solve for P(0) to get

$$P(0) = \frac{\beta_o}{\beta_1} e^{-rT}$$

and thus

$$P(t) = \frac{\beta_o}{\beta_1} e^{-r(T-t)}$$

Note that T is an endogenous variable, and therefore T must be independently determined. Note also that changes in exogenous parameters, such as a_o (the remaining amount of the resource) and the $\beta's$ in the demand function, affect P(t) by changing P(0) -- which is in turn a jump and not a simple rise in the growth in the value of oil. Taking this together with the demand Q(t) allows us to write

$$Q(t) = \beta_o e^{\beta_2 t}\{1 - e^{-r(T-t)}\}$$

The resource constraint can now be written as

$$a_o = \int_0^T Q(s)ds = \beta_o \int_0^T e^{\beta_2 s} ds - \beta_o e^{-rT} \int_0^T e^{(\beta_2 + r)s} ds$$

where a_o represents the quantity of the reserve remaining. This integral is easily found to yield approximately for large T (the time left till exhaustion)

$$T \approx \frac{\log(1 + \frac{a_o \beta_2}{\beta_o})}{\beta_2} + \frac{\log(1 + \frac{\beta_2}{r})}{\beta_2}$$

The two additive factors on the right hand side of (*) both play important roles in determining the length of time remaining to exhaust the resource. The time to exhaustion, T, is seen to depend on all of the parameters except β_1. The parameter β_1 is however instrumental in determining P(0). It should be emphasized that T is measured here in terms of days and not years.

We can use data from 2003 to illustrate the method above. In 2003 there were approximately Q(0) = 80 million barrels per day produced at an average price of P(0) = \$31/barrel. If we assume a demand point price elasticity ε= 0.10, then using 2003 data we get the following demand

$$Q(t) = e^{\beta_2 t}\{88.0 - 0.26P(t)\}$$

Next, assuming world real income grows at 3% per annum, oil demand should grow at half this rate (as follows from regressions of oil consumed on world real income) which means a growth of 1.5% per year. Converting this to a daily growth rate we get β_2 = 0.00004079. Using quarterly Moody's AAA nominal US interest rate data from 1959-2008, we employ an MA(3) time series model to forecast the interest rate in the future to be 5.5% per year. Converting this to a daily rate gives us r = 0.0001467. Let a_o = 1,200,000 (million barrels) be the global reserves of oil or approximately 40 years ***at current consumption rates*** (see Wikipedia's entry on combined top twelve oil reserves).

Using these and the other parameters as well as (*) above and converting T to T', having units measured in years rather than days, we get

$$T' = 29.7 \text{ years} + 16.48 \text{ years} = 46.18 \text{ years}$$

If we include all terms determining T we get a more exact figure of 45.35 years. We have used 2003 data to calibrate this model. We can check the calibration now by using r and T above to calculate P(0) from the model. In 2003, the actual value for P(0) was $31 on average. Using our data and the model, we estimate P(0) to be

$$P(0) = \frac{\beta_o}{\beta_1} e^{-rT} = \frac{88}{0.26} e^{-(0.0001467)(16856)} = 28.55$$

which is reasonably consistent with actual P(0) = \$31. Plugging this estimated value of P(0) into the demand, we can further estimate Q(0) to be

$$Q(0) = \{\beta_o - \beta_1 P(0)\} = \{88 - 0.26(28.55)\} = 80.57$$

whereas the actual value for Q(0) in 2003 was about 80.

Finally, we can estimate the price of oil at the time of exhaustion of the oil reserve.

This is equal to P(T) where

$$P(T) = \frac{\beta_o}{\beta_1} = \frac{88}{0.26} = 338.5 \text{ dollars per barrel}$$

which implies an average annual growth in the value of oil to be

$$\frac{\Delta P}{P} = (\frac{338.5}{31})^{1/46.18} - 1 \approx 0.0541$$

or 5.4% per year. Again, this is roughly consistent with the growth in value of oil over the past few decades (see Table 1). And, it closely follows Hotelling's Rule (per annum) that

$$\frac{\Delta P}{P} = r$$

Hotelling's Rule also tells us that ***over the long run***, commodity price inflation must be greater than general price inflation, if there is to be a positive real rate of interest.

Consider now a change in the interest rate r. This has two effects on oil prices – one related to an initial jump and the other related to the growth of P over time. First, P(0) is affected directly (or inversely) depending on how rT changes, which is of course related to the elasticity of T with respect to changes in r, since T is in part a function of r. Second, the growth in P changes in an unambiguously positive direction with r. Thus, it is possible that P(0) falls, with P(t) later rising at a faster rate when r rises. Our model above permits a clarification of these results if β_2 is small relative to r.

Suppose we differentiate T with respect to r.

This yields

$$\frac{dT}{dr} = \frac{1}{\beta_2}\left(\frac{\frac{-\beta_2}{r^2}}{1+\frac{\beta_2}{r}}\right) = -\left(\frac{1}{r^2 + r\beta_2}\right)$$

Multiplying by r and dividing by T, one gets (using the 2003 calibration value of $\beta_2 = 0.000040792$, $r = 0.0001467$, and $T = 16553$)

$$\varepsilon_r = -\frac{rdT}{Tdr} = \frac{1}{(0.0001467 + 0.000040792)(16553)} = 0.322$$

Hence, a 10% increase in r would reduce T by about 3%. T is seen to be relatively inelastic with respect to interest rates. Thus, an increase in interest rates, increases rT and reduces P(0). The instantaneous fall in P(0) is then followed by increased growth in P(t) over time, consistent with the higher interest rate and Hotelling's Rule..

While we have been somewhat successful in modeling oil price changes using the Hotelling framework and *average* growth in oil price prior to 2003, it is clear that after 2004, oil prices have been rising well above 5% per year, and therefore one cannot use the Hotelling model to explain the *recent* price rises. It nevertheless provides us with a long term basis for looking at the growth in the value of oil and establishes a lower bound on the time left to depletion. Naturally, with higher prices, greater conservation, slower extraction, and use of alternatives, the time to depletion of oil will be extended much longer. This is especially true of markets having monopolistic elements which reduce output and thus raise prices.

III. Quantifying the Relative Impacts of Factors Affecting the Price of Oil

As we have mentioned in Section I, there are at least seven separate factors involved in the recent extraordinary rise in oil prices. One would like to create a model including all such factors under the general rubric of supply and demand. This is a tall order, since one is limited in the quality of both explanatory variables that can be found and timely data that adequately reflects the true global flow of oil. In general, it is extremely difficult to econometrically identify a stable supply and demand structure for the world.[14] Naturally, it would be useful to know the price elasticity and income (or output) elasticity for both the global supply of and demand for oil. Unfortunately, while annual data on global price and quantity are readily available, our short history above shows the market is constantly undergoing substantial structural changes. A more productive course of action might be to investigate the data for strong and stable statistical associations or correlations which can then be linked to what we understand theoretically about the market.

1. Peak Oil

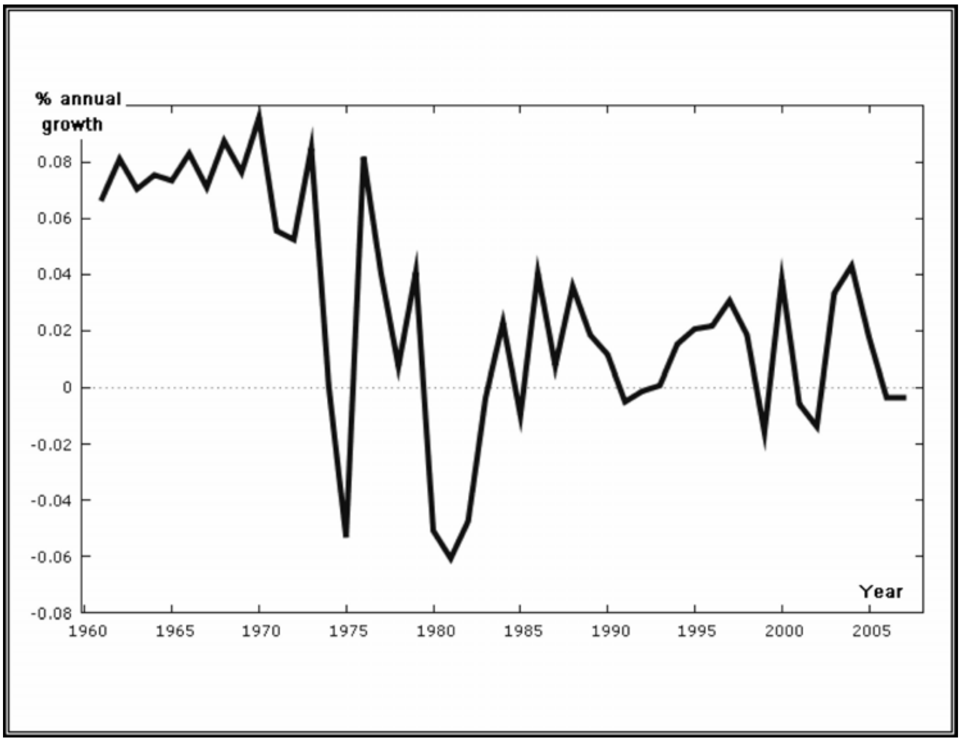
As the previous section showed, global oil reserves are roughly 40 years at today's rates of consumption, or slightly higher at 46 years, if income and prices are allowed to adjust upwards over time. This calls into question the

[14] To my knowledge there has been no comprehensive study combining all of the factors above in a single model encompassing world supply and demand for oil. One reason for this is that during the 1990s there was no real need to worry about oil since it was significantly underpriced. That is, the benefits of such a study were grossly lower than the costs involved in developing such a model. One might expect that large econometric models including many of the above factors would be constructed now that the price of oil has become a matter of serious concern.

notion that the world is experiencing a dramatic rise in the costs of discovery and extraction. Peak oil refers to the indubitable assertion that the world has limited quantities of oil which are non-renewable

Figure 2

Growth in Total World Production of Oil



Source: Same as in Figure 1

and which will eventually become depleted – leading to higher extraction costs and thus higher prices per barrel. The original attribution for peak oil is Hubbert who predicted the world would experience a peak in oil production in the1970's. This was clearly premature, as the price of a barrel of oil fell during the 1990's to a low of about $11/ barrel in 1999. Its value stands at 10 times that price today; a stupendous average rise of 26%/year since that time. It is this exaggerated rise that has elicited opinions that we have entered a period of peak oil for the world.

Figure 2 shows that growth in world output of oil after 1995, while unstable, has averaged roughly 1.6% per year. We do not see anything like an absolute and unavoidable, permanent decline in global production, although it is true that US production of oil has been declining since the mid-1970's. While it would *not* be wrong to say that the US has gone through a period of peak oil, this cannot be said about the world as a whole. Growth in the world production of oil has been somewhat lower, but certainly much more stable since 1985. If there was a peak oil problem, we would expect to find substantially negative growth in oil production in recent years if not decades. Furthermore, it is not at all clear how one can even precisely define peak oil if we factor-in changes in extraction technology, increased conservation, the emergence of oil substitutes and use of hybrids, reduced regulation on drilling, and improvements in extracting oil from shale, etc. Seen from this perspective, peak oil becomes less of a hard cold fact, and more of a highly subjective abstraction. In any event, the world is clearly nowhere near a period of peak oil using any objective measure.

2. Demand for Oil

As we have said, the demand for oil is highly variable (depending on both commercial and speculative motives) and is therefore difficult to econometrically identify for the world as a whole. Its structure is constantly changing. Nevertheless, oil is a commodity that is used both by producers and consumers in the production of real output. It is an essential ingredient in world GDP. For the US, roughly 70% of oil is used for transportation with another 25% used in industry. Transportation is not so dominant in developing countries for obvious reasons. Clearly as world real output rises, there is a concomitant rise in the demand for oil. Fortunately, world real GDP and world production of oil appear to be closely related *statistically* and this relation appears to be reasonably stable. If we regress the growth of world oil output on world real GDP, using annual data on world real GDP taken from the United Nations, we get just such a stable relation. Table 2 shows the regression results.

Dividing through on both sides of the regression equation in Table 2 by the mean value for the growth in world real GDP, provides us with a type of output elasticity. It is seen that the elasticity of production of oil with respect to world real GDP is equal to 0.476. Thus, a 3% rise in world income can be expected to generate a 1.5% increase in the production of oil. One should not read this as a demand elasticity *per se*, since we have not estimated a demand function. Rather, this is a simple association between two variables. It therefore becomes incumbent for us to test whether or not this relation is stable. Four stability tests were run on the regression, above, including CUSUM, CUSUMSQ, QLR, and Chow Test. Only the Chow test was significant at the 5% level for a structural break using the midpoint of the data, 1988. Even so, the first half of the data generated an elasticity equal to 0.45, while the latter half of the data generated an elasticity equal to 0.501. Clearly, while these two elasticities are technically different from a statistical point of view (according to the

Table 2: OLS estimates using the 37 observations 1971-2007
Dependent variable: Growth World Oil Output

Variable	*Coefficient*	*Std. Error*	*t-statistic*	*p-value*	
Const	-0.0470758	0.00887418	-5.3048	<0.00001	***
Growth World Real GDP	1.99344	0.266052	7.4927	<0.00001	***

Unadjusted R^2 = 0.61598 Adjusted R^2 = 0.60500

Degrees of freedom = 35 Durbin-Watson statistic = 1.75159

Source: Same as Figure 1 and UNSTATS_
http://unstats.un.org/unsd/snaama/selectionbasicFast.asp

Chow test only), they are not too different from a practical point of view. Both are roughly equal to 0.50. Therefore, it will not be harmful to think in general that a growth of world real income of 3% will on average generate a growth in oil production of about 1.5%. Once again, this is not a demand elasticity nor an output elasticity. It is merely a stable association or correlation between the two variables. There is no clear reason to expect that the stability it has shown thus far will continue in the future, except to say that it has been stable in the past. This is an example of Hume's famous criticism of induction and the use of probability and statistics in general.

The regression in Table 2, while very simple statistically, held up well when tested for autocorrelation and heteroskedasticity. Neither was present at the 5% level of significance, using a variety of tests (e.g. D-W test, LM test, and White's test).

The strength of association is measured by both the R^2 statistic and the t- statistics. These are quite high for log-differenced annual data.

It is interesting that the residual from the regression in Table 2 can be thought of as representing excess production of oil in any year. As a result, we considered the effect of this residual on the log-difference of both average and end-of-period data on oil prices. From a theoretical point of view, a large positive residual corresponds to an over-production of oil, which should be negatively related to the growth of oil prices.

We found that regressions of the residual over the whole sample 1970-2007 generated insignificant results though the regressions had the expected signs on the variable over-production as defined above. However, it was clear from residual analysis that there was structural instability beginning in 1985. The two oil shocks interrupted the more traditional nature of the impact of over-production on price. We therefore restricted our attention to a sub-sample 1985-2007. The results of the two interrelated regressions (one on growth in oil production and one on growth in end-of-period oil price) are given in Table 3.

The outcome of the two regressions is surprisingly good, despite the simple nature of the estimation method used. First, all signs on

Table 3: Regressions for Oil Output and Oil Price

Equation 1: OLS estimates using the 23 observations 1985-2007

Dependent variable: Growth of World Oil Production

Variable	*Coefficient*	*Std. Error*	*t-statistic*	*p-value*	
Const	-0.0145742	0.0115789	-1.2587	0.22196	
Growth World Real GDP	0.990454	0.371434	2.6666	0.01444	**

Unadjusted $R^2 = 0.25295$ Adjusted $R^2 = 0.21738$

Degrees of freedom = 21 Durbin-Watson statistic = 2.01873

Equation 2: OLS estimates using the 23 observations 1985-2007

Dependent variable: Growth in Oil Price

Variable	*Coefficient*	*Std. Error*	*t-statistic*	*p-value*	
Const	0.0557791	0.062654	0.8903	0.38341	
Residual from Eq1	-10.6186	4.48127	-2.3696	0.02747	**

Unadjusted $R^2 = 0.21096$ Adjusted $R^2 = 0.17339$

Degrees of freedom = 21 Durbin-Watson statistic = 1.83121

Source: Same as Table 2

explanatory variables are as would be expected. Over-production of oil (i.e. the residual from Equation 1) figures negatively on the growth in oil price. The explanatory variables in both equations are significant at the 5% level, although the constants are not. We calculate the elasticity of oil output to real GDP to be 0.506, which is again consistent with our finding that the elasticity should be about one-half. Tests were run to determine if either equation suffered from autocorrelation or heteroskedasticity, and these tests were uniformly negative. Neither equation had trouble in this regard. Therefore, the t-statistics were free of this particular form of bias. The equations were also subjected to stability tests and passed all four tests given above at the 5% level of significance. The R^2 statistics were somewhat disappointing being only in the range of about 1/4 to 1/5. This leaves a full 80% of the variation in both oil production growth and oil inflation unexplained during the sample period 1985-2007. It would appear that it is difficult to use under and over- production of oil to explain much of the change in the price of oil. Adding a variable for world inflation and for time in the second equation raises R^2 to about 0.34, but neither variable is very significant. It is possible to raise the R^2 of the second equation still further to as much as 0.40 by *deleting the last two years of data* and introducing a time trend and a world inflation variable (as defined by nominal and real world GDP data provided by the UN). This 40% represents an upper limit on the explanatory power of demand/supply disequilibrium. It also provides a bit of evidence that 2006 and 2007 were very different years in terms of price determination. That is, something other than excess demand caused the explosive rise in prices seen recently. Overall, it appears that oil's price does respond, but not significantly, to over and under-production of oil relative to the growth of

GDP.

Some economists have argued that Asian economic growth, along with Indian growth, has powered the enormous increase in the price of oil during the past few years. The data we have used here is from the UN. The contribution of Asia to world growth in real GDP can be seen in Figure 3. Note that there was a drop in 1993 with the slowing of the Japanese economy. In addition, there was a severe drop-off due to the Asian financial crisis in 1998, from which there has since been a recovery. However, Asia's contribution to world growth has not been exceptional although clearly China and India have both played an important part in this recovery. Asia now contributes about 40% of world real economic growth. It is possible that the use of oil by China and India is greater than the 50% output elasticity which we verified earlier.

Nevertheless, none of this could possibly explain the extremely large increase in the price of oil by using only the equations in Table 3.

3. Speculation and Spot Storage

The recent rise in oil prices has led some economists to conjecture that speculation in the futures market, along with producer and consumer hoarding of oil, has led to unprecedented inflation in oil values. Speculation in any commodity or mineral is impossible without concomitant storage of spot oil.[15] However, if prices are rising sufficiently, it is possible for producers to hold back extraction, just as is predicted in Hotelling's model. The producer declines to extract the oil

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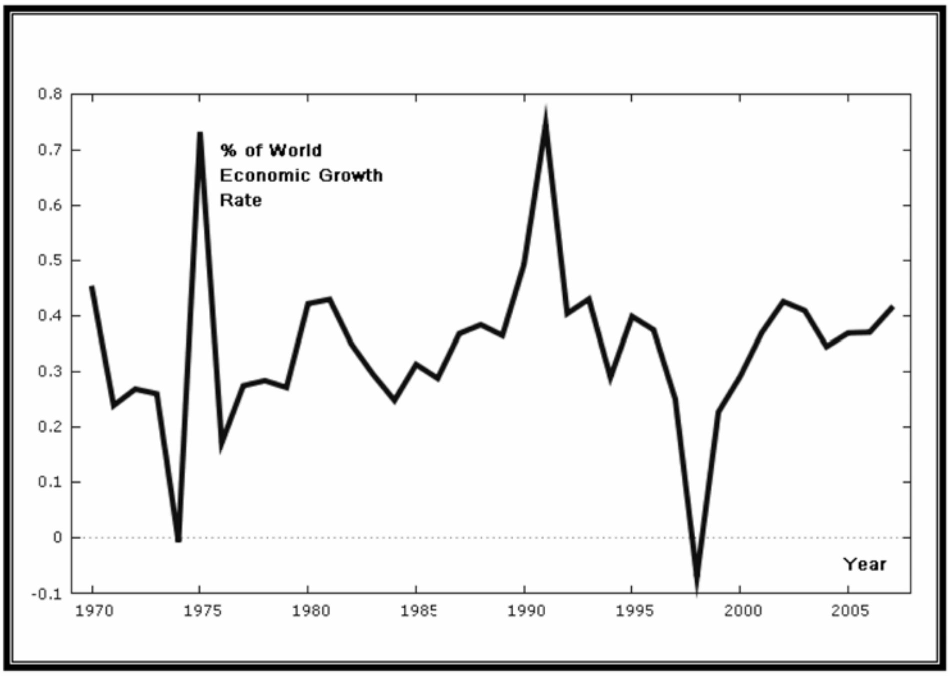
15 Bopp and Lady (1991) and Silvapulle and Moosa (1999) have investigated spot and futures prices as predictors of future spot prices. In general, economists have found that futures prices have not performed well as predictors of future spot values.

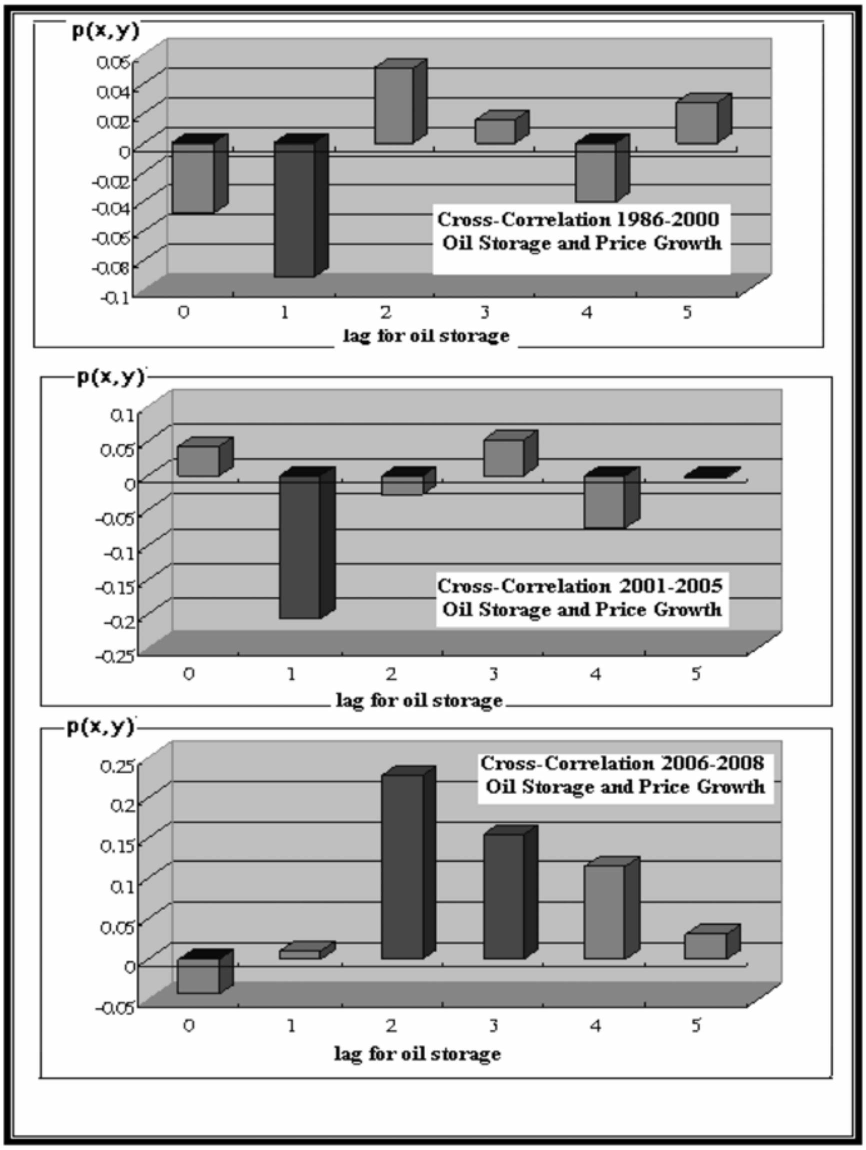
Figure 3: Percentage of World Growth due to Asian Growth



Source: UNSTATS http://unstats.un.org/unsd/snaama/selectionbasicFast.asp

until such time as the greatest profit can be earned overall. Downstream refiners and others may also get involved in this speculative game and this is difficult to distinguish this speculation from normal hedging behavior. If there are sufficient numbers of speculators who respond to an increase in oil's price by believing with firm commitment that oil will continue to rise, then it makes sense to buy oil futures. This is the basis of a bubble. Bubbles occur whenever speculators (including producers) are all of one opinion about the direction of the market. A stable market requires that there be a sufficiently wide dispersion of expectations by investors, or a sufficiently wide dispersion of conviction regarding such expectations,

Figure 4: Oil Storage Growth and Oil Price Growth



Source: EIA http://tonto.eia.doe.gov/dnav/pet/pet_stoc_wstk_dcu_nus_w.htm
Note: The auto-cross correlation coefficient p(x,y) is calculated as the correlation between the growth rate of oil price and the growth rate of lagged oil storage.

coupled with risk aversion. A large dispersion of expectations or perceived risks is needed to balance a market and thus stabilize it.

Even so, without substantial decreases in interest rates and storage costs, such speculation cannot last if there is not an associated removal of product from the spot market. Speculation requires storage of oil now.[16] The reason is simple. A higher futures price (due to excessive buying of oil futures) makes it possible to earn riskless profits by arbitraging away the difference between futures and spot markets. All traders know this. If the futures price rises too high (beyond that called for by its fundamentals), it will become possible to borrow money at interest rate r, buy the oil on the spot market, store the oil, sell the oil in the futures market, and later return the loan and interest with a riskless profit.[17] All of this means that along with the rise in futures prices, we should see an enormous increase in the storage of oil. The alternative to this is to see a producers speculate by creating a large reduction in the production of oil. Neither of these two seems plausible, although there is a measure of truth to this assertion.

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[16] Mazaheri (1999) and Milonas and Henkeer (2001) have investigated the relation of the lack of inventory on the convenience yield in oil and how this can affect the long run behavior of oil prices. Movements of inventory can signal what speculators feel about expected futures prices, leading to changes in both actual futures and spot prices.

[17] This is equivalent to the equilibrium between spot and futures market for a pure financial future where the positive cash yield on the underlying security is instead a negative storage cost per unit price. As such the arbitrage (no riskless profit) equilibrium between spot and futures market is just $F = P(1+r + c)$ where c is the storage cost per unit price. See Modigliani and Fabozzi (1992, Chapter 6, p. 174) for a discussion of this point.

To assess this factor quantitatively, we look at weekly data on the storage of US oil – data which is collected and processed by the Energy Information Administration (EIA). Naturally, it is possible that storage of spot oil is being undertaken by other countries than the US, possibly due to expansion of these countries' strategic petroleum reserves. We will consider this possibility later. However, if there are arbitrage opportunities, it should be clear from US data, whether or not there are changes towards speculative behavior in perhaps other countries.

Figure 4 shows an interesting set of three successive graphs. These graphs depict the cross-correlations between growth in oil price and *lags* in the growth of US oil storage for various non-overlapping time intervals. The first graph corresponds to the period 1986-2000, the second is from 2001-2005, with the third representing 2006 – 2008.

Clearly, the correlative structure of oil and storage has changed dramatically in the case of the third period. The first two graphs are reasonably consistent and indicate that storage is following a buffer stock formula – that is, storage is negatively and significantly related to price, with greater growth in prior storage being associated with lower growth in oil price. The issue of whether speculation or buffer stock motives is the driving force behind changes in storage is exactly analogous to the familiar speculation-buffer stock issue in the demand for real money balances. Here oil is being held in inventory (just as real balances) for two entirely different reasons. The recent change in oil being used as a speculative tool is fascinating because it was somewhat anticipated by

Keynes in the General Theory.[18] Indeed, the rates of return on hoarding oil can become a barrier to real aggregate investment if the increases in the quantity of oil cannot sufficiently reduce oil's own rate of return adequately to allow the rational production of other real assets. Exaggerating to make the point, we can say that people become so enamored of oil and its prospective yield that they fail to build houses and factories. In any event, the period 2006-2008 shows that growth in storage of oil is anticipating the rise in oil prices and producers or investors are choosing to raise their storage in line with their anticipation of the rise in the value of oil. If this is indeed true, we should see a return of the buffer-stock type negative cross correlation *after* the oil bubble has burst and the markets have returned to their previous state. This would perhaps be definitive evidence of an oil bubble and excessive speculation.

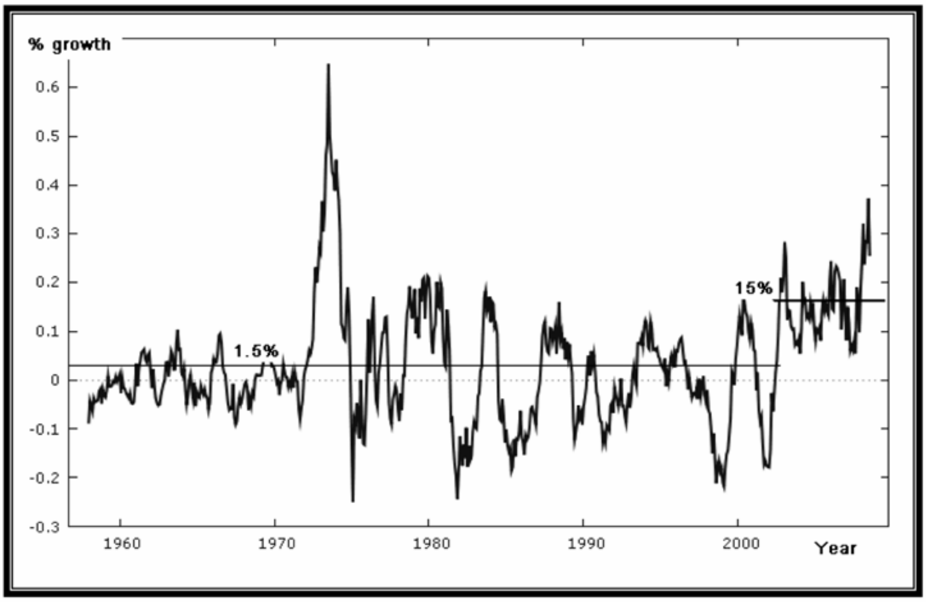
Even though there is a statistically significant positive cross correlation between lagged growth in the storage of oil and growth in the value of oil, the magnitude is not particularly large. The largest cross-correlation is 0.23 at lag 2 (weeks). Taking the square of this indicates explanatory power of a two week lag in storage growth with respect to oil price growth. That is, the lagged storage can only explain roughly 5% of the variation in oil price growth, statistically significant, but not

[18] For a concise model of speculation in oil that relies on the same basic features as the well known Cagan model of hyperinflation, see Kleykamp (2008a). The principal difference between the hyperinflation model that uses money as the focus and the oil speculation model that uses oil as the focus is that both price and expected price enter the demand function for oil, whereas only the expected inflation rate appears in the Cagan demand for real balances. In addition, money is controlled by a central bank monopoly, whereas oil is (at least partially) controlled by an OPEC cartel. Nevertheless, many of the features of speculation in a hyperinflation appear in oil speculation.

economically important.[19]

Figure 5

CRB-Reuters Commodity Futures Price Index



Source: CRB-Reuters Commodity Yearbook 2008

Another important measure of the effect of speculation on the spot price of oil comes from the so-called commodity indexes, which have become a target for speculators in recent years.

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19 This is exactly how that an R^2 statistic is computed. Regressing the change in oil price on a single lagged value of growth in oil storage results in an R^2 that is the square of the relevant cross-correlation in the graphs above. The R^2 is a goodness of fit statistic and measures the explanatory power of lagged growth in storage for change in oil prices.

Figure 5 shows that beginning roughly in 2003, the growth rate of the CRB-Reuters Commodity Futures Price Index jumped from average of 1.5% per year to about 15% per year. We should note that a rise in the futures price does not by itself confirm excessive speculation, since high spot rates will induce oil users to seek the futures market to hedge their risks. Ideally, one would have data on the number of contracts entered into based on commercial and speculative motives – something which is hard to assess since such data does not exist.[20] Looking instead at monthly data on the number of NYMEX oil futures contracts traded, we get Figure 6, which shows that from 1990-2004 trading volume in contracts grew at about 6.4% on average, and at 25.5% thereafter. That is, 2004 appears to be an important turning point in speculation. This is in line with our previous analyses. It is not plausible that commercial users of oil would generate such a large and sudden increase in contract volume. Most users of oil regularly use the futures market to hedge and therefore would see no need to increase their use of the market.

It is often asserted that increased speculation in oil futures has been a major factor in producing the astounding rise in spot oil prices. To investigate this further, we now consider the volume of contracts on the

[20] The author wishes to thank an anonymous referee for pointing out that the US Commodity Futures Trading Commission has collected data on commercial vs. speculative positions and have published these in tabular form up to 2006. The data supplied by the referee shows that speculators (noncommercial longs and shorts) are nominally about 15%-20% of the market, which seems somewhat low. Naturally this will depend on how close to expiration the future is, since open interest expands due to speculation near expiration. NYMEX has two contracts: physical and financial having basically the same margin requirements. Settlement for physical involves physical delivery, while financial is a cash settlement. However, we cannot see anyway that hedging and speculation can be successfully identified if offsetting positions allow one to eventually avoid physical settlement.

NYMEX and see if there is any strong and stable association between the growth in contract volume and the rise in oil prices.

To this end, we look at monthly data on both variables. Figure 7 shows the two variables plotted together as time series. While the general movement of both variables is consistent with a causative structure, there nevertheless remain long periods of time where there are departures from the trend. Moreover, much of the trend can no doubt be explained as normal hedging operations by airlines and other major users of oil in the face of rising energy prices (due perhaps to some other causes).

It should be clear that a single price series cannot, by itself, show whether it was generated by excessive speculation or normal market forces. The price series must be judged relative to some other price series whose product is physically fulfilling the same basic investment function. One way we can approach this is to use gold as analternative investment vehicle.[21] Gold has a very low storage cost and is as widely traded as oil.

According to Hotelling, a nonrenewable resource, such as gold or oil under competitive conditions, should exhibit a growth in its price equal to the nominal rate of interest. His analysis assumes that the future price is known perfectly. If instead the future price is known with uncertainty and with a greater or lesser degree of conviction, then the equality between price growth and the interest rate is broken.

[21] Chaudhuri (2001) has investigated the impact which rising oil prices have on commodities in general. We are interested here in looking at how that the speculative motives in play determining gold prices are also motivating to a great extent the current speculation in oil.

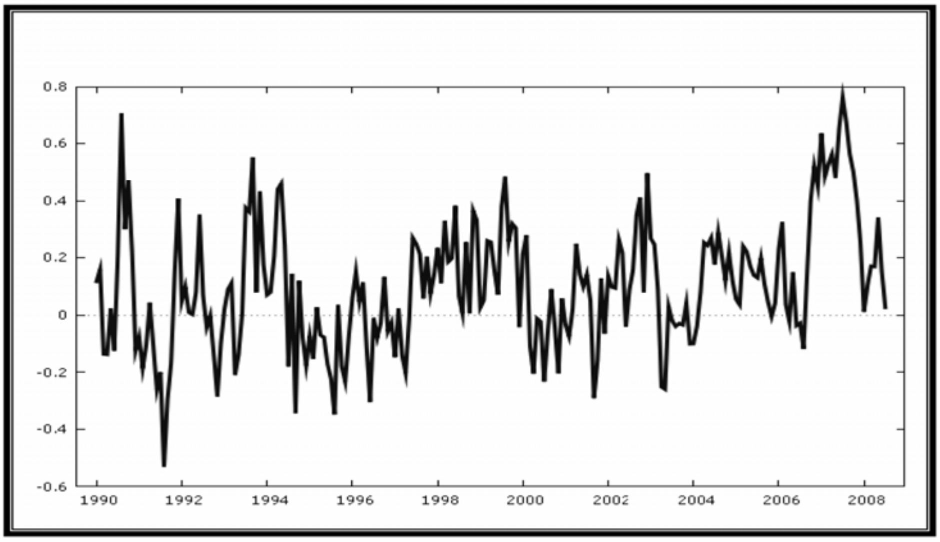
The appropriate rate of interest that is used in the case of gold will no doubt be different than that of oil. Additionally, oil has a major storage cost element. We can therefore assume that both the price of gold and the price of oil, respectively, satisfy the following:

$$P^G(t) = P^G(0)e^{rt} \quad \text{and} \quad P^O(t) = P^O(0)e^{(\beta r+\delta)t}$$

The two equations above illustrate the principle that oil must have the lure of higher profits (or the inter-temporal return) since it has higher storage costs and greater risk. Given the equal interest cost of the two

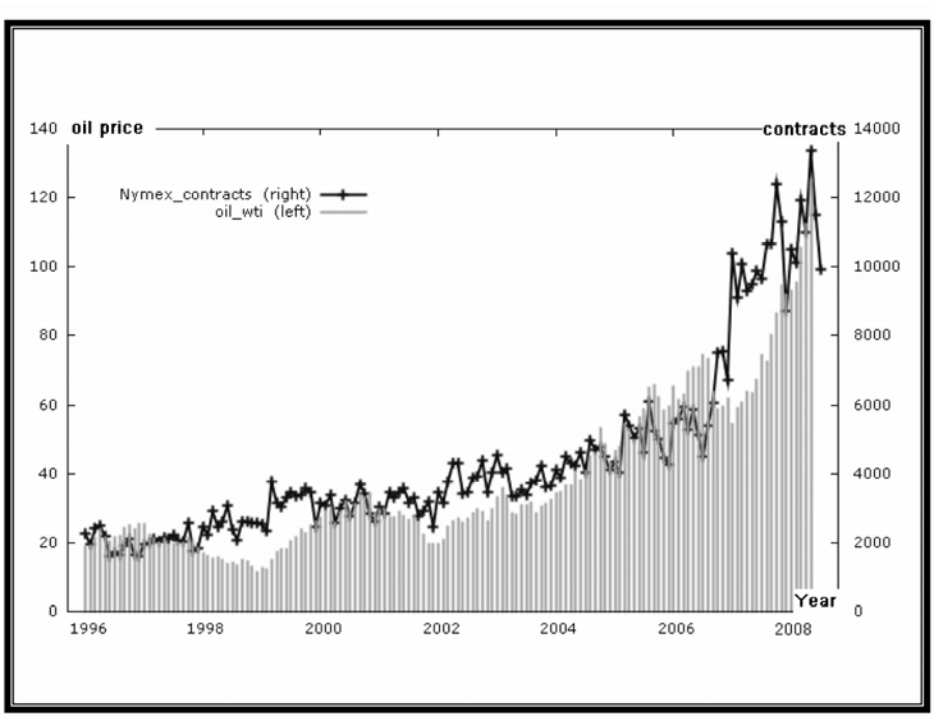
Figure 6

Growth Rate of Trading Volume in NYMEX Oil Futures Contracts



Source: CRB-Reuters Commodity Yearbook 2008 with supplements CRB from website

Figure 7: NYMEX Oil Futures Contracts and WTI Oil Spot Price



Source: Same as Figure 6. Note: Oil Price is WTI measured in USD, number of contracts is in '000s

commodities, the higher storage cost of oil must be balanced by a higher expected rate of return on buying oil spot now and selling it forward at price $P^O(t)$. We should note that there will be many other factors. Taking the log difference of both sides of the two equations and differentiating, we arrive at a regression equation, giving equilibrium between the two markets, assuming rational arbitrage. This regression can be written as

$$\frac{\Delta P^G}{P} = \delta + \beta \frac{\Delta P^O}{P^O} + \varepsilon$$

Table 4 shows the results of the regression of oil price growth on gold price growth using monthly data on the two variables. The regression was run twice over two different periods – the first from 1994:01 to 2007:10 and the second over the period 2004:01 to 2007:10. This was done to see if there was a change in the nature of the relation. Both regression were reasonably stable. The first regression suffered somewhat from autocorrelation, but this was not true in the second regression. There were two striking results from the regressions.[22] First, the second regression shows a marked increase in the effect gold has on the movement of oil. This indicates that those buying gold for both speculative and geopolitical reasons are increasingly buying oil as well. Oil is becoming the black gold of the 21st century. Second, it is clear that gold can explain roughly 3 times as much of oil's movements in the latter period as in the whole period. This means that the association between the two variables is converging and factors affecting the price of gold are quite likely similarly affecting the price of oil on a month to month basis. It should be remembered that Hamilton has stated that the monthly price of oil does not seem to be related to anymacroeconomic variables, nor to itself. He claims that oil prices follow a random walk process. We have found that

[22] An anonymous referee has suggested that the monthly regressions in Table 4 and 5 be re-estimated using the Cochrane-Orcutt method, due to residual autocorrelation in the first regression. This was done and the results confirmed in greater measure the previous results. During the period 1994-2007 there was in fact no significant association of gold price growth with oil price growth (even at the 10% level). However, for the period 2004-2007, a statistically significant association between the two variables was present, showing that gold and oil were indeed moving to similar influences after 2004. Oil, like gold, was being used as a speculative commodity.

Table 4: Regressions for Oil Price Growth and Gold Price Growth

Equation 1: OLS estimates using the 166 observations 1994:01-2007:10

Dependent variable: Growth in WTI Spot Oil Price

Variable	*Coefficient*	*Std. Error*	*t-statistic*	*p-value*	
Const	0.01089	0.005892	1.848	0.06638	*
Growth Price Gold	0.31270	0.167126	1.871	0.06310	*

Unadjusted $R^2 = 0.02090$ Adjusted $R^2 = 0.01493$

Degrees of freedom = 164 Durbin-Watson statistic = 1.47886

Equation 2: OLS estimates using the 46 observations 2004:01-2007

Dependent variable: Growth in WTI Spot Oil Price

Variable	*Coefficient*	*Std. Error*	*t-statistic*	*p-value*	
Const	0.0157432	0.010263	1.534	0.13220	
Growth Price Gold	0.461776	0.2414489	1.912	0.06238	*

Unadjusted $R^2 = 0.07673$ Adjusted $R^2 = 0.05574$

Degrees of freedom = 44 Durbin-Watson statistic = 1.819

* denotes significant at the 10% level **Data from CRB-Reuters Commodity Yearbook 2008**

gold appears to be becoming more and more closely related to oil.

4. Rising Geopolitical Risk Premiums for Oil from Middle East

It has been asserted by some economists that the rise in oil prices has been in part due to increased tensions and conflicts in the Middle East including the widening influence of Al Qaeda especially in Saudi Arabia, the second Iraq War, increased uncertainty over Iran's nuclear aspirations, and Israeli confrontation of Hamas and Hezbollah.[23] To quantitatively evaluate this factor we considered a regression of oil price growth on time and a series of dummy variables constructed from a timeline (1949-2008) of notable events and periods of time in the Middle East that might have been associated with the risk of a disruption of oil supply and thus represent a factor which would impact on oil prices. From this, one can obtain a rough picture of the size of the risk premium that attaches to such events in the Middle East. Unfortunately the results were uniformly dissatisfactory. Virtually nothing could be gleaned from using such a timeline and dummies to measure the risk premium.

While there were many historical events prior to the early 1970s that could affect oil prices, oil was largely a matter of the US-UK-Dutch

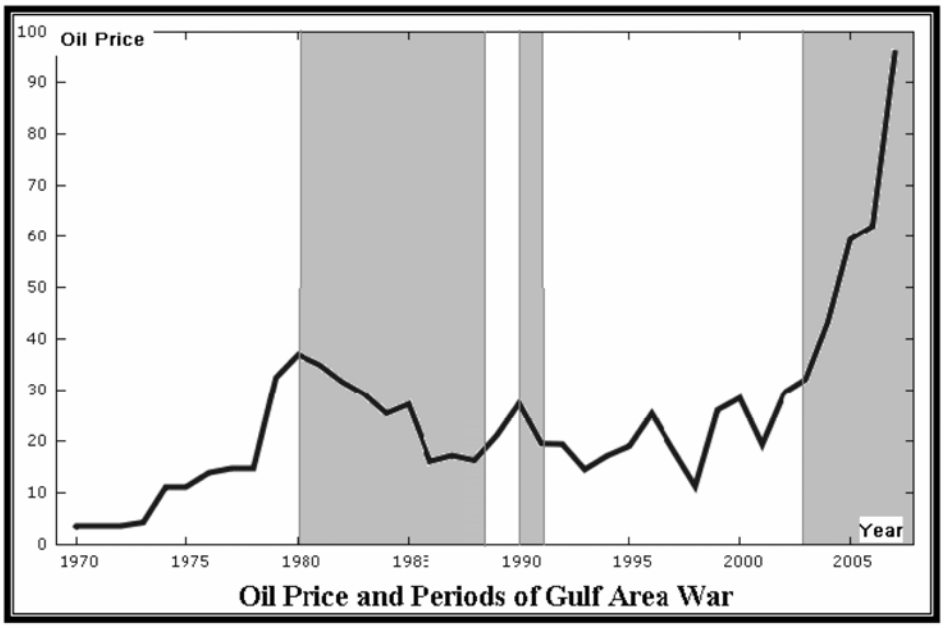
[23] The author wishes to thank another anonymous referee for pointing out that a detailed and highly useful chronology up to the year 2000 of newsworthy events, that have affected oil in the past, is available from the EIA website. Unfortunately, this timeline while providing ex post evidence for price changes does not *quantify* the effect of geopolitical risk (in particular) on the price of oil. We have constructed similar timelines to that shown on the EIA website and have run regressions on these timelines in hopes of determining their impact on the price of oil. The results of there regressions were uniformly poor and therefore have not been reported here. See EIA website and critical petroleum related events.

owned "Seven Sisters" and oil production and distribution was highly centralized both in the US and abroad. The 1960's brought a wave of nationalizations which eventually led to the formation of the OPEC cartel. After this, the production and pricing of oil became much more political in nature. The secular loss of US supply beginning in the 1970s ensured that OPEC and the Middle East would become the focus of oil determination. It follows that the impacts of events in the Middle East has intensified starting in the mid-1970's or perhaps as late as the early 1980s. Note the buildup to the war and then a drop. This is very characteristic of oil price in the face of imminent war.[24] This graph shows that oil rises well in advance of outright hostilities and usually falls rapidly thereafter. This may be due to the fact that war is expensive and the countries concerned produce at higher rates after the beginning of hostilities in order to pay for the war or defend against it. However, the Iraq II war in 2003 is different.

There is no return to normality after the end of major hostilities. Part of this may be due to lingering risk from potential reaction to the Iranian nuclear policy. It is alsotrue that much of the cost is not being defrayed by Gulf States and therefore there is no need to produce at higher rates as was true in previous episodes. Finally, the fact remains that large-scale terrorism is a continuing problem and this cloud of doubt hangs over the region causing unprecedented additional risk and uncertainty.

[24] Alkaderi and Fareed (2003) have looked at how the US involvement in Iraq could lead to much higher oil prices. However, the war did not lead to higher prices, since Saudi Arabia stepped in to produce oil at higher rates and the war did not widen to other Gulf countries.

Figure 8 War and The Price of Oil



Source: EIA and author's calculations

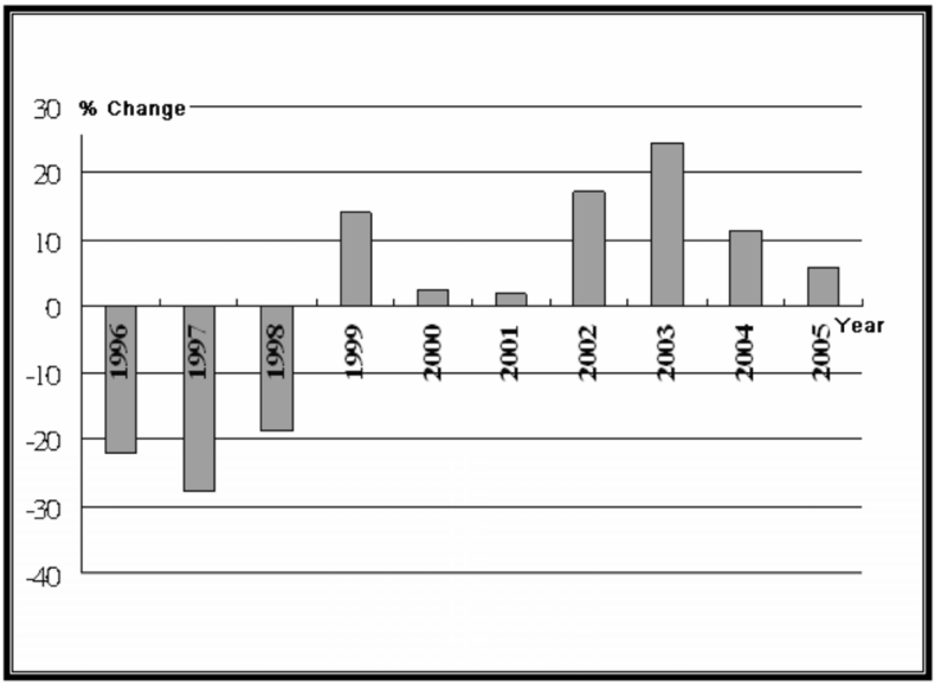
Most analysts before 2003 put the oil risk premium at somewhere between 10-20 % of the price. Their analysis was based on additional costs due to extra transport security and increased marine insurance rates. It is important to realize that both producers and consumers of oil face risks during times of upheaval and conflict.

Figure 9 shows the growth in marine insurance premiums (net) per vessel from the 2006 CEFOR Norwegian Marine Insurance Statistics. No later statistics are available, but using 2003-2003 as a basis, marine insurance premiums rose, prior to and during Iraq hostilities, an average of 20% per year. Assuming premiums are 10% of the price of oil, the rise of 20% in the value of these marine insurance premiums represents only a 2% of the increase in the market price of oil. It is difficult to believe that much of the increase in the price can be attributed to a rise in geopolitical risk exclusively through such marine insurance premiums.

The usual econometric method for testing for excessive volatility in a time series is the ARCH model of Engle. Furthermore, if this volatility affects the movement of the time series itself, the series can be modeled as an ARCH-M (ARCH in Mean) or GARCH-M model. The ARCH models have been very successfully used in modeling volatility in prices of financial products. While it is logical to employ the ARCH model to investigate the effect of volatility of oil prices, there does not seem to be much evidence for the ARCH-M effect. Growth in the price of oil displays clear ARCH effects up to lag 2, but this conditional heteroskedasticity does not seem to affect the growth rate in the value of oil itself. We use weekly (end-of-period) data on oil prices (wti crude). Hamilton has used a lower frequency monthly version of this data and has shown the growth in oil price to be a random walk without drift. He uses this to forecast the 95% bounds that oil can follow.

To move the analysis forward, we have elected to construct a time series based on specific search of Google using an appropriate search phrase coupled with the date.

Figure 9: Percentage Change in Marine Insurance Premiums



Source: 2006 CEFOR Norwegian Marine Insurance Yearbook

Ideally, Google would provide data on the date the webpage was created, which is possible, but only for the year and not the month. Our analysis here of the geopolitical risk premium embedded in crude oil's price relies on a set of data we have independently collected and organized. We have used Google's search engine over the period 1999 to 2008 and made a specific *simultaneous* search for "Persian Gulf", "heightened risk", along with "Month, Year" for each month in the period surveyed. Naturally, there are many problems associated with this type of data collection, as can be seen from implementing the search itself. However, we feel that the real test will be whether such data can provide us with reasonable estimates of the risk premium made independently by others.Obviously, searching phrases on Google can produce irrelevant hits. In some cases, the phrase “heightened risk” which we use may refer to illnesses stemming from the Gulf Wars. At other times the month and year do not correspond well to the date of creation of the webpage. This means that the data is heavily contaminated with measurement error. However, the data was compared with alternative data on the risk of external conflict for the country of Iran from well known the source ICRG. The ICRG data is much more qualitative in the nature, subjective, and very slow to change. Without question ICRG data performs uniformly worse in regressions on oil prices when compared with the data we have collected, at least with respect to Iranian risk of external conflict.

Using the data from the Google search, we are able to show a geopolitical risk premium in crude oil of about 10-15% for the period of monthly data spanning 2003 to 2006 – a striking result considering that there have been many informal assertions that the size of the geopolitical risk premium is in this range.[25] Table 5 contains the results of the regression. The sample period was contracted because of instability in the regression over the full period. This smaller sub-period produced good results and was stable. We should note that there have also been some commentators in the media that have claimed that the geopolitical risk premium contained in the price of crude oil is in fact extremely large

[25] Numerous reports in the news have placed the oil risk premium at about $8-$10 per barrel, which corresponds to roughly 10-15% at the time of publication of such news reports.

(along the order of 50% of the price) and that if Iran could be successfully deterred from acquiring nuclear capabilities, the price of oil would likewise drop 50%.[26] Our analysis here casts considerable doubt on that assertion. Even using two standard errors to calculate the

Table 5: Regressions of Log of Oil Price on Geopolitical Variable

OLS estimates using the 35 observations 2003:03-2006:01

Dependent variable: Log of WTI Spot Oil Price

Variable	*Coefficient*	*Std. Error*	*t-statistic*	*p-value*	
Const	1.60996	0.186911	8.614	0.00001	***
Log of Geo-Risk	0.0772918	0.0361756	2.137	0.04038	**
Trend	0.0259036	0.00117943	21.963	0.00001	***

Unadjusted R^2 = 0.94018 Adjusted R^2 = 0.93644

Degrees of freedom = 33 Durbin-Watson statistic = 1.31728

Source: Google Search and author's calculations

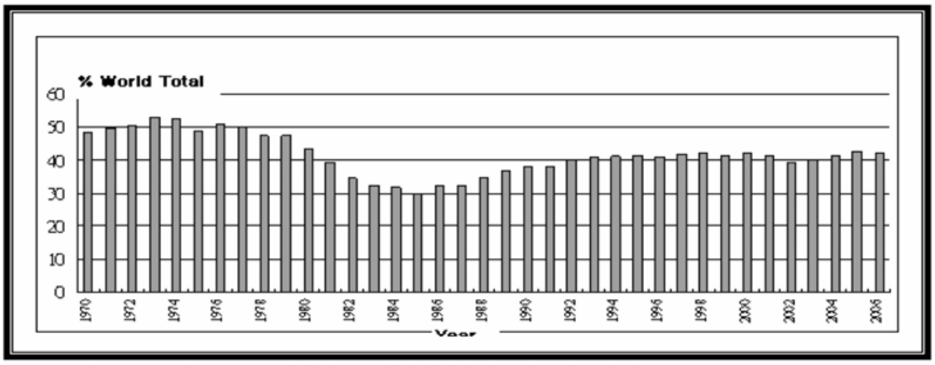
26 Steve Forbes has been outspoken in claiming (often very wrongly) that the oil price is extremely over inflated and that a risk premium of 50% of the price corresponds to the Iranian uncertainty. His estimate is that oil should fall to below $30 a barrel, something very few people are willing to assert. See Forbes(2008)….

possible size of the risk premium, we are only able to get a figure of 19.5% of oil price as the risk premium.[27] It is true that after 2006, oil continued to experience a tremendous increase in value nd therefore it is likely that the geopolitical risk premium may have grown. Nevertheless, it is unlikely that it grew as a proportion of price anything like the size being asserted by some media figures. A guess of 20% of the price would be a very generous assertion indeed.

5. Increased Assertiveness of OPEC and Big Oil Companies

The notion that the recent stupendous increase in the price of oil is due to large a multinational oil companies holding down production is not

Figure 10: OPEC Production as % of World Output



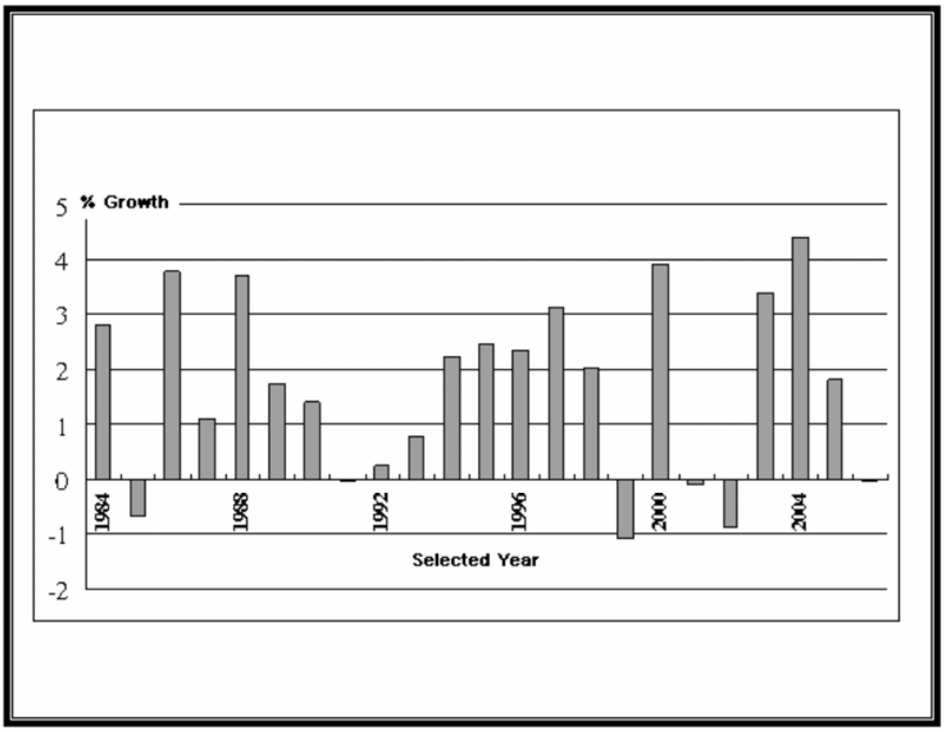
Source: Energy Information Agency http://www.eia.doe.gov/emeu/aer/txt/ptb1105.html

[27] The calculation which delivers the maximum risk premium for the log of WTI spot crude, evaluated at the means of the sample period, and which is equal to about 20% goes as follows: risk premium = (coeff. on risk + 2 std. errors)(mean of log risk var.)/(mean of log dependent var.) which corresponds to 0.19557 = (0.149643)(4.9013)/(3.75024).

very ◦ plausible. Nevertheless, such claims continue to capture the attention of the general public. Prior to the 1960s, US, British and Dutch multinationals were in tight control of the production of oil throughout the world. Despite this concentration, real oil prices were not particularly high compared with today. The 1960's and 1970s saw a movement of production away from private (Western) hands and into public (nationalist) hands. This is particularly true of OPEC. Today, OPEC generates approximately 40% of the world's production of crude oil, with nearly 75% of that coming from OPEC countries in the Middle East. To assess whether OPEC has been responsible for the rapid rise in prices, we need only look at OPEC's production as a percentage of world production, along with the growth of world production for recent years. Figure 10 shows OPEC's percentage of world oil production while Figure 11 shows growth of the world's production of oil. Clearly there has been no significant reduction in OPEC's share of world output anytime after 1992. However, there was a significant reduction in the growth of world production of oil. In this case, OPEC was not the sole factor as total growth in world production as a whole declined significantly to about zero in 2006. The reduction in output growth in 2001 and 2002 represents response of producers to the general recession period especially in the US. The same could be said 1999 with the fallout from the Asian financial crisis. The extremely fast growth in production that followed 2001-2002 is merely a rebound from the low production levels during the recessionary period.

However, the decline during 2005 and 2006 appears to be much more an attempt by producers to speculatively leave quickly appreciating oil in

Figure 11: Growth of World Production of Oil



Source: Energy Information Agency http://www.eia.doe.gov/emeu/aer/txt/ptb1105.html

the ground rather than on the market. We do not have complete data on world production of oil for 2007, much less for 2008, but Figure 12 shows that OPEC production increased during thisAssume that the output of each member, say X_t, of OPEC follows Saudi Arabia's output implicitly. In such a case, we could write a cohesion regression

$$X_t = \beta_o + \beta_1 Saudi_t + \varepsilon_t$$

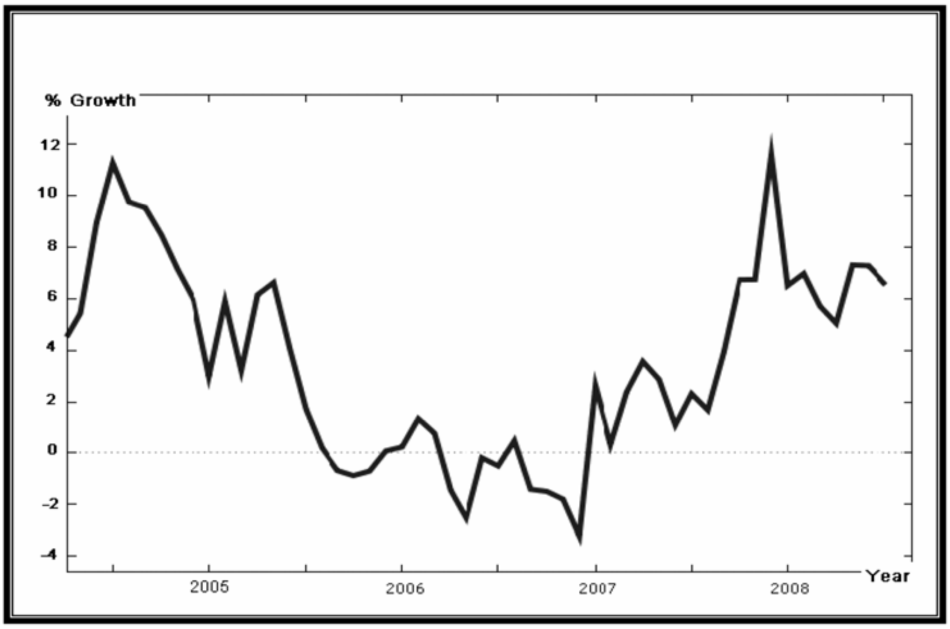
which would have a high R^2 statistic (say above 0.90) and would be stable (according time. This naturally leads us to the question of how disciplined OPEC has become. to standard regression stability tests), if the two countries were in strict cohesion. Using *monthly data* on OPEC production for each country over the period 1999:01 ~ 2008:07, we run the above regressions and then apply the QLR test for regression stability in order to identify the most likely period when structural change occurred. The results are in Table 6. In each case there is clear evidence of a structural break. This represents a break from lock-step behavior with Saudi Arabia. In addition, the R^2 statistics show that OPEC is not very united in its actions, having considerable variation of action within the group. It is obvious that smaller countries and those closest to Saudi Arabia have the highest correlations of their oil outputs with the Saudis. Iraq has a low correlation due to the war and the sanctions regime.

Both Figure 12 and Table 6 indicate that OPEC cannot be held responsible for the recent oil price increases. OPEC production, while decreasing substantially in 2006 along with world production, has expanded considerably in recent years.

6. Increased Use of Oil to Hedge US Dollar Denominated Assets

The very large trade deficits experienced by the US during the 1980's to present have generated large dollar reserve holdings outside of the US. Growth of these dollar holdings were known to be ultimately unsustainable (at such rates) and would involve a significant depreciation of the dollar against currencies of the US major trading countries. The view was that the US would not be able to remain the major destination

Figure 12: Growth of OPEC Oil Production



Source: Middle East Economic Survey http://www.mees.com/Energy_Tables/crude-oil.htm

for outgoing capital flows from surplus and high saving rate countries. Nevertheless, the US continued to run large budget deficits and the national saving rate remained extremely low during the Bush Administration. Large funds holding dollar assets began to diversify by buying gold, which led to a bubble in that particular commodity. This trend was exacerbated by the actions of some central banks deciding to hold more gold instead of US dollars as a reserve asset. Once it became clear that the US dollar was grossly overvalued, the dollar began to fall rapidly against the euro. Clearly anyone holding dollar assets needed a means of hedging against continued depreciation of the dollar.[28]

Table 6: OPEC Cohesion Regression R^2 Statistics

X = Country	R^2	Structural Break
Kuwait	0.81	2003.02
Qatar	0.74	2006:04
UAE	0.70	2006:03
Libya	0.62	2004:06
Iran	0.41	2003:02
Nigeria	0.31	2007:02 (2003:09)
Iraq	0.10	2000:12
Venezuela	0.10	2002:12

Source: Middle East Economic Survey http://www.mees.com/Energy_Tables/crude-oil.htm

Some economists have asserted that oil futures (and likewise commodity index futures) provide these large fund managers just the vehicle needed to hedge -- since buying such futures would be profitable if the dollar depreciated. The reason for this is simple. A barrel of oil can be sold in Europe or the US, which means that by arbitrage

28 By contrast, Akram (2004) has conversely considered how that changes in the price of oil can have an effect on the value of a currency.

$$(\frac{1}{e})P_{USD}^{oil} = P_{Euro}^{oil}$$

where $e = {USD}/{Euro}$ is the exchange rate. Any rise in this exchange rate (i.e., a depreciation of the US dollar) would result in a decrease in the Euro price of oil in Europe, *ceteris paribus*. Naturally, Europeans would view the rise of the Euro as lower oil prices for themselves and would respond by buying more oil. This increase in European demand (whether or not it is ultimately satisfied) raises the world demand for oil and powers the movement back to equilibrium. The price rises just enough to restore the arbitrage relation like before.

How much of the recent rise in the price of oil can be put down to a depreciating dollar?

To answer this question quantitatively we must consider daily data on both the price of West Texas Intermediate crude oil and the US dollar price of the Euro. A clear inverse relation exists between the US dollar price of the Euro and the US dollar price of oil. The Figure 13 shows this clearly. From 2002 to 2005 the US dollar depreciated substantially against the Euro; about 35%. Oil also rose in price during this time; roughly 125%. A similar episode occurred from 2006 to 2008. In this latter case, the Euro appreciated around 25% while oil rose around 130%. This latter case indicates a considerable strengthening of this portfolio effect, if it exists.

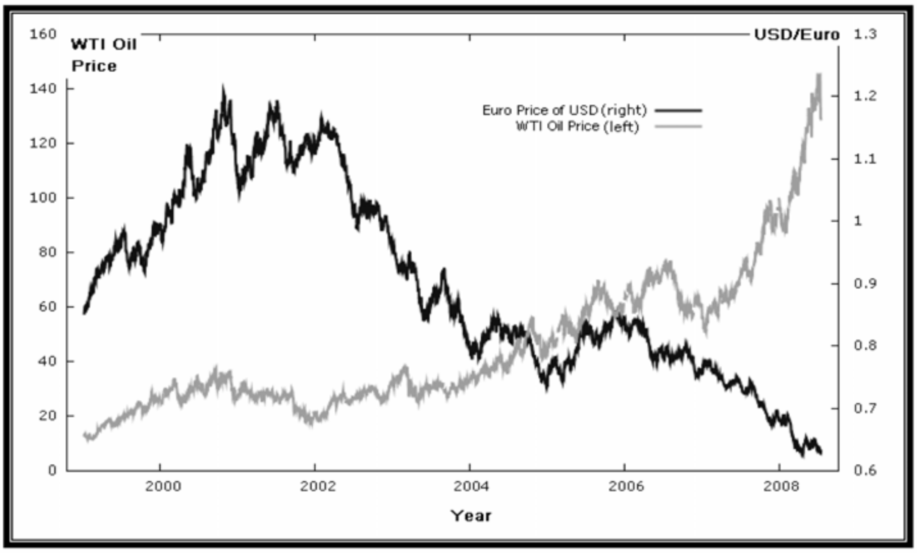
Regressions of the log of oil price on the log of the Euro and the log of the Japanese yen show elasticities of oil with respect to changes in exchange rates to be in the order of 3-3.5, which means that a 10 % fall in the value of the dollar would cause about a 30% rise in the price of oil. The regression in levels provides strong evidence that hedging of positions due to changes in exchange rates constitutes a main reason why there has been such an extraordinary rise in oil's price. Moreover, if instead we regress first differences in the log of oil price on first differences of the log of the exchange rate, we get an estimated elasticity of 3.2 which is very close to that estimated in levels. Unfortunately, the differenced data do not show any strong relation between the variables (i.e., insignificant t statistics) and the R^2 is nearly zero. This is mainly due to the fact that the level data have a long term discernible trend, while the high frequency short term data do not and are moreover highly contaminated with noise. The day to day changes in exchange rates are not significantly autocorrelated and are not correlated in a stable fashion with most economic variables, as has been pointed out by Hamilton.

7. Additions to Strategic Petroleum Reserves

The last reason we will consider for the recent rise in oil prices is the assertion that countries are excessively adding to their strategic petroleum reserves (SPRs) in order to ensure a steady supply of oil in the future at a reasonable price. This reason takes as a fundamental premise that oil is becoming increasingly and permanently scarce and is well subject to supply disruptions due to geopolitical events. Otherwise, there is no need to store oil at such high prices, since this period represents only a transitory period and oil prices will soon return to modest levels, making the storage both unwise and unnecessary.

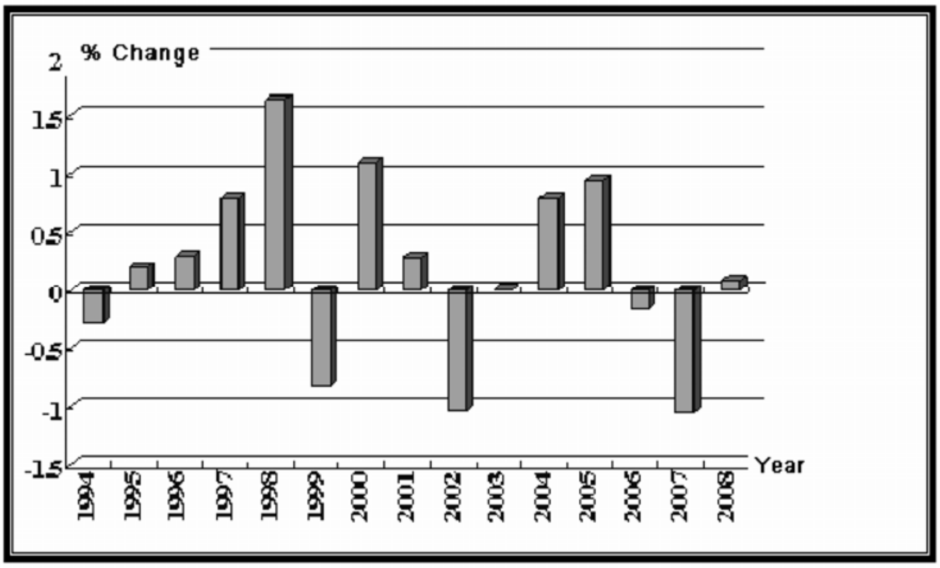
The very large negative value in Figure 14 for 2007 is at least consistent with a concerted attempt by various countries to store oil (but nevertheless list this in the statistics as commercial consumption). This hidden storage is in accordance with the 2002 entry both in percentage and sign. It is well known that in 2002 many countries, including the US, stored oil in preparation for projected hostilities in Iraq. The 2008 figure is a forecast and is clearly inconsistent with the enormous price rise that occurred during the early part of the year. As a result, this figure is quite likely to be revised downward in the future, once the actual data is tabulated

Figure 13: WTI Oil Price and the Value of the Euro



Source: Energy Information Agency and Oanda.com

Figure 14: Change in World Oil Stock as Percentage of Production



Source: EIA. Figures are computed as excess of world production of oil over consumption divided by total production for the world.

http://www.eia.doe.gov/emeu/international/contents.html

IV. Summary and Conclusions

As we have seen that there is no shortage of explanations for the recent rise in crude oil prices. All told, there are at least seven different factors helping to push prices up. However, it would be wrong to think that each of the causes has an equal impact on the value of oil. Some factors are clearly more important than others, at least at this point in time. This is of no little account, since identifying the proper set of causes for the recent price rise is important for both policymakers and for investors.

The sheer number of factors, the paucity of data having uniform frequency, global coverage, and high quality, and the ever-present problem of structural change forces anyone interested in this question to adopt a rather eclectic approach. The alternative of finding an encompassing model which could be used to cover all cases and eliminate hypotheses through formal statistical testing is simply not possible. Instead, we are forced to consider the effect of factors on oil's price one by one, sure in the knowledge that omitting one factor from another factor's analysis may very well bias the results. Judgment, reason and an open mind are all that can be offered in response to this.

The results of our analysis can be summarized by saying that roughly 40% of the recent rise in the price of oil can be explained by reference to fast growth in real world GDP. This figure may be slightly higher due to the emerging nature of China and India, but their overall contribution to world income and thus to world demand for oil is still limited. Another 10-20% of the price of oil is probably due to rising tensions in the Middle East (and in particular the Persian Gulf) which political scientists refer to as geopolitical risk. The residual portion of the price rise is due to spot purchasing and storage due to a combination of speculation, hedging of US dollar assets, and strategic storage. This latter forcing will subside once storage reaches levels that satisfy those involved. In other words, perhaps 40% of the pressure on oil's price to rise will abate if the US dollar stabilizes and bearish sentiments force those accumulating reserves to stop. Given that such pressures drove the price to a high of over $140 per barrel, a 40% drop in price from this high would put the price of oil at roughly $90-$100 during 2008-2009.

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