Explaining the Price of Oil 1861–1970: The need to use reliable data on oil discovery and to account for 'mid-point' peak

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Abstract

This paper explains the price of oil, in broad terms, from 1861 to 1970. Over this period the oil price was influenced by many factors, including technological progress, market forces and actions by governments and cartels. But we point to a main factor as being the amount of conventional oil (i.e., oil in fields) that had been discovered. Over most of this period the quantity of oil discovered in fields ran far ahead of demand, and this in turn led to chronic potential over-supply. A variety of methods was used by industry and by governments to try and control the oil supply, and hence to prevent the oil price from falling to ruinous levels.

To understand this potential for over-supply of oil over this period requires reliable knowledge of the rate that conventional oil was being discovered. This information, unfortunately, cannot be derived from the widely-available public-domain *proved* ('1P') oil reserves data, which have been very misleading, and instead must come from the oil-industry backdated proved-plus-probable ('2P') data. Accessing the latter data, however, has generally been difficult or expensive.

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Examining the potential for oil over-supply also requires an understanding of the decline in the production of oil in fields that occurs typically once a region's production 'mid-point' is passed. This 'mid-point' peak results from a region's field-size distribution, its fall-off in discovery, and the physics of field decline.

Lack of understanding these two factors; the quantity of conventional oil discovered, and the 'mid-point' peak, has led in our view to incomplete explanations for the price of oil.

1. Introduction

This paper sets out to explain the price of oil, in broad terms, from 1861, that is, from around the start of significant US drilled commercial oil production, up to the year 1970. A related paper (Bentley & Bentley, 2015) continues this explanation for the period 1971 to the present day.

Figure 1 shows the price of oil between 1861 and 2013, in both money of the day ('nominal', or current-terms), and after adjustment for inflation (real-terms). Data are from the BP *Statistical Review of World Energy,* 2014 edition.

Despite obvious caveats with such long-run data, it is clear that there have been three significant periods of high real-terms oil price (taken here as a real-terms price >$40/bbl): prior to about 1880, from 1973 to 1985, and since 2004. At other times the price has mostly been below this level, with a marked long period of generally declining price from 1920 to 1973.

There have been numerous attempts to explain the price changes shown in Figure 1, often relating to longer or shorter date sequences within the period shown. A brief review of some of the more recent literature in this area is given in Bentley & Bentley (2015). Generally, the explanations for the price of oil seem to have been sought from correlations with economic indicators, examination of the oil available as indicated by proved ('1P') reserves, or from analysis of external factors such as imputed OPEC behaviour, etc.

In our view, the explanation for the price of oil over the period covered by Figure 1 needs, in addition, to include several factors that tend to have been under-recognised in the literature. These are:

- the difference between conventional and non-conventional oil;
- the need to have a reasonably reliable indication of the amount of

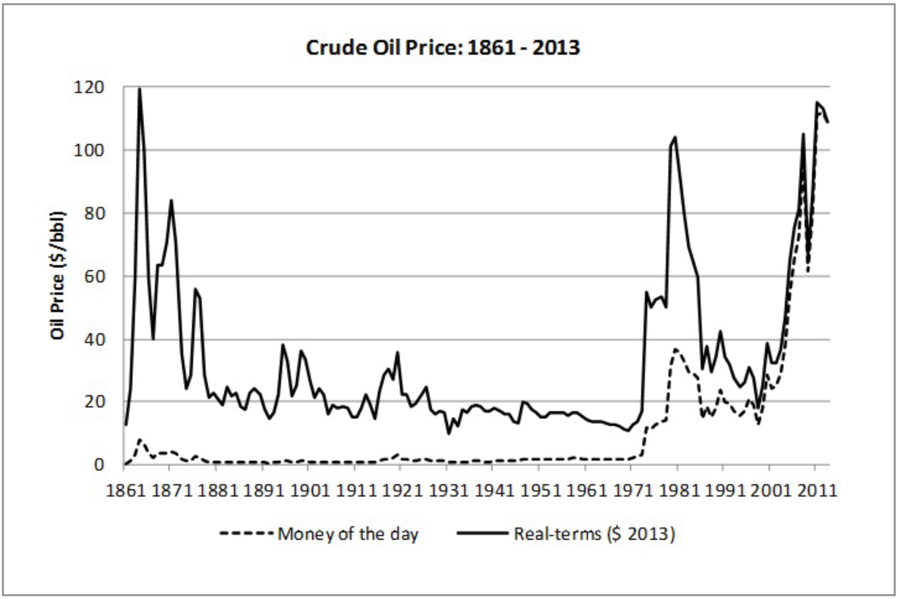

Figure 1. Crude oil prices (in money of the day and in real terms): 1861 to 2013.

Data: 1861-1944: US average; 1945-1983: Arabian Light posted at Ras Tanura; 1984-2013: Brent dated. Source: BP Statistical Review of World Energy, 2014.

Notes:

The chart in the BP Stats. Review annotates significant events effecting oil price.

The oil price at the start point of this chart is somewhat misleading: Prior to the US 1859 Drake well, oil in the region from 'surface springs and salt wells' was selling at a today's real-terms price of from $750 to $2,000/bbl. By the end of the following year, due to the resulting Pennsylvania oil boom, the local price of oil had fallen to $50/bbl in real-terms, and as low as a $2.50/bbl real-terms by the end of 1861. But then a combination of reduced drilling, a tax on alcohol (an alternative illuminant) and the effects of the Civil War caused the oil price to rebound sharply, as shown in the Figure (Hamilton, 2011).

Slightly different data are given in the chart on page 792 of Yergin (1991).

conventional oil discovered at any given date; and

- the need to account for the 'mid-point' production peak of this class of oil.

We recognise that knowing the amount of conventional oil discovered has been difficult for many analysts because of the difficulty in accessing the relevant oil industry data, and we suggest that this has contributed to some of the past historical weakness in the analysis of the price of oil. In addition the 'mid-point' peak in production has often been poorly understood.

The next section looks in more detail at these factors, and also at a number of other factors, that have affected the price of oil.

2. Background Information for Explaining the Oil Price

2.1 Conventional oil vs. non-conventional

(Note that this section, and Section 3.2, is taken from Bentley and Bentley, 2015.)

In this paper we make a critical distinction between conventional and non-conventional oil. This is because it has been the quantities of *conventional* oil discovered at different points in time which, along with technological progress, has been the main driver of the oil price over the last century and a half.

The term 'conventional oil' takes many meanings, but here it is adequate to take it as referring simply to *flowable oil in fields*, i.e., oil within a trap that under a 'standard' drive mechanism (own-pressure, mechanical lift, or gas- or water-drive) is able to able to flow to a production well. The bulk of all oil production currently, and by far the largest part of that historically, has been of conventional oil.

By contrast, 'non-conventional' oils tend to be found in extensive regions (within which there may be 'sweet spots'), and where flow to a production well is not possible without significantly changing the nature of the oil (for example, by heating, or treating with a solvent), or the surrounding rock (for example, by fracking, or sometimes by mining). Such oils include 'light-tight' oil, very heavy oils, oil from tar sands, and the oil pre-cursor kerogen in shales and other rocks.

(Note that oil *production* data often include not only conventional and non-conventional oil, but also 'other liquids', such as natural gas liquids, 'NGLs', coal or gas to liquids, and sometimes biofuels.)

The reasons for making the distinction between conventional and non-conventional oil are twofold: production cost, and energy return:

Production cost

We need to ask why, over the last century and a half, have we used in the main conventional oil (i.e., oil in fields), rather than oil from the many non-conventional sources that exist, and where some of the latter (such as oil from biomass, and from coal and kerogen) were used extensively before conventional oil came to dominate? The answer is simple: Up until now the oil in fields has usually been far cheaper to produce than these other oils. This is because oil in fields flows easily, is concentrated geographically, and often yields large flow rates when produced by relatively simple drive mechanisms, such as its own pressure, gas-drive or water-flood.

For example, in terms of flow rate, while the 1859 Drake well in the US yielded up to about 20 barrels of oil per day (b/d), only two years later the first major US gusher yielded 4,000 b/d, and in 1901 the Spindletop field in Texas flowed at 100,000 b/d. In these early years such flows were often short-lived, but subsequently large fields have typically yielded over 500,000 b/d for considerable periods of time; while the Middle East giants produce 1 million b/d and above, and the world's largest field, Ghawar, averages over 5 million b/d. Thus, once located, oil from large oil fields has generally been intrinsically cheap to produce due to relatively easy production methods and high flow rates.

While it is true that the 'petrol tank does not care' what type of oil (conventional or non-conventional oil) is used, the user certainly does. The user would far prefer pre-1973 conventional oil at its long-term real-terms average price of \$15/bbl, or even post-1985 average price (up to the 2004 increase) of \$30/bbl, than to have to pay ~\$60/bbl for US light-tight oil, or the > \$160/bbl for the 'Canada oil sand mine upgraded' oil cost estimated by IHS–CERA, or the full cost - whatever it will be - of retorted kerogen oil plus carbon capture, or of synthetic fuel made from electrolysis of water plus CO_2.

Energy return

A second reason to distinguish conventional oil from non-conventional is that nearly all of the non-conventional oils have lower energy returns than conventional oil. The data are hard to establish unequivocally, but Hall and Day (2009) suggest that the ratio of energy return on energy invested (EROI) for conventional oil was about 30 in the 1930s, rising to 40 in the 1970s as scale increased and technology improved, and subsequently falling, with the more difficult conventional oils, to a ratio of perhaps 14 today. By contrast, nearly all non-conventional oils have lower energy ratios; tar sands, for example, being quoted as having ratios of from 1.5 to 8, and corn ethanol also low. Since Hall *et al.* calculate that modern society will have difficulty in functioning if its fuels have energy ratios of less than perhaps 5 to 10, the current transition from mainly conventional oil to increasing quantities of non-conventionals is likely to be significant.

2.2 1P reserves vs. 2P.

Next we look at the difference between 1P and 2P reserves (see also Bentley *et al.*, 2007). The *reserves* of an oil field give an estimate of the amount of recoverable oil remaining in the field at a given point of time. The *resource* of the field, by contrast, refers to the total amount of oil in-place, and thus includes the oil that is recoverable and unrecoverable. (By volume average, perhaps some 40% of the global oil-in-place in fields is recoverable under reasonable technological and economic assumptions.)

For a region comprising a number of fields, there are also fields yet to find. Here the term 'reserves' refers only to oil that has been discovered. The resource for a region, by contrast, includes the estimated amount of oil yet to be discovered. Thus at a given point in time, a region's ultimately recoverable resource (URR) is given by:

URR = cumulative production to-date + reserves + recoverable oil yet-to-find

but this estimate can be expected to change with the recovery technology used, and the price of oil.

Public-domain proved ('1P') oil reserves data

Annual summary tables of oil reserves data given in the public domain are usually of *proved* (1P) reserves, for example those in the BP *Statistical Review of World Energy*, the annual tables in *World Oil* or the *Oil & Gas Journal*, or on the US Energy Information Administration (EIA) website.

Although such reserves data are used in company reports they have been extraordinarily misleading on the actual quantity of oil discovered, especially in the past, and they generally cannot be used to forecast oil production despite many analysts having done just this. The problems with proved reserves include under-statement, over-statement, and non-statement. Instead, the oil industry *proved-plus-probable* (2P) reserves data must be used. Both categories of reserves are discussed in more detail in Appendix 1.

2.3 The 'mid-point' production peak of conventional oil

Though it has long been known, still too often overlooked is the fact that production of conventional oil in a region typically reaches its '*resource-limited*' maximum and subsequently declines when *only roughly half* of the region's recoverable resource of such oil has been extracted. Three factors taken together provide the basic mechanism for this: the region's field size distribution, its field discovery sequence, and the physics of field decline. A simple model that explains the mechanism of 'mid-point' peak, and also why this peak is counter-intuitive, is given in Appendix 2.

3. Factors Influencing the Price of Oil: Over-supply, & Other Factors

3.1 Over-supply: The discovery of too much conventional oil

So now the question is: What does the above information (conventional vs. non-conventional oil; 1P vs. 2P reserves, and mid-point peaking) tell us about the price of oil?

The answer lies in Figure 2. This gives the cumulative backdated 2P discovery data from 1900 to 2011 from one major industry source (IHS Energy), and compares these with the cumulative production data over the same period.

As Figure 2 shows, from 1920 (and possibly from before, but where clearer pre-1920 2P data would be needed) up until around 1965 (the inflection point of the discovery curve) the discovery of *conventional* oil as measured by backdated 2P data raced far ahead of production, and put large quantities of conventional oil 'in the bank' as 2P reserves.

But the rate of conventional oil discovery peaked around 1965 (some fifty years ago) and from that date forward increases in production were catching up on declining discovery. Even so, up until about 1980, the rate of discovery was still the greater, and hence the volume of oil 'in the bank' as 2P reserves was still increasing. But about 35 years ago, around 1980, global production finally caught up with discovery of oil in new fields, and from that point onwards the reserves of conventional 'in the bank'

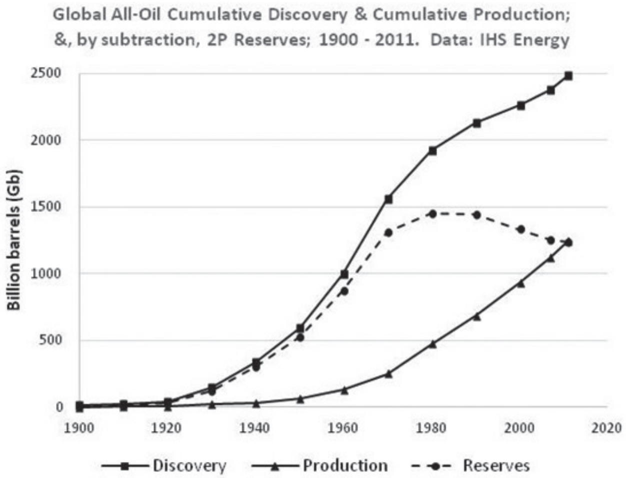

Figure 2: Plot of oil-industry backdated mainly proved-plus-probable ('2P') data for global cumulative 'all-oil' discovery vs. corresponding production, 1900 - 2011.

Notes:

- Data are from IHS Energy, and are 2P except for the US and Canada where the data are proved ('1P') data.
- Both discovery and production are for IHS Energy's 'Liquids' category, and hence comprise: crude oil, condensate, NGLs, light-tight oil, very heavy oils, oil from tar sands, and Orinoco oil. These data exclude liquids from GTLs, CTLs, biomass, and refinery gain.
- The plot is generated by reading data at 10-year intervals from Figure 7 of Miller and Sorrel (2014) for cumulative discovery from 1900 to 2007, and from the corresponding Figure 3 for cumulative production over the same period. Included in this plot are the data for end-2011 as given in the text of Miller and Sorrell.
- IHS Energy data are for oil in fields for conventional oil; and as announced in projects for non-conventional oils. Data are largely for conventional oil up until about the year 2000, after which significant amounts of tar sands and Orinoco oil projects were included, and most recently also data for 'light-tight' oil projects.
- Note that the 2P data are backdated in that they reflect information available to the IHS Energy as of 2007 (for the discovery curve), and to 2011 (for the final discovery data point).
- Reserves data are calculated here (as also by IHS Energy) by simply subtracting cumulative production from cumulative discovery, and therefore are 2P reserves data (except for US & Canada).
- As the plot shows, the global proved-plus-probable (2P) all-oil reserves at end-2011 were ~1250 Gb. This contrasts to the corresponding end-2011 value for global proved only (1P) all-oil reserves (from BP Stats.) of 1652 Gb. The difference, as explained in the paper by Laherrère in this issue of The Oil Age, is likely to be mainly in the probable overstatement of Middle East OPEC proved reserves; plus differences in the non-conventional oil quantities

started to be drawn down, although allowance must also be made for technologically-driven 2P 'reserves growth'.

Today, as Figure 2 shows, this long period of potential global over-supply of *conventional* oil (oil in fields) is drawing to a close. Though there still remains today about 50 years' worth of 2P reserves of conventional oil 'in the bank', the 'mid-point' rule says that production of this oil is close to its decline. This can be seen from the Figure, where a reasonable extrapolation of the 'conventional oil only' discovery curve (i.e. the curve up to about the year 2000) might be seen as some 2500 Gb for the global conventional oil URR, and where production of this oil has reached roughly half of this, at about 1250 Gb. Though the actual details of the global oil peak are complex (see Bentley, 2015b), this simple calculation says that the peak of global conventional oil production must be close.

The final question of this section is then: How have these long-term discovery and production trends affected the price of oil? As Figure 2 shows, the entire period from at least 1920 up to about 2004 has been one of *potential* over-supply of conventional oil, because much more of this class of oil was discovered over this period than was used; and hence it has been this potential for over-supply that has helped keep the price of oil low for most of this period. (Note that the relatively brief period of high oil price from 1973 to 1985, due in part to the US peak, is discussed in Bentley and Bentley, 2015.)

For much of the period of Figure 2, from at least 1920 up to 2004, the potential for over-supply of oil has been at least partly managed, variously, and to a greater or lesser degree, by the following:

- quasi-monopoly of supply in both the US and Russia in some of the very early years;
- subsequently by agreements, often imperfect or short-lived, between oil companies;
- by government encouragement, or government edict; such as in times of war, or the long period of US pro-rationing;
- by the 'Severn Sisters' husbanding production in major oil provinces overseas;
- and mostly recently, up to about 2004, and even today to some extent, by OPEC control.

It is a fascinating story, and Section 4, below, gives greater detail on the period 1861 to 1970.

3.2 Other factors that have influenced the price of oil

Of course other factors, in addition to the quantity of conventional oil discovered and the mid-point peak, are also important for understanding the price of oil. Three of the more general of these are: improvements in knowledge, improvements in technology, and the need to access the more difficult oil. These are described in more detail in Appendix 3.

4. Explaining the price of oil: 1861 to 1970

With the information of Section 3 now in place, we are in a position to address the main aim of this paper: to explain in broad terms the evolution of the oil price between 1861 and 1970. Note that the following is based in large part on Yergin's outstanding book *The Prize* (1991). It would be hard to imagine a better-written or more insightful description of the history of oil, with its dramatic twists and turns, deep political implications, and fascinating cast of characters. In the following, references to Yergin are given simply as: (Y, page x). Mention must also be made of the excellent papers by Hamilton, including Hamilton (2009 and 2011).

4.1 1861 to 1900: Boom & Bust before the Motor Age

Prior to about 1900, oil was used for mainly lighting. In terms of price, in the mid-1800s whale oil in the US typically went for between $500 and $1500/bbl in today's money, depending on catch and demand (Pees, 2015). Poorer lighting oils came from a wide variety of sources, including coal, and were generally somewhat cheaper. The advent of kerosene from 'rock oil' changed the picture dramatically, and gave cheap lighting to the many.

Oil production from 1861 to 1900, especially in the US, was an age of boom and bust, resulting in significant oscillations in the price. A key factor in the US was 'flush production'. Once a new petroliferous province opened up, the 'rule of capture', lack of knowledge of any field's probable lifetime, the presence of multiple independent operators, many mobile workers, and simple greed meant that individuals and companies had every incentive to produce a region as fast as drilling would allow.

Note that while there were plenty of 'busts' in production that applied to individual fields (and to the economic life of towns that relied on these fields) overall production generally (though not always) increased, and large price oscillations generally resulted when supply significantly outpaced demand.

The first US supply boom was that of Pennsylvania. Following Drake's well in 1859, oil production grew rapidly, reaching ~0.45 Mb/y in 1860, and 3 Mb/y just two years later. Not surprisingly, over-supply ensued, and the oil price fell dramatically, from $10/bbl in January 1861 to 10 cents/bbl by the end of that year. But demand for the new wonder lighting oil soon caught up, and the price was back to $7.50/bbl by September of 1863 (Y, p30).

New fields led to serious over-supply in the 1870s, and numerous attempts were made to agree curtailments in production. All came to naught however, primarily because of the large numbers of players involved and their typically independent outlook (Y, p42)

As Figure 1 shows, from 1880 the oil price swings became less severe. This was partly because the price-setting supply/demand balance had begun to become international. The US was shipping kerosene to Russia and Europe as early as the American Civil war (Y, p30); while the other major producer, Russia, saw production expand nearly 20-fold in the decade 1874 to 1884 (from 0.6 Mb/y to 10 Mb/y), with its own exports starting from around 1882 (BP, 2014).

A significant factor in oil's price in these early years, both within the US and internationally, was the growing ownership by Rockefeller's Standard Oil Company. At times this amounted to near-monopoly; initially of oil refining and transport, and later of supply to some degree. The issue was finally partly addressed by the US 'trust-busting' legislation against Standard in 1911 (Y, p110). There is no doubt, however, that though the combine's commercial practices in terms of trying to force reluctant partners to join the Standard camp were often brutal, its willingness to expand rapidly, make large speculative investments, standardise product, and market aggressively allowed it to introduce new technologies and achieve major efficiencies of scale that led in turn to dramatic reductions in product cost, and hence in the price to the consumer.

Crucially around this time, new US provinces began to open up. Ohio and Indiana in the mid-1880s, then Colorado and Kansas, then California and Texas in the 1890s. (Note that California had short-lived discoveries in the 1860s; while production from Texas in the 1890s was only small.) Outside the US, oil was found in Sumatra in 1885; and in Borneo in

1897, with its first gusher in 1898 (Y, p116). By contrast, also in 1897, the Sumatran wells began watering out, and 110 dry holes followed before a big new field was found in 1899 (Y, p118).

No-one should underestimate the immense amounts of capital and effort it took to find and produce oil; with this leading later to the intrinsic tension between the oil companies and concession holders that became a near-permanent feature of the industry. In terms of the price, though supply increased rapidly in the 1890s, so too did demand (including from the Boer War in 1899 (Y, p117)), and the price kept generally high.

Despite the booming production, seeing what could happen to individual fields and to regions, there were many voices of caution; and the fear was always of shortage. In 1885 the State Geologist of Pennsylvania warned that "the amazing exhibition of oil" from Pennsylvania's 'Oil Regions' was only "a temporary and vanishing phenomenon – one which young men will live to see come to its natural end" (Y, p52).

This view (though probably premature in its timing) was substantially correct: Pennsylvania's 'amazing exhibition' did indeed come to an end within a young man's lifetime, when its production of conventional oil peaked in the late-1930s (at ~19Mb/y). Production then steadily declined, falling as low as its 1860 volume (3 Mb/y) by the second 'oil shock' of 1978. Small resurgences in production resulted from the high price then, and post- 2002, but the State Geologist's 1885 view of inevitable decline of oil from fields within 'a young man's lifetime' was essentially correct.

4.2 1900 to 1920: Oil price in the early Motor Age

From 1900 a major change in the oil market took place as result of innovations having roots in the 1880s. In 1882 Edison had demonstrated commercial electrical generating plant and lighting, while in 1886 Karl Benz had patented the petrol-powered car. From 1900 the impact of these inventions was becoming significant: car registrations in the US, for example, rose over 100-fold from 1900 to 1912 (8,000 to 902,000, Y, p80), and globally gasoline sales, mainly for vehicles, first exceeded those of kerosene, mainly for lighting, in 1910 (Y, p112).

Markets had a new reason to grow rapidly - provided supply could keep up.

Supply could indeed increase, on the back of major new discoveries: In January 1901 Spindletop in Texas came in as 75,000 bbl/d gusher, sending the local price of oil down to 3 cents/bbl; oil was discovered in Oklahoma in 1901 (and in its Glenn Pool in 1905), and significant first discoveries occurred also around this time in Louisiana and North Texas.

Outside the US, major finds were made in Persia in 1908, and in the 'Golden Lane' in Mexico in 1910. But overseas demand and supply also had its risks: famine in Russia in 1900 reduced its demand for kerosene, which was then dumped on the world market impacting the global price (Y, p117), while the 1905 revolution in Russia's set her main producing fields, in Baku, ablaze.

Despite such uncertainties, throughout the early part of this period, over-supply became the dominant concern, and to prevent disastrous price cutting many agreements and 'near cartels' between companies were discussed, and some enacted. For example, fears of potential competition on the supply side led Burmah Oil in 1905 to bow to pressure from the UK Admiralty to rescue D'Arcy's concession with the Shah in Persia; while on the marketing side, and partly triggered by rising production in Rumania, Deutsche Bank joined the Nobels and the Rothschilds with their Russian oil to form the European Petroleum Union in 1906, which then cut deals between themselves and with Standard Oil over market share (Y, p132). Over this period, the oil price roughly halved, from about a today's real-terms $35/bbl to under $20/bbl.

However, concerns about over-supply waned dramatically with the First World War, during the course of which the oil price doubled, back to a peak of about $35/bbl. The connection between waging war and the need for a secure supply of oil was becoming apparent. Churchill's decision in 1912 to turn the UK Navy's new capital ships to oil burning is well known; perhaps less so were the many steps by governments around the world, but primarily by Russia, the US, the UK and France, both before and during the First World War, that were aimed at obtaining security of oil supply. Clemenceau had declared that gasoline would be "as vital as blood in the coming battles", and efforts to secure and manage wartime supply included the UK's 1914 decision to invest £2.2 million (in money of the day) in Anglo-Persian to obtain 51% of its stock, the setting up of an Inter-Allied Petroleum Conference during the war, and likewise of the US Fuel Administration (Y, p161, p178).

After the war (when US motorists had to endure 'gasolineless Sundays'), increasing evidence of decline in known basins, coupled with recognition of the growing importance of oil to economic activity, reversed the pre-war concern about oversupply to that of almost-certain shortage.

In 1919, the director of the US Bureau of Mines predicted that "within the next two to five years the oil fields of this country will reach their maximum production, and from that time on we will face ever-increasing decline." The USGS warned of a possible "gasoline famine", and that US known oil reserves would be exhausted in nine years and 3 months. President Wilson noted that: "There seemed to be no method by which we could assure ourselves of the necessary supply [of oil] at home and abroad." The oil price supported these fears: in the US the oil price rose 50% between 1918 and 1920 (from $2 to $3/bbl in money of the day), and the winter of 1919-20 saw a shortfall in oil supply (Y, pp 194-5).

What was to be done? Should the US (then producing two-thirds of the world's oil) fall back on oil from shale, and likewise the UK on oil from coal, as some advised, or should industry explore more overseas? Now strongly backed by their various governments due to lessons from the war, the industry chose the latter.

4.3 1920-1970: The Long Price Decline

Despite these widespread fears of shortage, from 1920 the oil price entered a remarkable fifty-year period of on-average steady decline.

What happened? Firstly the US reserves data quoted by the USGS were *proven* reserves, where these were much less than the known reserves that had actually been discovered. (On *proven* reserves, the US R/P ratio has remained fixed at close to 10 years of supply for well over a century – misleading many analysts to the present day!). Secondly, significant finds were made in the US, including Signal Hill in California, the Greater Seminole field in Oklahoma in 1926 (which yielded 527,000 bbl/d), and the Yates field in Texas which opened up the US Permian Basin (Y, p223). Thirdly, production overseas continued to grow. Russian oil had been constrained, first under the Tsar and then by the 1917 revolution, but in the 1920s it began ramping up again. Elsewhere oil production also flourished, from the East Indies, Persia, Rumania and Mexico, and now also from new finds in Venezuela.

The problem for the producers thus became not one of shortage, but how to manage over-supply. This led to the Achnacarry 'As-Is' agreement of 1928, where participating companies agreed quota in different markets based on existing market share; and later also agreed actual production levels. In the event there 'were too many producers, and too much production, outside the 'As-Is' agreement for it to work' (Y, p265), but nevertheless a variety of marketing deals and understandings enabled the oil majors avert much in the way of major price wars.

The over-supply situation worsened with the discovery of the East Texas field in 1930. With a URR of ~6 Gb, this remains the largest conventional oil field discovered in the US Lower-48, and its discovery helped set the global oil pricing regime for the next forty years.

In East Texas itself the oil price collapsed, falling from an average of $1/bbl in 1930 to 15 cents/bbl by May the following year. This, coupled with a similar price collapse associated with the Seminole field in Oklahoma a little earlier, finally concentrated minds, and between about 1933 and 1935 Harold Ickes with Roosevelt's strong backing was able to formalise 'The Oil Code' that brought about prorationing of much of US production (Y, Chapter 13). Prorationing had been suggested earlier in the US on the back of fears of oil shortage, and hence of the need to manage output to prolong field life, but had always been vociferously defeated, mainly by the independents. The heroic alignment of interests that finally secured the measure is summarised in (Y, pp 258-9).

On its actual mechanism, Wikipedia (accessed 9th Feb. 2015) writes:

> *"Allowable oilfield production was calculated as follows: estimated market demand, minus uncontrolled additions to supply, gave the Texas total; this was then prorated among fields and wells in a manner calculated to preserve equity among producers, and to prevent any well from producing beyond its Maximum Efficient Rate (MER). Scheduled allowables are expressed in numbers of calendar days of permitted production per month at MER."*

Although this related specifically to Texas, under the control of the Railroad Commission the Texas allowable took into account production in other US states; and some of these in turn had their own prorationing mechanisms. The result was near US-wide prorationing of production from the mid-1930s; and for which, to stem a potential flood of imports, a tariff on oil imported into the US was needed, enacted from 1932 (Y, p 258).

After the price fall of 1930/31, Figure 1 would seem to indicate a long period of market stability and calm.

In fact this was very far from the case, and three major new forces began to play out in the oil markets of the world; the surprise being that the oil price reacted so little. These forces were nationalisation, big new finds, and arguments over rent; and there was also the matter of oil disruption in the Second World War to contend with. We discuss these in turn.

(i). Nationalisation

The UK government's 1914 purchase of a stake in oil production was described earlier; and Russia had nationalised much of its oil industry in 1918, though later Lenin had to open this up to outside help. In the years 1920 to 1971 covered in this paper there was a spate of nationalisations: Bolivia in 1937 (and again in 1969), Mexico in 1938, Iran 1951, Brazil 1953, Iraq 1961, Burma and Egypt in 1962, Argentina 1963, Indonesia 1963, and Peru in 1968. (Wikipedia, accessed 12 Feb. 2015).

The motives were various, and the periods before and after each nationalisation were usually extremely fractious and difficult both for companies and governments alike. Part of the motive was undoubtedly transferring rent from the producing companies to government (see below); but simple national pride, and the desire of leaders (particularly despots) to secure support at home by blaming outsiders also weighed heavily. For example, Mexico's struggles concerning nationalisation, and its impact on the oil companies, and on production, were fairly typical, and are described in (Y. pp231-233, and pp271-277).

(ii). Big new finds

A second major factor that one would have thought would have had a dramatic effect on oil price over this period was the very large new finds in the Middle East. Using data from Nehring (1978), which he cautions were often low estimates, Middle East fields with URR's over 10 Gb were discovered in this period as follows: in Persia: Gach Saran, discovered in 1928, URR = 16 Gb, Agha Jari (1938, 14 Gb), Ahwaz (1958, 18 Gb), Marun (1964, 16 Gb) and Fereidoon-Markan (with Saudi. Arabia) (1966, 10 Gb); and in Iraq: Kirkuk (1927, 16 Gb) and Rumaila (1953, 20 Gb).

As for oil in the Arabian peninsular, as late as 1926 some in the industry considered the region "devoid of all prospects" (Y, p281). But a small find in Bahrain in 1932 was critical, as it indicated that oil could also be found on the Western side of the Persian Gulf. Large finds here were: Kuwait: Burgan (1938, 72 Gb); Saudi Arabia and the Neutral Zone: Abqaiq (1940, 13 Gb), Ghawar (1948, 83 Gb), Manifa (1957, 11 Gb), Safaniya (1951, 30 Gb), and Barri (1964, 12 Gb); and Abu Dhabi: Zakum (1964, 12 Gb). By the time DeGolyer, following a mission to appraise the oil potential of the Persian Gulf, reported to Washington in 1944 (i.e., even before the discovery of Ghawar) he suspected total Middle East oil reserves could be up to 300 Gb. Indeed, the State Department was told by a member of the mission that: "The oil in this region is the greatest single prize in all history" (Y, p393).

(iii). Rent

Third in this list of factors that would be expected to impact oil's price during the period of the 'long price decline', we include arguments over rent. Although early nationalisations were partly about rent, it was perhaps only after the start of major finds of the Middle East that the issue of the division of rent between producer companies and governments came to be approached on a consistent basis.

Rent had been moot of course from the beginning. If a government granted exploration and production rights to its land, and a company then brought in expertise and risked very large investments, how should the potential rent be split? In the early days in the Middle East, for example, concession fees were often set simply by how empty were the coffers of the concession giver. Later, once oil was found and being produced, the topic became subject to ever-more fraught negotiation, with each side often deeply suspicious of the other.

Yergin gives a good description of the problem. Eventually, in many cases, both sides came to accept the concept of a 50:50 split; producing companies and owner governments each getting roughly half of the profits from the oil. Venezuela was the first to follow such a formula in 1943, and others followed. However, after a while even this became contentious, with oil-owning governments noting that the *countries* of the oil companies were getting the majority share, via company profit *plus* government taxes, and new formulae were requested.

The stage was set for OPEC. The latter had been set up in 1960, modelled on the Texas Railroad Commission concept of prorationing. Initially not particularly effective, OPEC's resolve was strengthened when global oversupply led first BP, and later Jersey [Exxon], to seek to reduce the *posted* price of oil, and hence undermine the 50:50 formula. But when OPEC tried more than once to raise prices *prior to1973*, the US opened its taps and the global supply balance was restored.

(iv). The Second World War

Finally we look briefly at the impact of the Second World War on the oil price. Readers wanting to understand this war could do a lot worse than look at Yergin's excellent coverage, where access to resources (oil in particular) explains much of the causes of the war, and also some of the major strategies adopted within it. However, despite massive disruptions in supply, this time, unlike in the First World War, there was little impact on the global oil price due to cooperation, planning and controls. In the war itself, oil was to prove crucial. For the Axis powers, despite programmes to produce oil from coal in both Germany and Japan, military activity slowly ground to a halt due shortage of oil; while for the allies' supply was always just adequate, in significant part due to production from the East Texas fields.

5. Discussion

In this Section we look at the information above in rather broader terms.

5.1 Price stability from 1920 to 1970

Given the information above, the question thus remains: How, for 50 years from 1920 to 1970, in the face of nationalisations, super-giant finds in the Middle East, shifts in the distribution of rent, and global war, did the oil price remain on its apparently placid downward path for so long?

The answer during the Second World War (as indeed partly also the case in the First) was almost certainly in large part because of the bodies set up by the allies to allocate oil supply, ration demand, and control price. But in the two long peacetime periods before and after this war, it is harder to identify definite causes.

Among these, however, must be the following: the fundamental global oversupply throughout this whole period as described earlier; the impact of the great depression from 1929 in reducing growth in demand; the major impact a little later of US prorationing, smoothing the price consequences of changes in supply and demand; and, especially in the years after the Second World War, market control by the 'Severn sisters' oligopoly in trying to prevent over-production (often against the wishes of the owners of the oil!) by the main Middle East producers.

5.2 Why was there potential over-supply?

It is a deeper question, and one of economic theory, to ask why was there this potential for over-supply: Why would oil companies spend oil exploration effort and dollars when already too much oil was to hand?

The answer is provided by the details within Yergin's *The Prize*:

- Sometimes the large reserves were held by a company with a small market, and vice versa, so that a company in the latter category needed to look for more.
- Sometimes it was simply the entrepreneurial spirit of 'independents' to look for more; originally the relatively small independents in the US fighting Standard Oil, and then fighting the US majors that appeared (many spawned from Standard). But subsequently the 'independents' were the smaller (but still large) newer oil companies (ENI, for example) that were prepared to take on large exploration risks in order to break the market stranglehold of the very large incumbents.
- Also, as Campbell notes, for commercial companies exploration is fully tax deductible, and hence can be nearly free to these companies.
- But almost certainly the main reason to keep finding ever more oil, even when the global 2P reserves were already large, was that once the reserves were 'overseas' (outside of the US; or both within or outside Russia in the case of the main Russian suppliers), these reserves were not nearly as large as they seemed. Such 'overseas' reserves were always at the risk of higher rent, nationalisation, or complete loss (from the oil company's point of view) from embargo, revolution or war. Yergin has good sections on how CEOs of the oil majors saw these risks. Thus, counter to a pure 'economic' view, there was *always* a strong need for individual companies to find more oil.
- And in this context, in terms of reserves, it is important to differentiate an 'Adelman' view of 'oil reserves being just inventory', to always be replaced as and when needed (a view, it must be admitted, solidly supported by the data on the apparent continual replacement of *proved* (1P) reserves, especially in Canada and the US; but in the UK and many other places also) from the reality of the proved-plus-probable (2P) reserves of conventional oil (oil in fields) being decidedly finite, and in decline since about 1980.

5.3 What should we expect for the future price of oil?

Finally we look briefly at what the information given above tells us about the likely future price of oil.

Since about 2004, proximity to the global peak of conventional oil production (indicated by Figure 2, combined with the 'mid-point' rule) has limited the availability of this class of oil, and required most of today's marginal barrels to come from the non-conventional oils; pushing the real-terms oil price back up to the levels of the 1970s (Figure 1).

As noted earlier, conventional oil is generally *intrinsically* cheaper to produce than the non-conventionals (indeed some which it largely displaced a century-and-a-half ago; those of biomass, and oil from kerogen and coal), because of its general ease of production, at least from large fields once discovered, due high flow rates; and lack of the need to alter either the oil itself, or the surrounding rock or other material, for it to flow to the well.

Once the conventional oil peak is passed, there are indeed many types of non-conventional oil that can be produced, some with potentially large resource bases (see Chart 2 of *The Oil Age*, vol. 1 no. 1). But it is not clear that the generally lower energy returns, high intrinsic costs, large investment requirements, and generally higher CO_2 emissions of these non-conventionals will allow them to compensate for conventional's decline.

As a result, we suggest that it is likely that the price of oil will remain high, on average, unless dramatic change occurs in both the production and cost of the non-conventional oils, or if global oil demand declines substantially for climate change or other reasons.

6. Conclusions

Overall we conclude as follows:

- In the early years of oil supply, from 1861 to perhaps 1900 or so, production was often characterised by 'boom and bust', with production decline in one region being offset by flush production from a new region. As a result, the price of oil fluctuated substantially.
- But from about 1920 (and maybe from before that date) the predominant situation turned to that of potential over-supply of conventional oil (oil in fields), as total discovery of this oil raced ahead of production.
- To see this discovery trend it is necessary to access the oil industry backdated proved-plus-probable (2P) data.

- As to why oil companies would go looking for more oil when plenty was already to hand is an interesting question of resource economics. The answer is discussed in Section 5.2, above, but where the main reason was probably that these apparent large reserves were never secure (at least from the point of view of an individual oil company) being at risk of higher rent, nationalisation, or loss from embargo or war. There was thus always a need to find more oil.
- To counter the resulting potential for over-supply, a wide range of mechanisms were enacted by the oil industry and by governments to prevent the oil price from sinking too low. These included, for example, the Achnacarry agreement of 1928 and US prorationing.
- This period of potential over-supply of conventional oil is now drawing to a close. Though today there still remains large global reserves of such oil, the 'mid-point' rule says that production of this oil is close to its decline. Proximity to this peak has required that most of the recent marginal barrels to meet demand have been of non-conventional oil, pushing the real-terms oil price back to levels last seen in the 1970s.

Caveat

The authors recognise that information provided in this paper is tentative in a number of respects. In part this is because the canvas is large; in part because some of the topics, particularly on the economics of resource supply, are not well known to us; and in part because there are questions that remain unanswered. Feedback to improve future versions of this paper is welcome.

Acknowledgements

This paper could not have been written without immense amounts of time generously given by many practitioners in the field. A partial list is given in Chapter 4 of Campbell (Ed.) 2011. Our thanks go to all of them; and also to the reviewer whose comments significantly helped improve the paper.

Appendix 1: 1P Oil Reserves Data vs. 2P

Proved (1P) oil reserves data

As noted in Section 2.2, analysts should not use the proved oil reserves when considering either past or future oil production. The problems with these data are many:

- In the early years of oil exploration, particularly for large US and Canadian fields, the size of proved reserves reflected limited knowledge of the fields, and also simply the extent that fields had seen production drilling.
- In most cases today proved reserves oil data are *understated*, i.e. they are conservative estimates of the actual reserves. This is part simply because the data are *proved* (notionally 'P90%' values), rather than the more-likely mean or 'P50%' values of the proved-plus-probable reserves. Also aggregation of P90% values significantly underestimates the total at the same level of probability for statistical reasons. And proved reserves can also be low for other reasons, such as fields not yet being sanctioned. In the UK, for example, total proved ('1P') oil reserves have long stood at only *about half* the corresponding value given by industry proved-plus-probable ('2P') reserves.
- In some OPEC Middle East countries the reserves are probably *overstated* (see, for example the article by Laherrère in this issue, and also Figure 2 above).
- For many countries the data are *not stated*, in the sense that the reported data are not changed from year to year.

Oil industry proved-plus-probable (2P) reserves data

Instead the 2P reserves data should be used. Such data can be gathered for individual oil fields from a wide variety of published industry data sources, but with considerable effort. Large commercial *by-field* 2P datasets can instead be purchased from firms such as IHS Energy, Wood Mackenzie and PFC Energy, where the data have been assembled and checked, and where there is also much proprietary information.

Fortunately, simpler 2P datasets are available at moderate cost, for example extremely useful *by-country* 2P data are available from IHS Energy's 'PEPS' database (where researchers should use the version with data back to 1834, and note that the US and Canada data are only 1P).

Some collected 2P data now are in the public domain. For example, 2P data for adjusted 'Regular conventional' oil for a wide range of countries are in Campbell (2013), and excellent plots of past and forecast production (but not of discovery) for all oil-producing countries, based on detailed by-field 2P data are free on the Globalshift website (www.globalshift.co.uk). In addition, Rystad Energy's UCubeFree facility gives past and future production by-country, but again not of discovery, based presumably on their estimates of 2P data. Additional detail on 1P and 2P oil reserves is given in Appendix A of Bentley & Bentley (2015).

Comparing global 1P oil reserves data with 2P data

The main difference between 1P and 2P oil data is simply, as mentioned, that the former cover only 'proved' estimates; and also are subject to the various errors listed above. By contrast, the industry 2P reserves data reflect what are intended to be best estimates of the mean or 'P50' values for the fields or regions concerned (and where, for individual fields, industry practice was often to assume the sum of 1P reserves in full, plus two-thirds of 2P reserves, plus one-third of 3P as the best estimate of a field's size).

A second difference is that the 1P data are generally given on a *current* basis, i.e. are estimates made on the data available in the year for which the reserves are quoted. 2P data, by contrast, are generally *backdated* data, such that a 2P estimate of reserves for some prior year includes *today's* information on the reserves that would have been available at that year.

These two effects, conservative values for the 1P data, and the backdating of the 2P data, lead to very different evolutions of the global reserves data over time, and this, in turn, has led to different analysts drawing very different conclusions about the future availability of oil.

Specifically, for largely conventional oil, the size of global 1P reserves showed a steady ever-upward trend until 2002, and has since increased more sharply still due to inclusion of the proved reserves for tar sands and Orinoco oil. By contrast the industry data for global 2P reserves of conventional oil show that these reserves peaked in about 1980, and have been in steady decline since (see Chart 4 in *The Oil Age*, vol. 1 no. 1), and for the 2P data, Figure 2 above. It is no wonder that different analysts drew such different conclusions.

Appendix 2. The 'mid-point' production peak of conventional oil

This appendix gives a simple model to explain the mechanism of 'mid-point' peak, and also to show why this peak is counter-intuitive.

Assume a sedimentary basin containing conventional oil, where this oil is in many discrete fields of a wide variety of sizes. These fields can be ranked by the size of their initial reserves, based on the basin's field size distribution, as shown schematically in Figure 3. As can be seen, this basin has many fields, each reducing in size by 10%.

Next we need to look at discovery. At first the petroleum geology of the basin may be little understood, and a few unrelated discoveries made. But pretty quickly a pattern sets in which typically the largest fields are found early because they are (usually) the easiest to find, and are also put into production first as they give the best return on investment.

Now we examine production from an individual field. In practice this can take many profiles, but typically - certainly with newer fields and smaller fields - production tends to ramp up fairly quickly to a peak or short plateau, and then decline away, often approximately exponentially. A true exponential decline would result if the oil flow were driven simply by an expanding gas cap combined with an unchanging production column; and, correspondingly, a steady flow would result from a fixed-pressure water or gas drive in a truly homogenous reservoir. But reservoirs are rarely homogenous, and low-resistance paths in the reservoir, coupled with falling drive pressure and reducing length of the production column, result in most fields entering, quite soon in their lives, a long phase of ever-diminishing production of oil, often accompanied by increasing water-cut if water drive is used.

Figure 3 illustrates production from a *region* that results from such a very simple model.

As can be seen in Figure 3, the total production in the region sums that from successively smaller fields that are assumed to come on-stream annually, and where the production profile of fields takes the form of similar triangles of diminishing sizes: each steeply up, and then with a long decline.

As is clear, from such a model the total production from the region follows a roughly 'whale-back' shape, where the peak of production comes at very roughly the half-way point of production of the region's total recoverable resource. As is also clear, the fundamental drivers of this peak are: the field size distribution in the basin; the fall-off in volume of oil in new fields being discovered (new fields *are* being discovered, but are smaller than those in the past because of the field size distribution); and the production decline in fields due to the physical causes listed earlier.

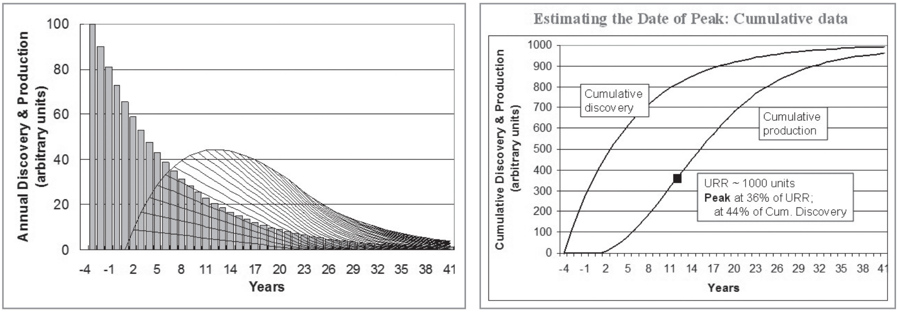

Figure 3: A simple model of oil production in a region.

Left plot: Shows the field size distribution and discovery sequence (grey bars), and each field's subsequent production (triangles), where each field is assumed to take 5 years from discovery to production. The plot is to-scale such that for example the volume of oil shown as discovered for field 1 (leftmost grey bar, 100 units) is the same as indicated for field 1 production (the lowermost production triangle, which starts in year 1, reaches 9.09 units/yr. in year 2, and falls to zero by year 23).

Right plot: The same data for discovery and production, but on a cumulative basis. The resource-limited peak in production (at year 12) is denoted by the small solid square.

The peak is *counter-intuitive* as follows. Imagine a forecast being made at year-10 (two years before the peak). At this date production is still rising steadily; there are plenty of reserves in fields already discovered; new fields of significant size are still being discovered; and, in the real world, advancing technology will be raising recovery factors. Few analysts not well versed in the mechanism of 'mid-point' peak would forecast this region's production as going into decline in the near term.

To-date, some 60 countries are past their peak of conventional oil production, and the majority of these show production profiles generally in line with that of Figure 3.

Appendix 3: Other factors that have influenced the price of oil

This appendix discusses briefly three of the more general factors, in addition to the quantity of conventional oil discovered and the mid-point peak, that are important for understanding the price of oil.

Improvements in knowledge

In the early days of oil, little was known about either its origin or wise extraction, and this, plus the 'rule of capture' (Yergin, 1991, p32), explains some of the early discovery and oil exploitation policies followed by individuals and companies. Proper knowledge of oil's origin and its probable location came only surprisingly recently, once an understanding of plate tectonics was in place in the 1960s, and of the petroleum system (source rock, thermal history, migration, trap and seal) in the 1980s. We now know, for example, that most of the world's conventional oil was produced in two relatively brief epochs, some 90 and 150 million years ago (Aleklett, 2012, p25); and that for example, Western Iraq has relatively poor oil prospectivity because migration from its source rocks has been substantially vertical (Ahlbrandt, 2003).

Improvements in technology

In terms of reducing the cost of oil, the advance of technology clearly had a major role. Better drilling rigs, railways and ever-larger tanker ships, and thermal and then catalytic cracking have all played significant roles; as did photo and magnetometer aerial surveying, and the use of seismic. The latter was especially important: it allowed oil below unconformities to be found, as with some key Middle East fields; and later - in the form of digital seismic - led directly to the vast majority of the world's conventional oil being discovered by about 1990, with the peak of this discovery occurring in the mid-1960s. And better knowledge and technology not only reduced the price of oil directly, but also by generating ever more efficient infrastructures within society reduced the cost of economic activity generally (and some of which, in turn, such as ease of transport, depended in large part on the increasing energy available from oil).

The need to access more difficult oil

Against such cost-reducing processes, it has long been recognised that oil was generally getting harder to access (even if the size of the largest individual fields discovered were still increasing, up until Ghawar in 1948). Exploring for oil in Mexico or Venezuela, for example, was generally more expensive than in the US; while working in the deserts of the Middle East was more expensive still with large concession fees on top. And once the shallow fields in Russia, the US and elsewhere were tapped, progress had to be made to deeper fields, and then, from the 1930s, to offshore oil and to heavy oil with thermal stimulation; then in the 1960s to Arctic and tar sands oil, and most recently to very-deep offshore, light-tight oil, and revisiting kerogen. Once the large Middle East fields were tapped, it has been a clear history of extracting technically ever more difficult oil.

The cost of extraction is one indication of this trend, see Figure 16 of Miller & Sorrell (2014). But the energy needed for the discovery, production, refining and delivery of a barrel of oil may be a better indication as discussed in Section 2.1.

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Charts

As mentioned in Issue-1, it is the intention that each issue of this journal will include a small number of charts - often from already-published sources - chosen as being particularly informative.

In this issue we focus on the production of *conventional* oil, and ask specifically: What has happened to global production of this category of oil in recent years, and what is forecast?

In the two issues of *The Oil Age* to-date, we have presented four forecasts: two top-down forecasts, respectively by Campbell and Laherrère; and two by-field bottom-up forecasts, respectively by Globalshift and Miller. Both of the top-down forecasts predict that the global production of conventional oil (and indeed of 'all-liquids') will go into decline in the near term; whereas by contrast both the bottom-up by-field forecasts see the production of conventional oil as being able to increase (assuming 'above-ground' constraints allow) out to perhaps 2025 or so, before then declining (and 'all-liquids' production also).

Note that the scope for increased conventional oil production in these two bottom-up forecasts is partly based on recent finds, but is largely from the few remaining 'swing' producers, whose production could potentially go quite a bit higher, were they to decide to do this; plus oil currently in 'fallow' fields (though see Miller's caution on this oil in this issue); and also from the increased application of enhanced oil recovery (EOR).

The charts presented below examine two things:

- Global production of conventional oil (taken here as primarily oil in *fields*) from 1980 to the present day, including its components; and also the production costs of some of these to see the impact on the maximum production cost of oil in recent years.
- Three recent 'mainstream' 'all-liquids' forecasts, from the IEA, BP and Exxon. The latter all show global conventional oil production as remaining more-or-less on plateau out to the end of their forecast horizons.

Specifically, the charts presented are:

- Mushalik: Global oil production 1980 to 2014 by oil category. This shows that global production of conventional oil has been on-plateau since 2005.
- Mushalik: A production-cost table from the consultancy: Energy Aspects.
- Mushalik: The resulting global production data categorised by production cost.
- IEA: A 2011 forecast of global 'all-liquids' production to 2035.
- BP: A 2015 forecast of global 'all-liquids' production to 2035.
- Exxon: A 2015 forecast of global 'all-liquids' production to 2040.