Forecasting future production from past discovery

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Abstract: There is a huge discrepancy between the 'political' values of the reserves by country as reported by the *Oil and Gas Journal*, *World Oil*, *BP Statistical Review*, OPEC… and the 'technical' values which are confidential to most countries. Yet, most production forecasts by official agencies are based on the political data. Some countries report minimum values (e.g. the USA with Proved values), others report maximum values (e.g. the FSU), and most countries report likely or median (called Proven + Probable) values which are generally close to, yet lower than, 'mean', e.g. 'expected', values. When technical data are used to calculate the 'mean' values of field reserves, a good fit is found between annual (and cumulative) discoveries and annual (and cumulative) production, the former being close to the latter with a time translation of a certain number of years. This procedure makes it possible to forecast future production from the corresponding past discovery trend. Examples shown for conventional oil are the US Lower 48, FSU, France, UK, Middle East, deepwater and the world outside 'Middle East and deepwater', and for conventional gas, North America.

A long-term forecast for world production of all hydrocarbons, based on these methods, is far below all the scenarios developed for the 2000 Third Assessment report of the IPCC.

Keywords: Oil; gas; reserves; discovery; production; political data; technical data; mean reserves; ultimates; decline; deepwater; world; USA; FSU; OPEC; Non-OPEC; swing producers; UK; France; conventional; unconventional; IPCC.

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Biographical notes: After graduation from the Ecole Polytechnique and Ecole Nationale du Pétrole in Paris, J. Laherrere participated with Compagnie Francasie des Pétroles (now TOTAL) in the Sahara exploration with the discoveries of two supergiant fields: Hassi Messaoud and Hassi R'Mel. He went to explore Central, Southern and Western Australia. He was in charge of exploration in Canada for TOTAL headquarters in Paris where he was in charge successively of new ventures negotiation, technical services and research, basin exploration departments and finally became deputy exploration manager. He has been director of the Compagnie Génerale de Geophysique, Petrosystems and various TOTAL subsidiaries. After 37 years of worldwide exploration with TOTAL, he retired in 1991.

Jean is now writing articles and giving lectures. He has written several reports with Petroconsultants and the *Petroleum Economist* on world oil and gas potential and future production. He will chair the 2002 World Petroleum Congress (Rio de Janeiro) panel on hydrates (block 3 RFP3 'Economic use of hydrates: dream or reality?')

1 Introduction - reliability of the data

Publishing reserves (even production) data is a political act and depends upon the desired message: either optimistic for the financial community when trying to borrow money, or cautious for the shareholders in order to leave room for later growth. This explains why political (or financial) data are very different from the technical data, which are usually kept confidential.

Usually reserves (which should represent future production) are classified on the degree of certainty. Proved (P or the minimum) is associated to a high probability level (90% or P90 in the probabilistic approach of the SPE/WPC/AAPG rules) meaning that the reserves will be larger than P in more than 90% of the possible outcomes. Proven + Probable (2P) could be either the most likely value (mode), or the median value (50% probability or P50 or as likely as unlikely) or the statistical 'mean' (also called weighted average, or expected value) that summarises all the possible outcomes. Proven + Probable + Possible (3P or the maximum) is associated to a low probability level (P10 which means that the probability that reserves might be larger than 3P is less than 10%).

In the USA, the practice of only reporting Proved reserves, omitting the Probable and Possible reserves to comply with SEC (Securities and Exchange Commission) rules means that the declared reserves are systematically under-reported, leaving room for future growth. During the past 20 years, 88% of the annual additions of oil reserves have come from the re-evaluation of past discoveries because previous estimates were systematically too conservative. An obvious advantage is that this permits the company to demonstrate a significant growth of past reserves, even when no discovery was made, a possibility that oil and gas companies find to their advantage. Conversely, the obvious drawback is that country data based on such underestimated individual reserves are so conservative that they have no meaning (called an 'illegal addition of proved reserves' by Capen [1]). Yet this is done every year by the oil journals and many 'experts'. Only the addition of 'mean' field reserves corresponds with the 'mean' reserves of a country. A Monte Carlo simulation is necessary to obtain the P90 value for a country from the P90 values of individual field reserves (and the rest of the probability distribution).

Regarding OPEC, the production quota allocated to its member countries partly depends upon their declared reserves. This led these countries to make large upward revisions of their official reserves in the 1980s despite the absence of any exploratory work. There was obviously no incentive to explore when it was not possible to produce at the full capacity of the existing fields. OPEC countries (except the Neutral Zone) increased their previous reserve figures by 300 Gb even though no significant discovery was made. It is difficult to know what is the right 'mean' value in these circumstances. The reserves of these countries are certainly large but are unlikely to be as large as the new official figures, which have hardly changed for the past ten years despite the draw down of what was produced.

The *Oil and Gas Journal*, (OGJ) reports before the end of the year what it calls 'estimated proved reserves' as of end of year. The reported values are compiled from inquiries with government agencies, but they are either purely 'political', or based on the sum of individual field figures that systematically underestimate expected values because of methodological flaws. When no answer to the enquiry was received, as most studies are not completed by the year end, previous figures are often repeated without change, implausibly implying that the amount of hydrocarbons produced was exactly equal to the net addition of new reserves during the year. This was the case for 80 countries in the latest *OGJ* report.

Table 1

OGJ Dec18, 2000	*end of 2000*		*change from 1999*		*change %*	
	oil Gb	*gas Tcf*	*oil Gb*	*gas Tcf*	*oil*	*gas*
80 countries	586	4025	0	0	0	0
25 countries	443	1253	12.4	132	2.9	11.8
total	1028	5278	12.4	132	1.2	2.6

These values are repeated by other sources, such as the *BP Statistical Review* and the US-DOE reports. *World Oil* delays publishing until the middle of the year in order to obtain the estimates of the previous year, and correct the early release. They also moved in 1991 to report Proven + Probable but reverted to Proven in 1996. Analysts either mistakenly accept these published data, which are reproduced by BP and USDOE, as valid, or, if they know them to be false, use them to mislead the general public and the policy makers. The IEA did just that in its latest *World Energy Outlook* even though it had made a courageous attempt to reveal the true position in 1998. The oil companies furthermore use these flawed public data to improve their image with the investing public.

The ‘expected’ values of the reserves can only be estimated from technical data that are generally held confidential and only available through ‘scout’ companies. The present technical estimate is backdated to the year of discovery. But some corrections are necessary for some countries.

A good example is that of the reserves of the Former Soviet Union (FSU) which are taken for granted by all the official western bodies. They ignore the fact that Khalimov, who presented the Russian classification in the 1979 WPC [2], made a statement in 1993, revealing that the FSU estimates were “strongly exaggerated due to the inclusion of reserves and resources that are neither reliable nor technologically nor economically viable” [3], because they were based on the maximum theoretical recovery factor. In fact, the reported reserves were close to their 3P values.

Figure 1 shows that the world’s remaining ‘political’ oil reserves, as reported, have been rising steadily from 100 Gb in 1950 to 1000 Gb in 2000, which has misled some analysts into proposing that they can continue to do so. By contrast, the ‘technical’ data show a decline since 1980, with a peak around 1200 Gb.

Figure 1 World remaining oil reserves from political and technical sources

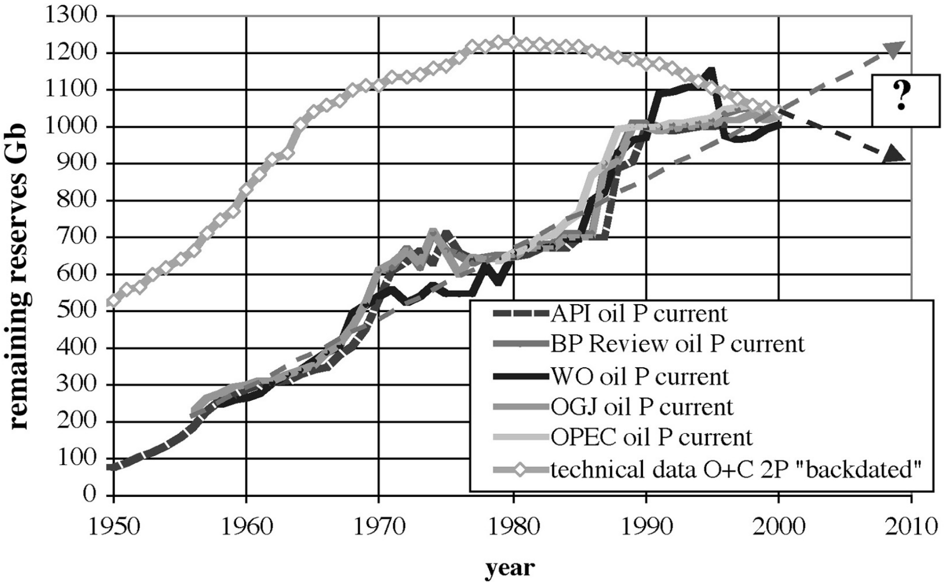
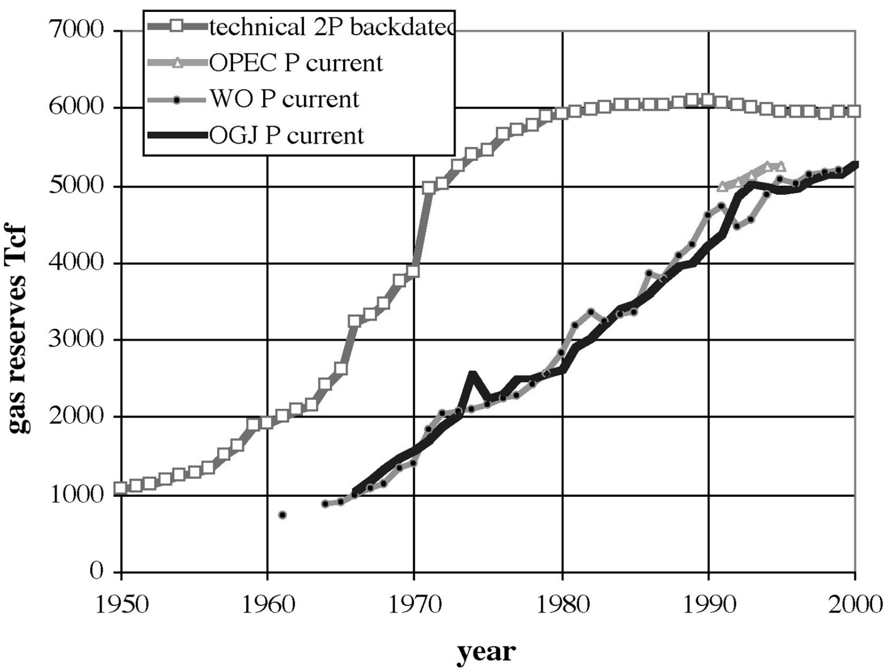


Figure 2 World remaining gas reserves from political and technical sources



The world's remaining 'political' gas reserves (Figure 2) also shows a steady rise from 1000 Tcf in 1965 to 5000 Tcf in 2000, whereas the 'technical' data indicate a levelling at 6000 Tcf since 1980.

2 Correlation between production and shifted discovery

In 1956, King Hubbert made a forecast that US oil production would peak around 1970. He was right. His famous bell-shaped curve is justified as a statistical aggregation of many independent producing fields, but it does not work when exploration is discontinuous or for a domain covering only a limited number of fields. The main mistake in Hubbert modelling is to assume only one peak, when most of the countries display several peaks. The important message from Hubbert's work, which is often forgotten by economists, is that oil has to be found before it can be produced. It means that, if there are no constraints, the production curve has to mirror the discovery curve, so that if there are several discovery cycles, production will also have several corresponding cycles.

The correlation between production and the shifted discovery curve, when based on technical data giving the 'mean' values, is usually quite good for countries producing at full capacity and not subject to drastic economic changes. But the correlation is not good for the swing producers, being the five countries of the Middle East: Saudi Arabia, Kuwait, Iran, Iraq and the UAE, as their level of production is set on the basis of political decisions.

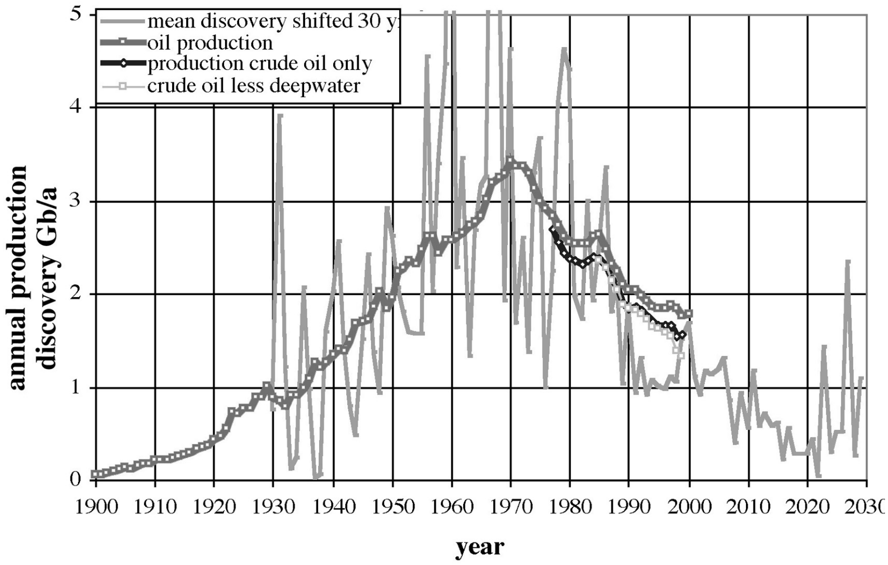
3 US lower 48 states

As US reserves are reported only as Proved values, it is necessary to adjust them upward to equate with a 'mean' value. To do that, we rely on the published data comprising: the 1990 USDOE/EIA-534 report 'US oil and gas reserves by year of field discovery' [4]; the new fields' discovery reported in the annual reports from 1989 to 1999; and the growth function calculated by the MMS (USDOI/Minerals Management Service) on the basis of the average annual revisions of reserves of the about 1000 GOM fields over time. According to this function, the initial Proved estimate of the discovery year needs, on average, to be multiplied by 4.5 to approach the 'mean' reserve 50 years later. This model needs to be improved.

With the backdating of the 'mean' reserves at the time of the discovery, there is a good fit between the discoveries shifted by 30 years and production. Based on the shifted discoveries, one may infer what future production will be for the next 30 years. However, as mentioned earlier, there is evidence that a new oil cycle has started at the end of the 1980s with the advancing production of the deepwater discoveries.

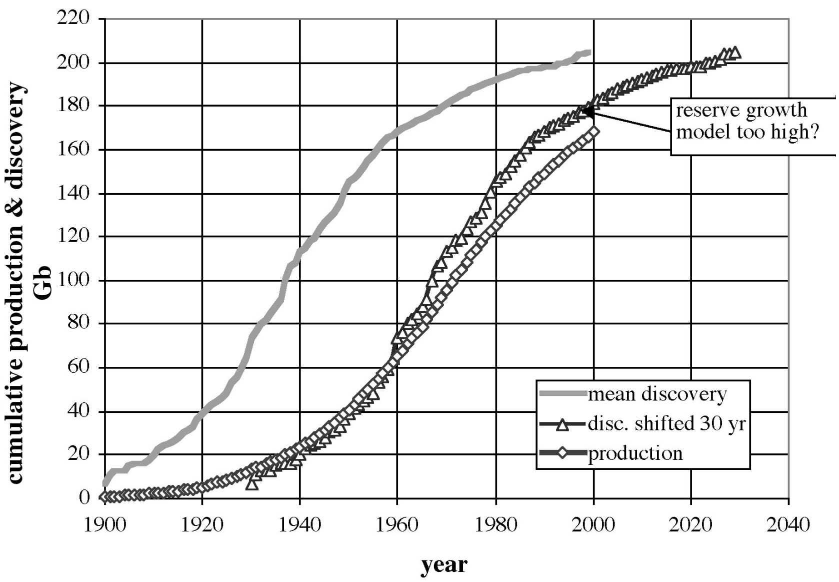
The following Figure 3 displays US Lower 48 annual oil production and annual discoveries shifted by 30 years. Note the impacts of the depression of the 1930s, the proration at the end of the 1950s and the high price in 1979. They explain the two 'shoulders' of the production curve, which for unknown reasons occurred at about the same level at 2.6 Gb/a.

Figure 3 US lower 48 annual oil production and discovery shifted by 30 years



In the following Figure 4, we display the cumulative discovery, backdated and poorly adjusted to a 'mean' value, with a 30-year translation, in order to facilitate the comparison with cumulative production. The fit is not quite so good since 1960, suggesting that the MMS model of reserve growth (the ultimate multiplier of 4.5 after 50 years) has become too high due to better initial appraisal with the help of modern technology.

Figure 4 US lower 48 cumulative oil production and discovery shifted by 30 years

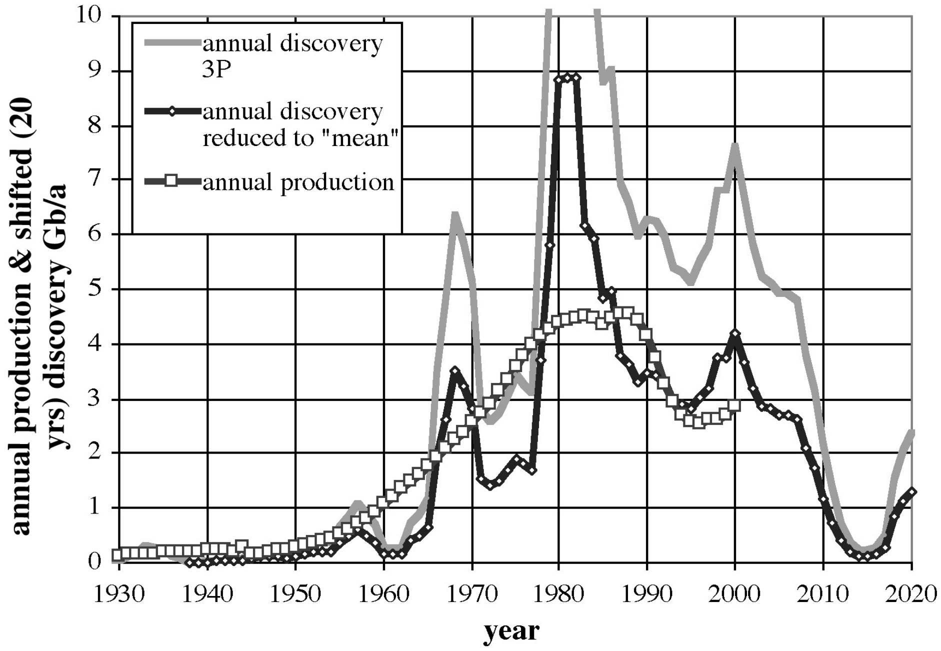


4 FSU (Former Soviet Union)

Since the FSU reserve data are maximum values (3P), one needs to reduce them to their 'mean' value to show a good fit between production and shifted discovery. A reduction of 45% allows such a good fit.

The following Figure 5 provides a comparison between annual production and shifted annual discoveries. It also suggests, simply by extrapolating the shifted discovery trend without any sophisticated modelling, that production will, after a small rebound during the first half of the present decade, decline significantly after.

Figure 5 FSU annual oil production and discovery smoothed on five years and shifted by 20 years and reduced by 45%



As mentioned in the first part of this paper, this reduction of the official FSU figures is consistent with the observations of Khalimov [3]. Evidence of over-estimation on reserves is also clear in individual field production data. For instance, Samotlor, the largest oilfield, is reported as having 28 Gb initial reserves whereas the extrapolation of the decline curve puts ultimate recovery at 20 Gb as the following Figure 7 shows.

Figure 6 FSU cumulative oil production and discovery (3p and 'mean') shifted by 20 years

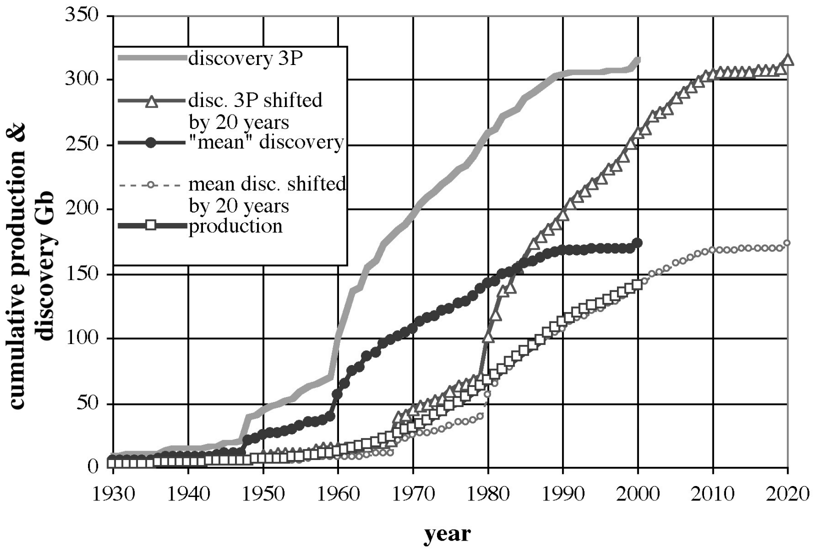
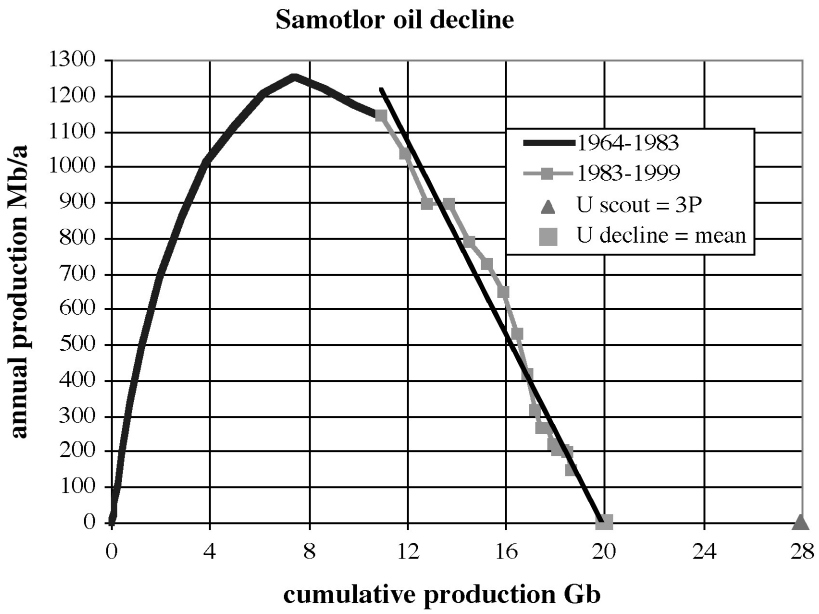


Figure 7 Samotlor oil decline and estimate of ultimate recovery



5 France

Exploration and production in France occurred in two cycles. The following Figures 8 and 9 show the correlation between shifted discoveries and production. The annual plot (Figure 8) is of a 'qualitative' nature. It shows how the troughs and peaks coincide, and even suggests that, whereas the shift is ten years for the first cycle, it might be five years only for the second. The cumulative plot (Figure 9) is more 'quantitative'. It shows that there are too few fields for a good fit: discoveries are made in quick succession but the time to deplete them is much longer.

Figure 8 France's annual oil production and discovery shifted by 10 years

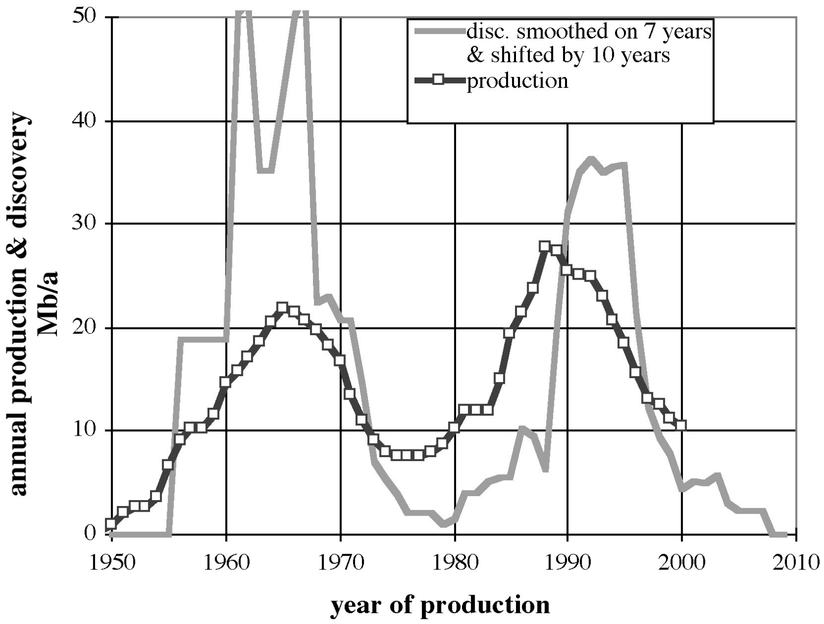
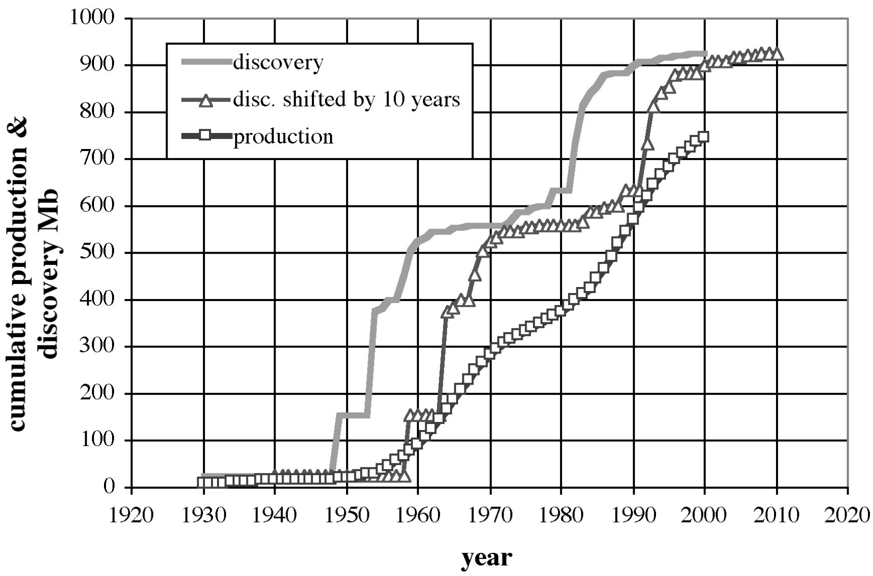


Figure 9 France's cumulative oil production and discovery shifted by 10 years



6 UK

The UK also displays two E and P cycles, with production peaks in 1985 and 1999. The rebound of production in the 1990s was already predictable in 1990 on the basis of the second cycle of discovery (peak during the 1980s). As in the case of France, the correlation is more qualitative (see Figure 10 based on annual values) than quantitative (see Figure 11 based on cumulative values which displays a poor fit on the details). The reason is that the large initial discoveries (85% of total reserves) are concentrated over a few years whereas their production spreads into the second cycle.

Figure 10 UK annual oil production and discovery shifted by ten years

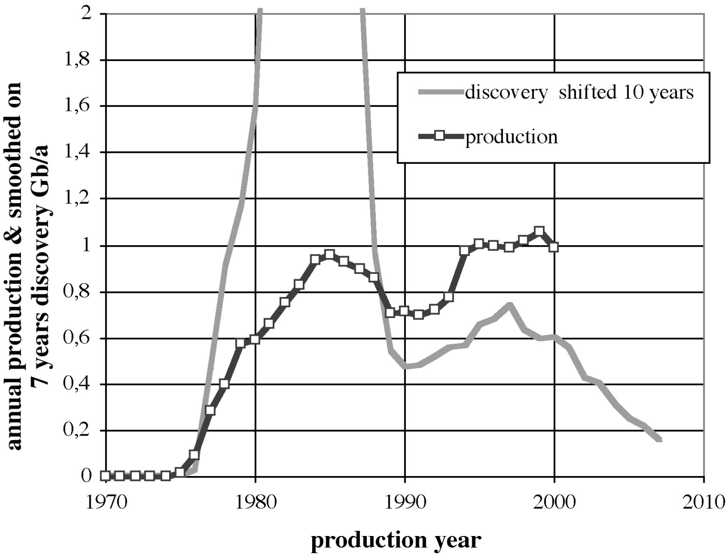
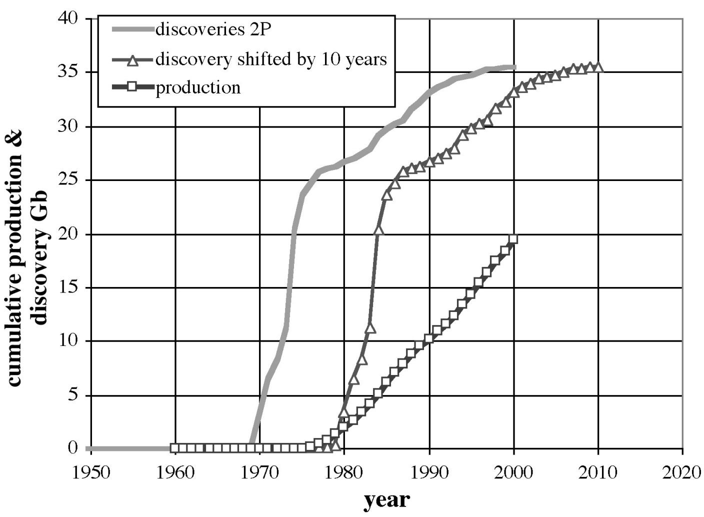


Figure 11 UK cumulative oil production and discovery shifted by ten years

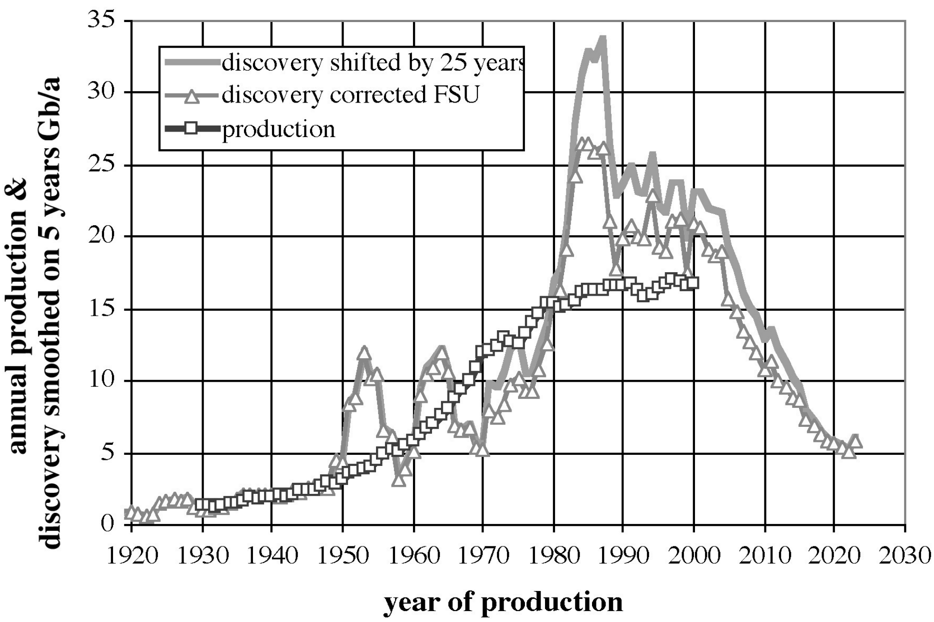


7 World outside the Middle East (swing producers) and deepwater

The report 'Energy for Tomorrow's World: Acting Now!' published by the WEC in 2000 [5] displays my correlation between discoveries and productions for the US Lower 48 and the world outside the five large OPEC producers of the Middle East (these are the only countries which significantly limit their production and capacity). But deepwater production (below 300 metres depth or 1000 feet) needs to be excluded as being a new cycle.

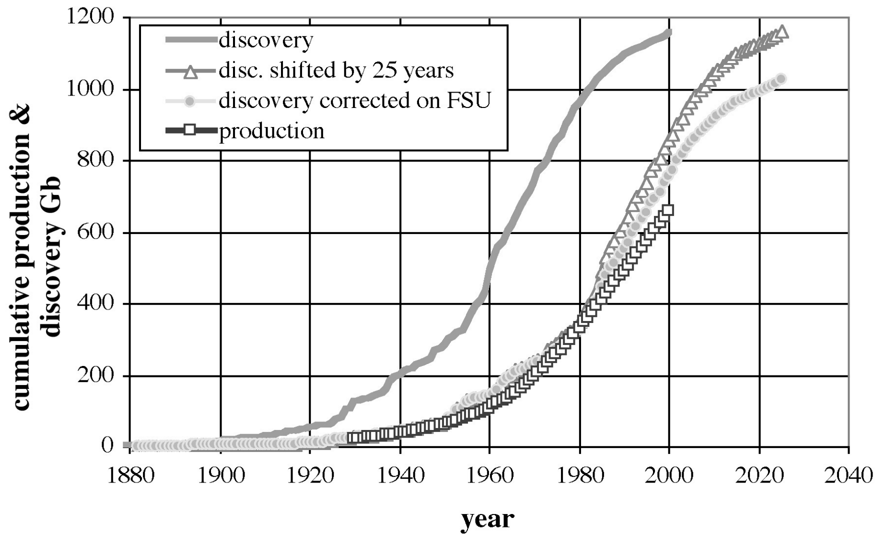
The fit between annual production and annual discovery is good with a 25-year shift. The raw data on discovery is too high, and we have added the curve correcting the 3P values of FSU into 'mean' values. The fit suggests that production will peak soon and decline fairly strongly for the next 20 years.

Figure 12 World outside Middle East (swing producers) and deepwater (>300m): annual oil production and discovery shifted by 25 years



The cumulative discovery plot shows a levelling towards an ultimate around 1200 Gb. Cumulative production to 2000 is past the mid point (600 Gb) and will follow the corrected shifted discovery for the next 20 years.

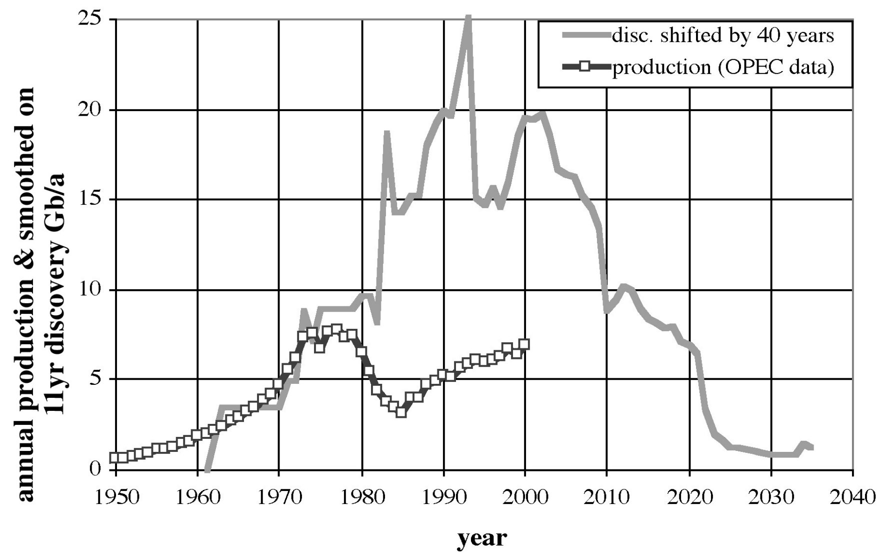
Figure 13 World outside Middle East and deepwater: cumulative oil production and discovery shifted by 25 years



8 Middle East (swing producers)

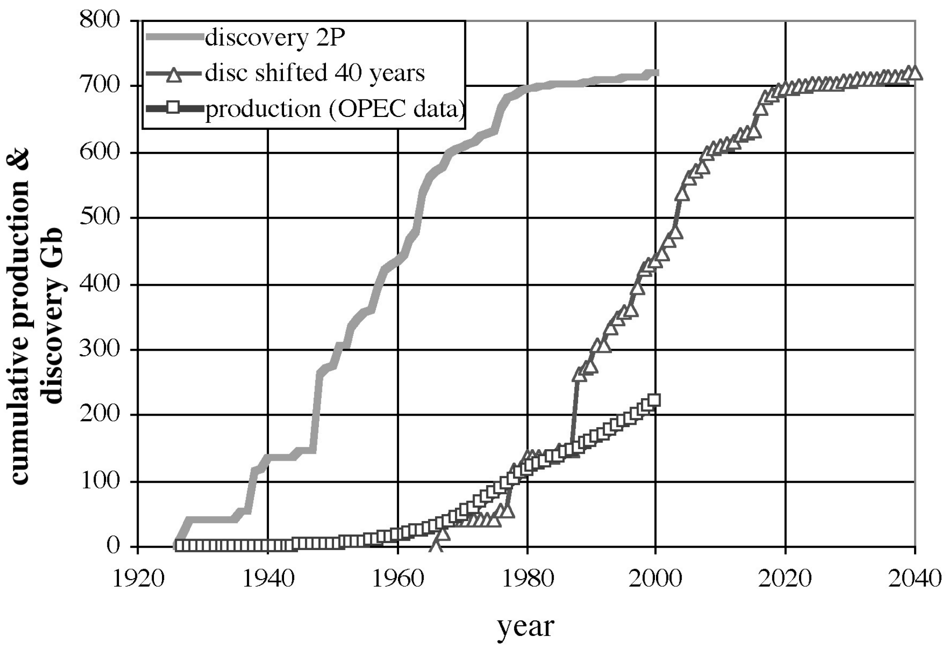
Since the oil shocks, Saudi Arabia, Kuwait, Iran, Iraq and the UAE have curtailed their production deliberately, which therefore no longer fits the corresponding discovery trend. The following Figure 14 tentatively shows how unrestrained production might have evolved, based on a 40-year shift.

Figure 14 Middle East annual crude oil production and smoothed discovery shifted by 40 years



Cumulative production indicates that only 30% of the reported amount discovered has been produced, assuming with some hesitation that 'mean' values have been reported.

Figure 15 Middle East cumulative crude oil production and discovery shifted by 40 years



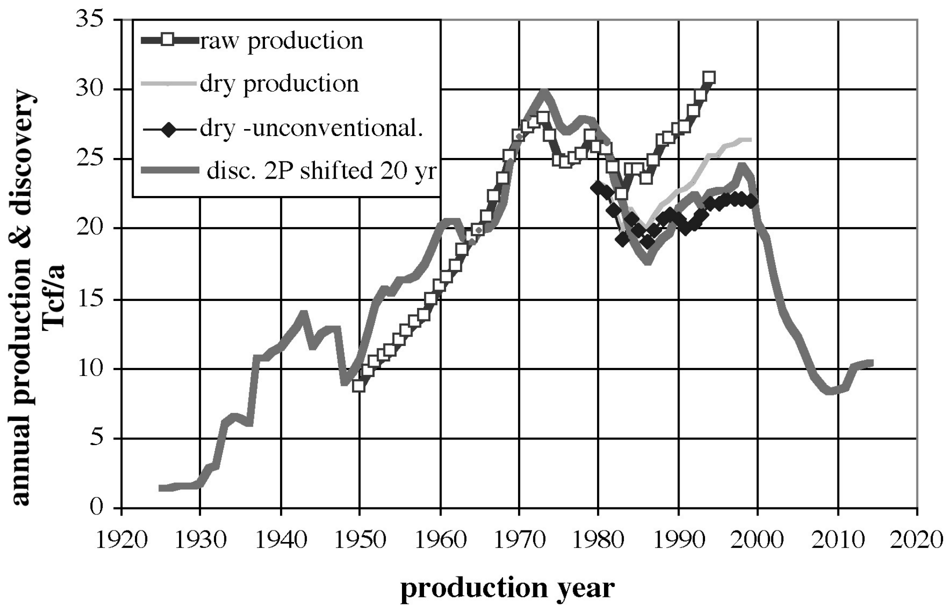
9 Natural gas in North America

The supply of gas to North America is important as being almost the only source, apart from LNG, to meet demand. Electricity generation in California, which has already suffered from blackouts, depends on gas supply.

The discovery (corrected to 'mean') shows a fairly good fit with production for a 20-year shift giving a trough around 1985. However these data are still heterogeneous and unreliable, suggesting that the governments need to make sure of obtaining more accurate data from the operators (in particular on federal lands which are not supposed to be confidential). Most of the recent production data are for dry production, being around 85% of the raw production. The discovery trend relates only to conventional fields, so the comparison has to be with dry minus unconventional production.

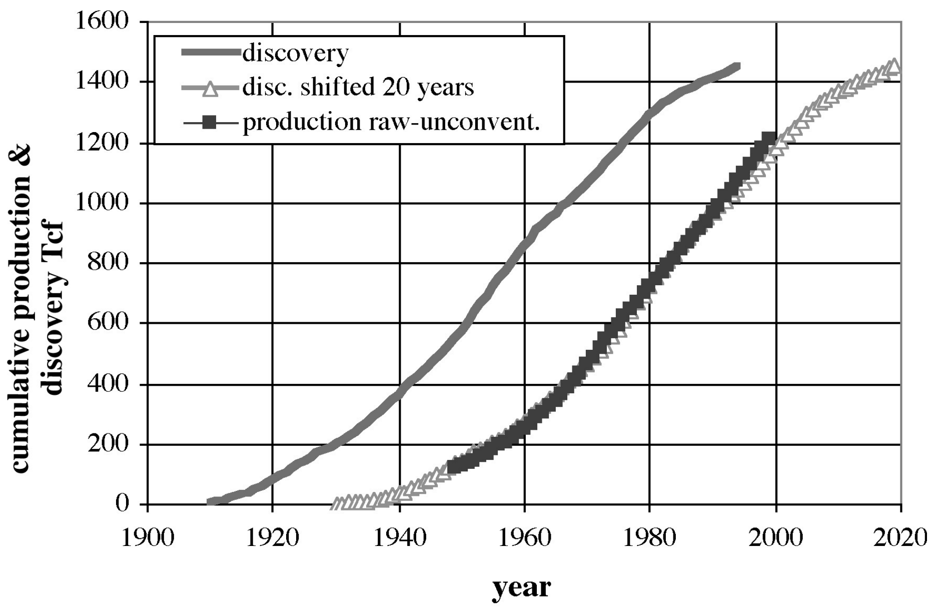
It seems that production will peak soon and decline strongly for the next decade, reflecting the fall in discovery.

Figure 16 US +Canada +Mexico annual gas production and discovery shifted by 20 years



Cumulative production displays a very good fit with cumulative shifted discovery from 1950 to the present. Production during the 1990s seems to have drained the reserves faster, due to new technology and infilled drilling.

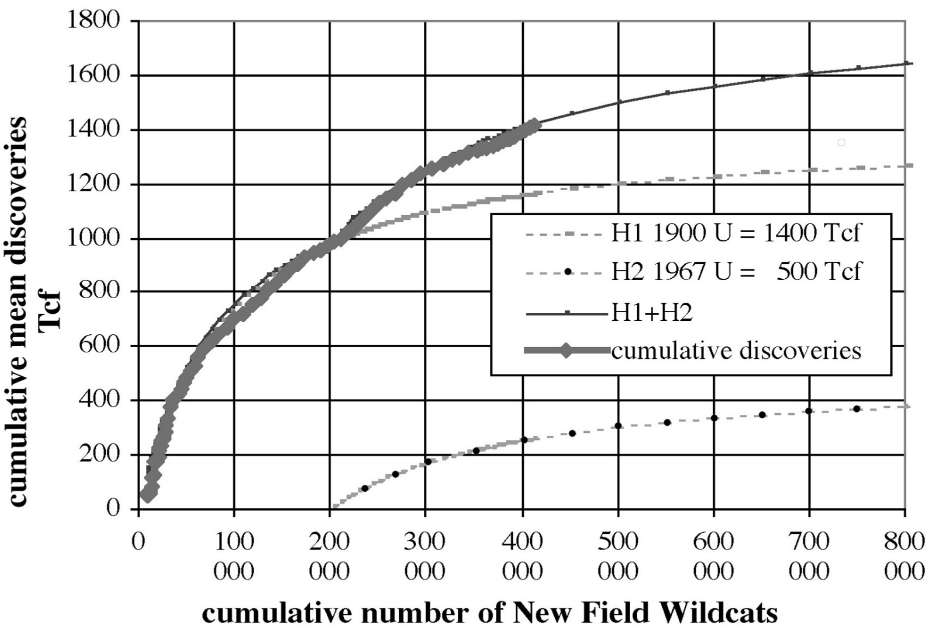
Figure 17 US +Canada +Mexico cumulative gas production and discovery shifted by 20 years



Cumulative gas discovery versus time shows a levelling, but it is much better to display its trend by plotting it against the cumulative number of new field wildcats (‘creaming curve’).

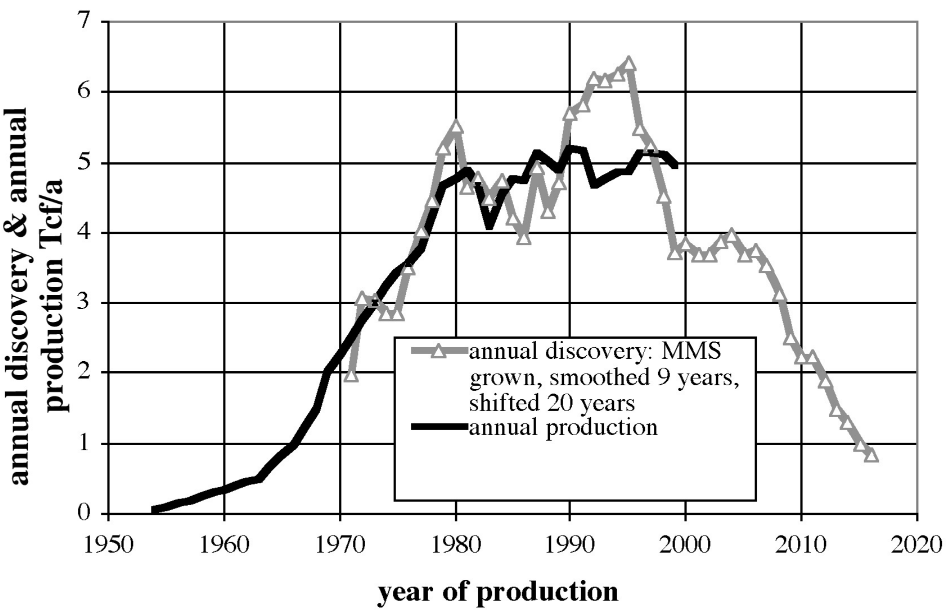
The creaming curve of Figure 18 displays two hyperbolic curves, as do most of creaming curves: the first one from pre 1900 to 1967 and a second from 1967 to the present (more efficient exploration). With 1400 Tcf already discovered by about 400 000 new field wildcats, the modelling shows that another 400 000 new field wildcats would bring only an additional 250 Tcf.

Figure 18 US+Canada+Mexico creaming curve of gas discoveries versus number of new field wildcats



Official reports place great faith in future gas from the Gulf of Mexico (GOM). The MMS publishes the details up to 1998 from 984 fields in the GOM OCS (Outer Continental Shelf). It would be reasonable to assume that the data on discovery from this official source would be of high quality, but a careful study shows many discrepancies. Some records even show diminishing cumulative production, which is clearly impossible and the comparison with other confidential data sources shows large variation. However, there is a good correlation between MMS discovery (grown to ‘mean’ values) and production, showing that the GOM production is about to peak and decline strongly. The fields in the deepwater area contain one-third gas (and two-thirds oil), presumably because of lower geothermal temperatures, whereas those in the shallow waters contain two-thirds gas.

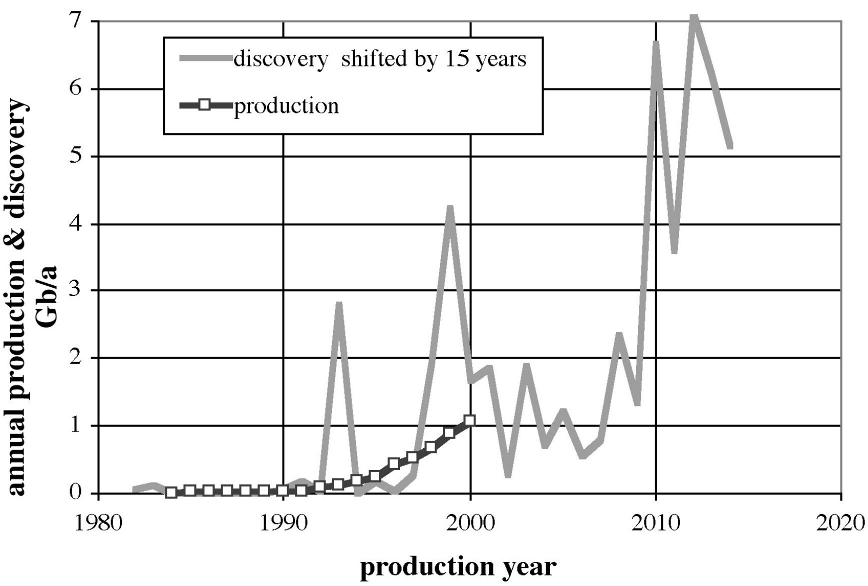
Figure 19 US GOM OCS annual gas production and discovery shifted by 20 years



10 World's deepwater

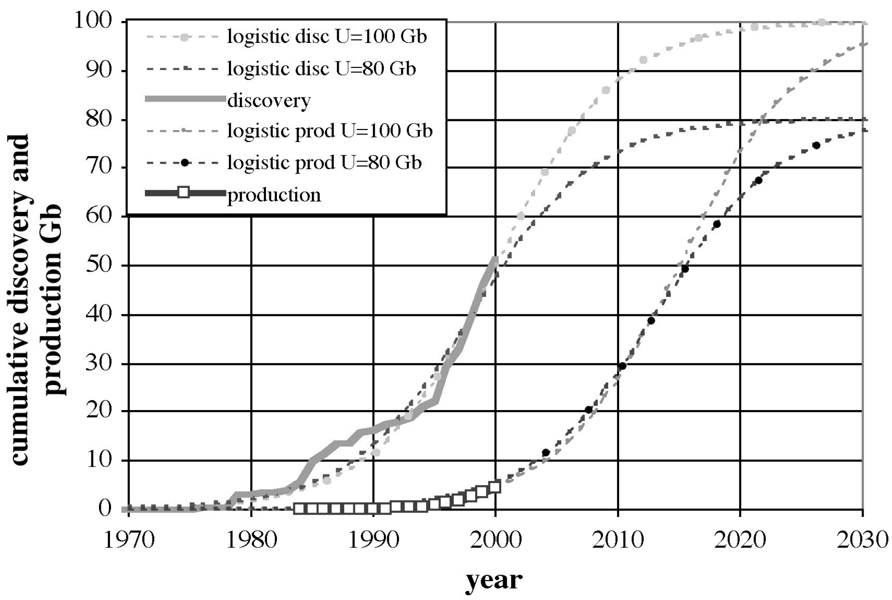
There is no consensus on the definition of the deepwater domain, which is variously placed at between 200m and 600m; nor whether it should be treated as 'conventional' or not. The most common view, as adopted here, is to put the boundary at 300m (>1000 ft) depth. Under this definition, deepwater production started in the 1980s. The Albacora oilfield in Brazil, for example, was producing in about 1000m of water in 1987. So far, deepwater finds have been made in only a limited number of basins, where few giant (>500 Mb) oilfields were discovered in the 1990s: one giant (Crazy Horse) in the GOM; four in Brazil; four in Nigeria and seven in Angola. Annual deepwater production was about 0.5 Mb/d in 1994, rising to 3.5 Mb/d (1 Gb/a) in 2000. If discovery has now come close to peak, as seems likely, production might peak at about 10Mb/d (3.5 Gb/a) around 2010-2015. Figure 20 shows annual production and discovery curves with a 15-year shift, found from Figure 21.

Figure 20 World's deepwater (>300 m) annual oil production and discovery shifted by 15 years



Cumulative discovery gives a fair correlation with production for a shift of 15 years. But as the discovery curve has not reached maturity, we have plotted two logistic model with ultimates of 80 and 100 Gb respectively, meaning that the undiscovered deepwater oil is either 30 or 50 Gb compared to the 50 Gb already found.

Figure 21 World's deepwater (>300 m) cumulative oil production and discovery shifted by 15 years with logistic modelling

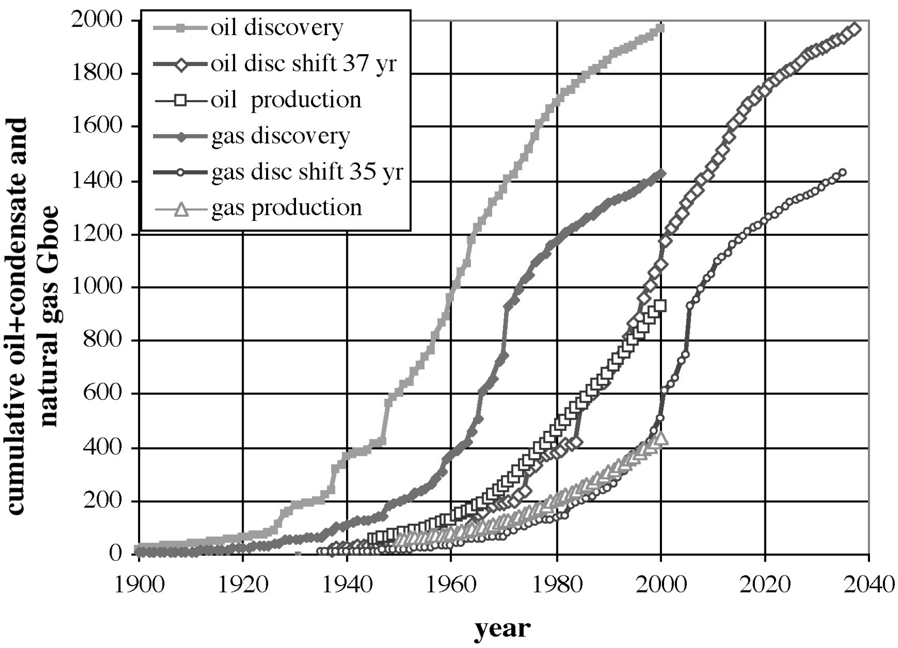


11 World

Economic and political constraints have meant that the five large OPEC producers of the Middle East have produced below the capacity of their resource base. Accordingly, a good fit between discovery and production is not to be expected. Further problems are introduced by the fact that the discovery-production cycles occurred at different times in different parts of the world; differences of geological habitat from dispersed, with many small fields, to concentrated, with most reserves in a few very large fields; the nature of reservoirs, and the differing economic conditions.

Nevertheless, such an approach does provide an aggregated view of reserves and production in Gboe (= 6 Tcf). A shift of 37 years for oil, and 35 years for gas, provides a fair correlation. It in turn allows some qualitative, if not quantitative, predictions for the next decades. Figure 22 provides such a comparison between the cumulative conventional oil and natural gas discovery and production. The discovery data should be adjusted to a 'mean' value, but that is not yet possible.

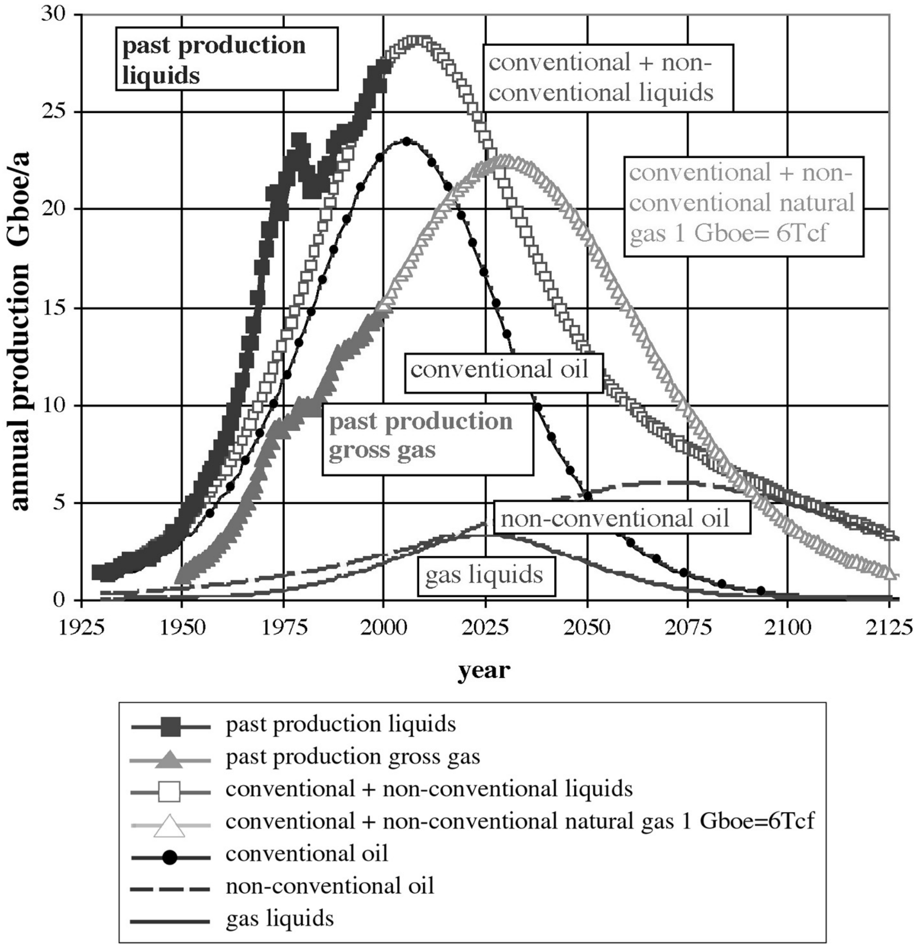
Figure 22 World cumulative discovery and production for conventional oil and natural gas



The preceding graph is for conventional oil and natural gas only. It has its limitations, given the evidence of the growing contribution of unconventional hydrocarbons, and so it would useful to present a simple model for the total production of all liquids and natural gas, including the unconventional categories. In order to achieve such a model, it is necessary to estimate the expected ultimate reserves and their depletion over time. This has been done in a major eight-year study, made up of four large reports by Laherrere, Perrodon, Demaison and Campbell. It gave the following ultimate reserve estimates [6]:

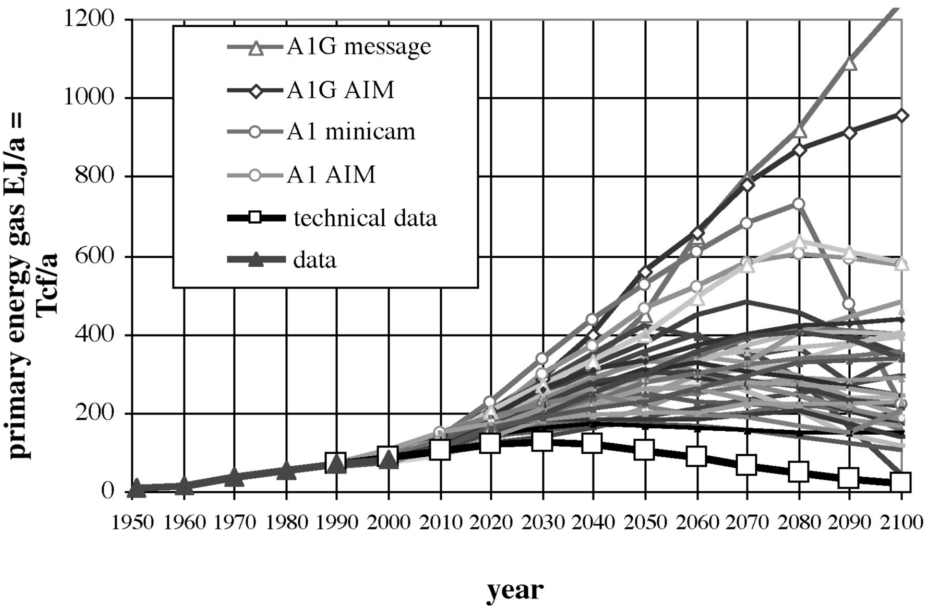
2000 Gb of conventional liquids, 750 Gb of unconventional liquids, 10 000 Tcf of conventional natural gas and 2500 Tcf of unconventional gas. Figure 23 summarises the conclusions with production peaking around 2010 for all liquids and around 2030 for gas. Three years later, the estimates for conventional hydrocarbons appear to be still valid on the basis of new data, but the potential for unconventional hydrocarbons may have been exaggerated.

Figure 23 World's conventional + non-conventional liquids and gas future production



It is interesting to note that these oil and gas production (for the world = consumption) profiles, built from technical data, are completely out of the range of the IPCC 2000 scenarios (Third assessment report) shown in Figure 24. In my view [7], these scenarios are pure 'wishful thinking' based on the unrealistic assumption of nearly limitless (and cheap) fossil fuel resource (e.g. oceanic methane hydrates). One may wonder why the IPCC has chosen such assumptions against the evidence?

Figure 24 World natural gas scenario from IPCC 2000 and Laherrere's forecast from technical data



12 Conclusion

Most public reserve data are biased by politics, and are unreliable. They lead to false conclusions, be they the optimistic view that there is no need to be concerned by a possible scarcity of oil and natural gas, or the pessimistic view supporting extreme 'green' attitudes, according to which, the world is heading to a catastrophe in terms of climate change.

This paper shows that it is possible to work out the 'mean' (expected) reserve values from the technical data and then to correlate these 'mean' annual and cumulative discoveries with annual and cumulative production after a certain time shift, at least for the countries producing without restraint. This shift allows us to forecast, qualitatively and, sometimes, more precisely, what the future annual production will be.

The data described in this paper indicates that oil production outside the OPEC Middle East would have started to decline in 1997 but for the arrival of deepwater oil and its fast rising production. Excluding deepwater (the other unconventional oils do not influence the shape because their production profile is a nearly linear gentle rise), non – Middle East crude oil production has been level at around 46 Mb/d since 1988, apart from a 'bump' in 1997 to 46.8 Mb/d, and will now start to decline. This overall decline is bound to continue and accelerate. So the uncertainty is the extent to which deepwater production, as well as that from tarsands and extra-heavy oil can compensate for the decline of the non Middle East production.

These approaches need to be discussed and investigated in depth by the world community.

It is necessary to establish a politically neutral agency (or institute) to gather true 'mean' data on world's reserves and production.

A step in this direction has already been made with establishment of the Association for the Study of Peak Oil ('ASPO') and the Oil Depletion Analysis Centre ('ODAC') in London, which intend to gather the technical data, draw the conclusions and publicise the results.

A great contribution to stability would be made if the OPEC countries were to publish the true values of production and reserves, and if the price were set at a level consistent with the supply/demand balance. There would be less reason for concern that low prices would damage the OPEC economies, and lessen the incentive for lower energy intensities. There would also be less scope for unjustified extreme 'green' reactions. In the same way as oil consumers need to understand the prime importance of energy for life, and the need to avoid disruptions, oil producers have to realise that the best way to secure an overall agreement on a fair price is to tell the truth about their reserves.

The developed and developing countries have to work together to determine what the reserves are and to find out if future production is as ominous as the shifted discoveries curves suggest. They also need a better understanding of the price setting mechanisms, based on the cost of competing energies and on the impact of taxes in consuming countries. Finally, they all need to maintain a fair and stable oil price for the benefit not only of the producers and consumers of today, but also of our children and grandchildren.

OPEC's goal of a fair price around 25$/b (in 2000 $) seems to be a good compromise. Everyone has to come to understand the true implications of past discovery and production trends, which demonstrate that the age of cheap oil has come to an end. OPEC also needs the help and support of western governments in facing its extremely difficult task of managing depletion.

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