The Oil Drum: Canada
DISCUSSIONS ABOUT ENERGY AND OUR FUTURE

Modeling Oil Production to Estimate URR - Saudi Arabia, Kuwait and World

Posted by Stoneleigh on September 29, 2007 - 9:00am in The Oil Drum: Canada
Topic: Supply/Production
Tags: logistics, loglets, saudi arabia, urr [list all tags]

This is a guest post by Apparent Peak. He started his career as an aeronautical engineer and is currently retired. Now he has more time to study peak oil and write posts for TOD. He has selected "Apparent Peak" for his handle which will become obvious once you have read the post.

1) Background

I have followed the subject of peak oil since the seminal article by Campbell and Laherrère appeared in the March 1998 edition of Scientific American. Approximately one year ago, I began to casually follow some of the discussion threads at TOD. The posts, the ensuing discussions and in particular, discussions on HL, logistic functions and Khebab's The Loglet Analysis caught my interest. I decided to investigate these topics since I did not know what HL was, let alone logistic functions. A quick trip to Wikipedia explained the Logistic function. As it turns out, it is a fancy exponential function that has characteristics similar to the Gaussian distribution.

Having read Khebab's paper a few more times I realized that I did not have the patience to understand "successive Fischer-Pry decompositions". However, one sentence in his paper was very insightful: "The Loglet decomposition is an elegant mathematical framework which consists in fitting a sum of logistic curves". The idea of fitting a sum of logistic functions to model oil production made the process sound much simpler than successive Fischer-Pry decompositions.

More recently there has been much discussion regarding estimating a country's URR using HL, Hubbert's linearization, and especially the URR of the Kingdom of Saudi Arabia (KSA) and its potential oil production decline due to the depletion of the Ghawar oilfield (Ghawar reserves update and revisions by Euan Mearns and Depletion Levels in Ghawar by Stuart Staniford). To get a better understanding of the logistic function and its role in peak oil analysis, I decided to combine the concept of least squares with fitting the sum of multiple logistic functions to the oil production history of KSA as suggested by Khebab.

The least squares approach would provide a best fit to the country's oil production and would address my curiosity to assess the quality of the results this method of analysis would produce. One of my objectives was to find another methodology that would complement HL and at the same time provide further insight into those situations that are difficult for HL.

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2) Methodology

Calculating a least squares fit of a non-linear function is quite a simple and straightforward procedure using the "Solver" algorithm in Excel. Solver is designed to find an optimal value of a given "Target" cell that is related through formulas to other "Variable" cells. It does this by the adjusting/optimizing the variable cells until the desired optimum value is achieved in the target cell. For those interested in understanding how Solver finds the optimum solution, Excel provides the following note regarding its algorithm: “Microsoft Excel Solver uses the Generalized Reduced Gradient (GRG2) nonlinear optimization code developed by Leon Lasdon, University of Texas at Austin, and Allan Waren, Cleveland State University.”

For this exercise, by altering the parameters that define the individual logistic functions in the variable cells (Q_0, the exponential constant and the peak year), the sum of squared errors in the target cell would be minimized. This methodology could be useful to interested TOD participants since Excel is well understood and readily available to many. The process used in this post is described below.

The logistic function for the cumulative production is given by:

$Q(t) = Q_0 / (1 + \exp(-a(t – T_p)))$ (1)

Where:
$Q(t)$ = Cumulative production to the year/time t
Q_0 = URR or ultimate recoverable reserves
a = constant affecting the height to width ratio of the logistic function
t = calendar year/time
T_p = peak year, production peak for each individual logistic function
exp = the exponential function

The annual production rate P is the differential of (1) and is given by

$P = dQ(t)/dt = aQ_0 * \exp(-a(t – T_p) / (1 + \exp(-a(t – T_p)))^2$ (2)

Units: Throughout this report, B refers to U.S. Billions, 1,000,000,000

3) Kingdom of Saudi Arabia URR: 160 B barrels or 260 B barrels?

The methodology described above was first applied to the Kingdom of Saudi Arabia’s daily oil production.

To model the KSA oil production, data was taken from the 2005 OPEC Annual Statistical Bulletin for the years 1938 to 2005. This data includes ½ of the oil produced in the neutral zone. The 2006 data point was taken from the April 2007 OPEC Oil Market Report. The annual KSA oil production data from 1938 to 2006 was input into Excel. Seven production rate logistic functions (Eq. 2) were then used to model the average daily production from 1938 to 2006. The spreadsheet (SA7_LS_Mult_Logistic), which details the KSA analysis and the results, is available to interested readers on request (*from Stoneleigh(at)theoildrum(dot)com*)

Since the Solver algorithm requires an initial guess to begin its iterative process, the logistic function parameters were adjusted to roughly approximate the KSA production history. It was this initial guesswork that indicated that six or seven logistic functions would be required to model the highly variable KSA oil production profile. Having set up the initial guess, the Solver algorithm was launched through the “Solver Parameters” window shown below to find the least squares solution.

The sum of squared errors, i.e. the error/difference squared between the actual and predicted production values, was placed in cell $M$8 in the spreadsheet and was specified to be there in the “target cell” box in the Solver Parameters window. Similarly, the twenty one parameters controlling the seven logistic functions were placed in the cell range $E$4:$K$6 in the spreadsheet and were specified to be there in the “changing cells” box. Solver varied the parameters in the cells $E$4:$K$6 until a least squares solution was found. By setting Q_0 to zero and by changing the cell range in the “changing cells” box, the number of logistic functions desired/required in a given model could be varied.

Solver Parameters Window

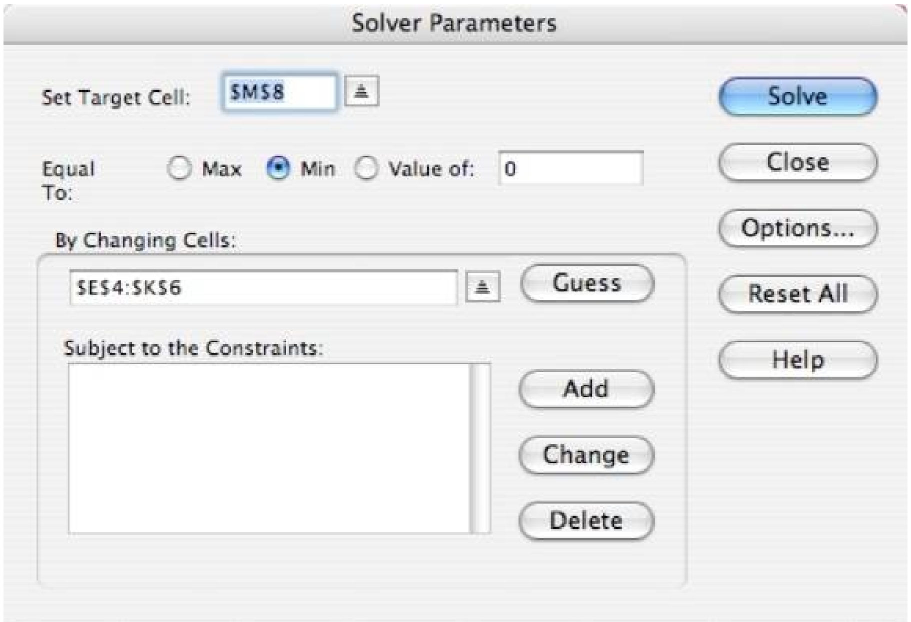
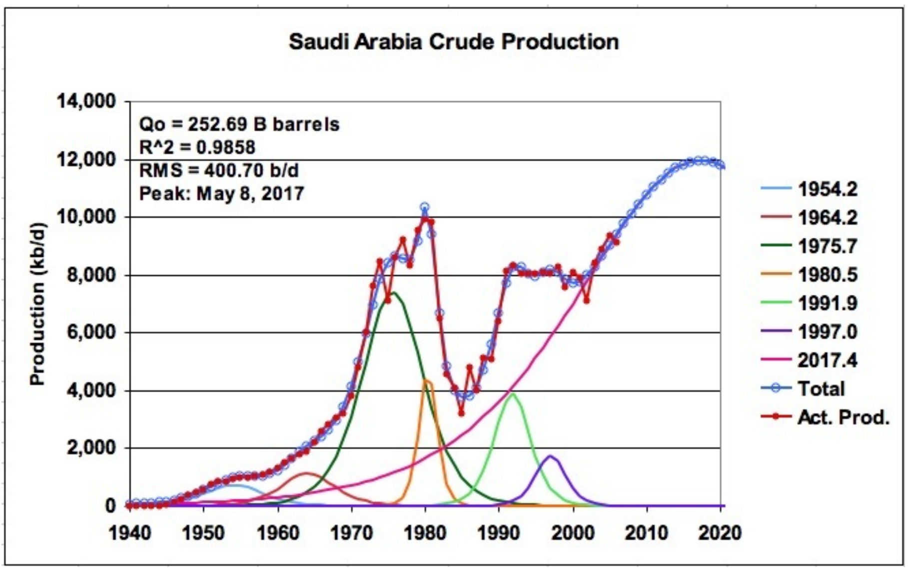


Figure 1: Seven logistic model of KSA production



The first run using seven logistic functions yielded the following solution shown in Figure 1 (taken from Tab SA7-7-1 in SA7_LS_Mult_Logistic). It shows a URR of 252.69 B barrels and peak production of 11.94 M b/d on May 8, 2017. This solution is surprisingly close to the current Saudi Aramco claim on its website of proven oil reserves of 259.8 B barrels at the end of 2005 and its expansion plan of increasing production capacity to 12.5 Mb/d by 2009. Depending on the source, the question of whether the 259.8 is the URR or remaining proved reserves is still an ongoing issue.

The parameters that define each of the seven logistic functions in Figure 1 are given in Table 1. As can be seen, the logistic centred in the year 2017.4 dominates all of the other ones and accounts for 78% of the KSA URR.

Table 1: Parameters defining the seven logistic functions

Qo	2.771	4.012	30.376	5.642	9.335	3.462	197.089	252.69
Const	0.38218	0.41179	0.35514	1.22471	0.60821	0.73648	0.08849	
Peak Yr	1954.168	1964.171	1975.678	1980.452	1991.851	1997.008	2017.350	

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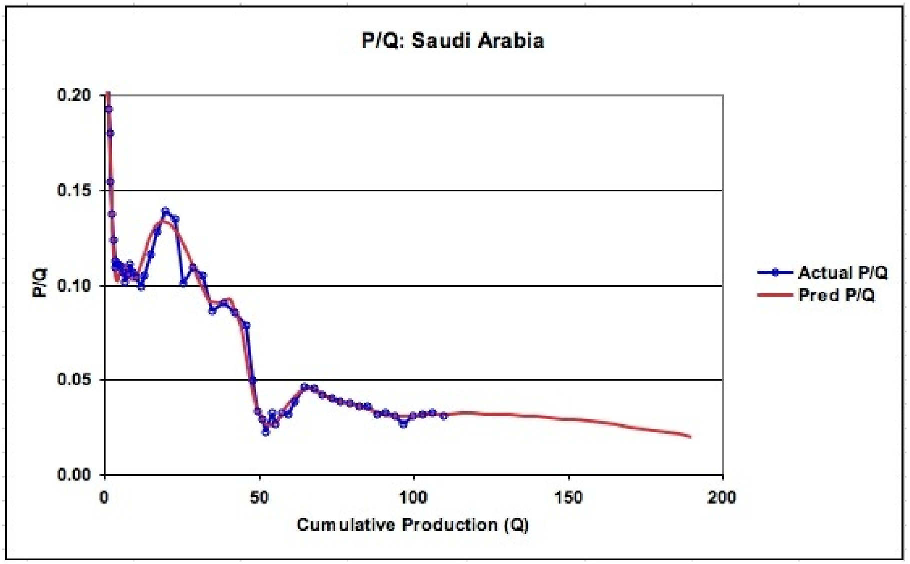
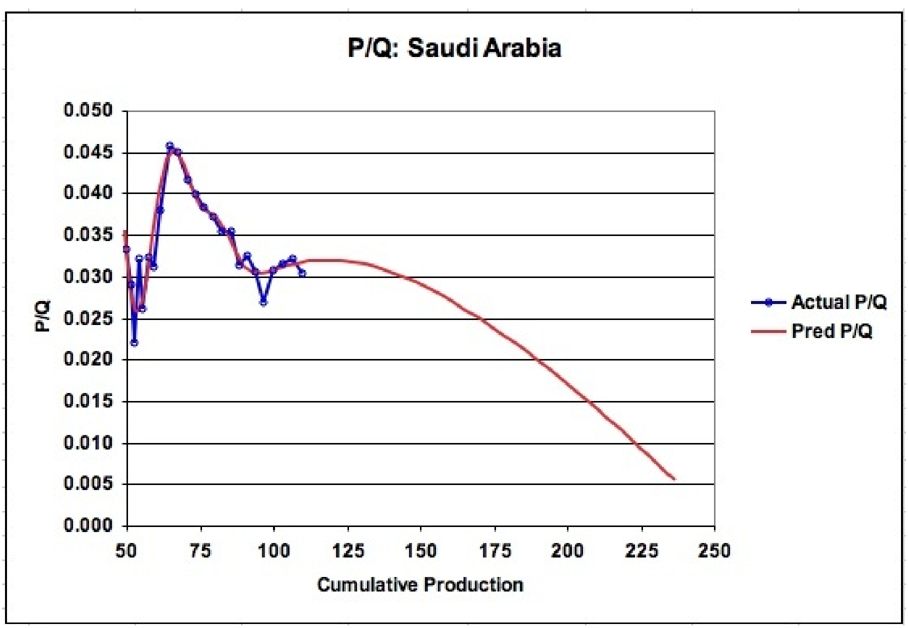
The predicted oil production profile follows the actual production reasonably well and the quality of fit can be assessed from the square of the correlation coefficient, R^2, and the root mean square error of 400.70 b/d.

Figure 2: P/Q for KSA



While this method directly provides URR, it is instructive to view the associated P/Q charts shown in Figures 2 and 3. As can be seen, the model predicted graph of P/Q follows the actual P/Q reasonably well and is not affected by the break in the linear portion of the curve at a Q of 96.7 B barrels. An expanded view of how the P/Q graph continues to curve down toward the URR of 252.7 B barrels is shown in Figure 3. Note that P/Q does not become linear until it passes Q of about 225 B barrels.

Figure 3: Expanded view of P/Q for KSA



Since this methodology uses an iterative non-linear least squares process to arrive at a minimum value for the sum of squared errors, the solution is a function of the initial conditions/guess. Consequently, the solution can only be described as a local minimum/optimum. Different initial conditions yield different solutions. It is necessary to vary the initial conditions to assess the sensitivity of the solution to the initial conditions and to determine the range of plausible solutions.

Having the first solution, the parameters in Table 1 were changed to find different solutions and to obtain a sense of the possible variation in the solutions. A number of runs were made. The results for two of the more extreme cases are shown in Figures 4 and 5 (Tabs SA-7-2 and SA-7-3). The runs produced URRs that ranged from 233.95 B barrels to 286.77 B barrels. Note that the quality of fit, as quantified by R^2 and the RMS error, is very similar to the run shown in Figure 1.

Figure 4: KSA daily production for a URR of 233.95 B barrels

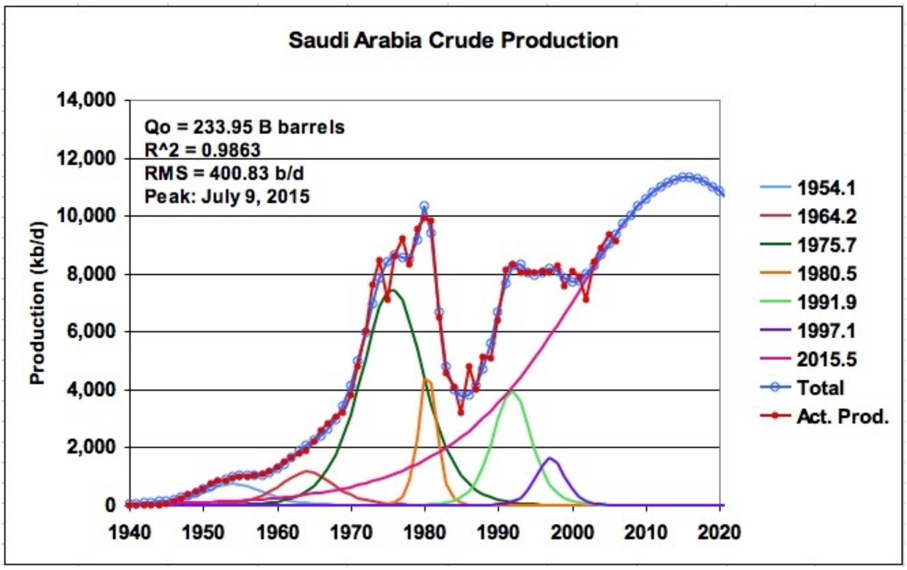
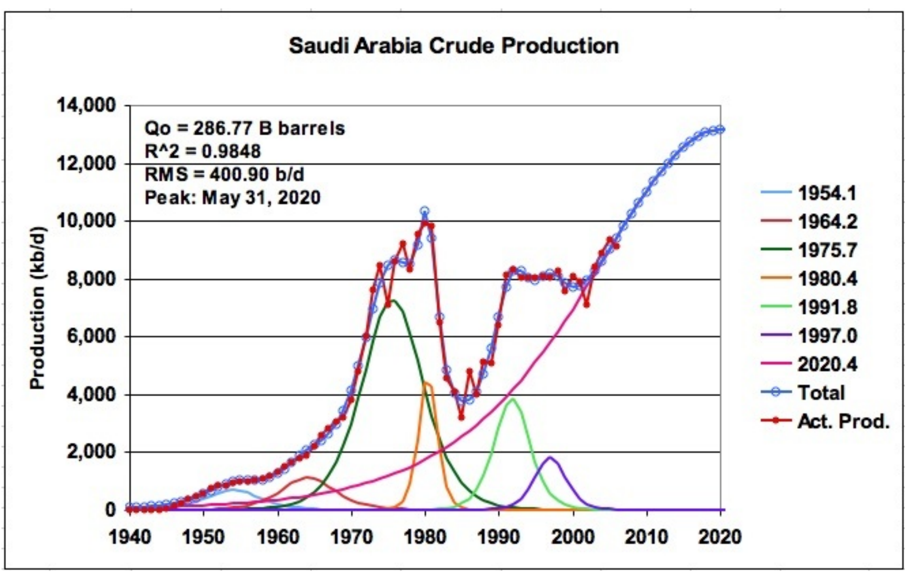
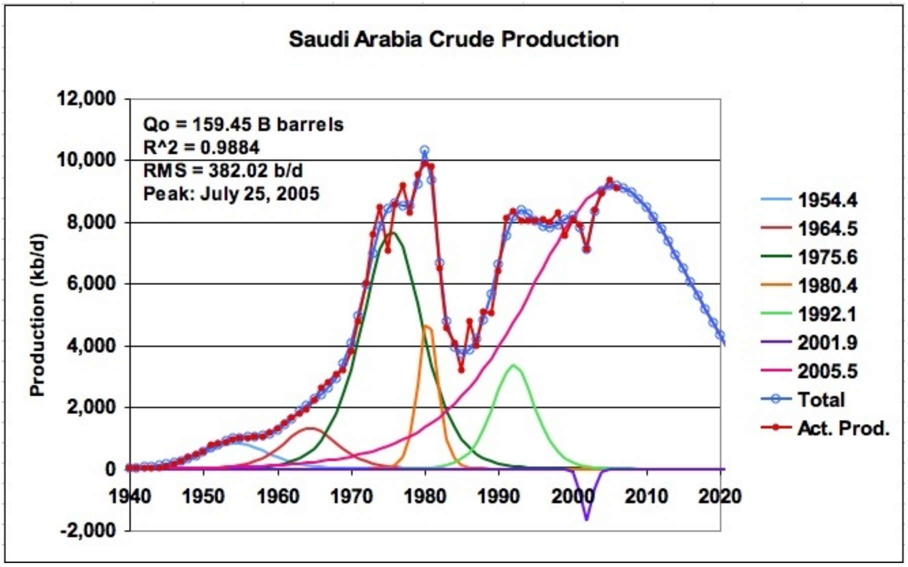


Figure 5: KSA daily production for a URR of 286.75 B barrels



In reviewing the quality of fit of the model, it was noted that while the actual KSA oil production from the years 1998 to 2003 varied significantly, the model averaged the oil production variation over those later years. I wondered what would be the impact on the URR of trying to more accurately model the behaviour in the years after 2000. To do this, an earlier solution was modified by placing a small logistic function with a negative URR in the area of the production decline that occurred in 2002. The solver routine was then launched to find the least squares solution. The result was startling as shown in Figure 6.

Figure 6: KSA daily production using negative logistic centred in 2001.9



The URR decreases to 159.45 B barrels with a peak production of 9.176 M b/d on July 25, 2005. This is a reduction of approximately 100 B barrels from the earlier solutions. As can be seen, the model tracks the 2002 oil production excursion very well as quantified by the reduction in the RMS error to 382 b/d. Clearly the attempt to accurately model the years 2000 to 2006 has a profound effect on the URR and the future peak production date. This raises the question of how accurate does the fit need to be and where does it need to be accurate? The associated and expanded P/Q graph for this case is shown in Figure 7.

Additional cases were run using six logistic functions (SA6_LS_Mult_Logistic, also available on request) instead of seven and in general the URRs came into the 160 B barrel regime. Again the best fit was obtained when a logistic function with a small negative URR was added to one of the runs and is shown in Figure 8.

Some may question the merits of using a logistic function with a small negative URR in a model to predict oil production. However, the objective here was to treat the curve fitting of the production profile as a mathematical exercise to assess the impact of accurately fitting the profile over the years 1998 to 2004. The use of the very small negative logistic function was an expedient way to accomplish this. It should be noted that it is possible to create a decline in a profile by placing two positive logistic functions close together. This was done for clarity and the result is shown in Figure 9. This procedure results in a forced fit of the production profile in the last five years that gives an unrealistically low value for URR and a future production profile that appears to be unlikely at this time.

Figure 7: Expanded P/Q prediction with a small negative URR in 2001.9.

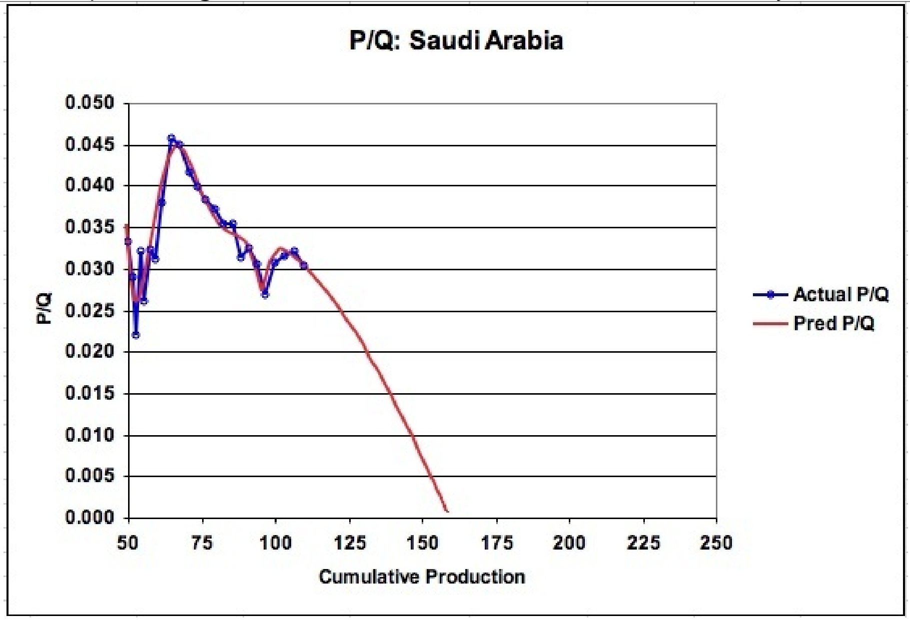


Figure 8: KSA production: 6 logistic functions (Note Tp = 0 for #1 logistic)

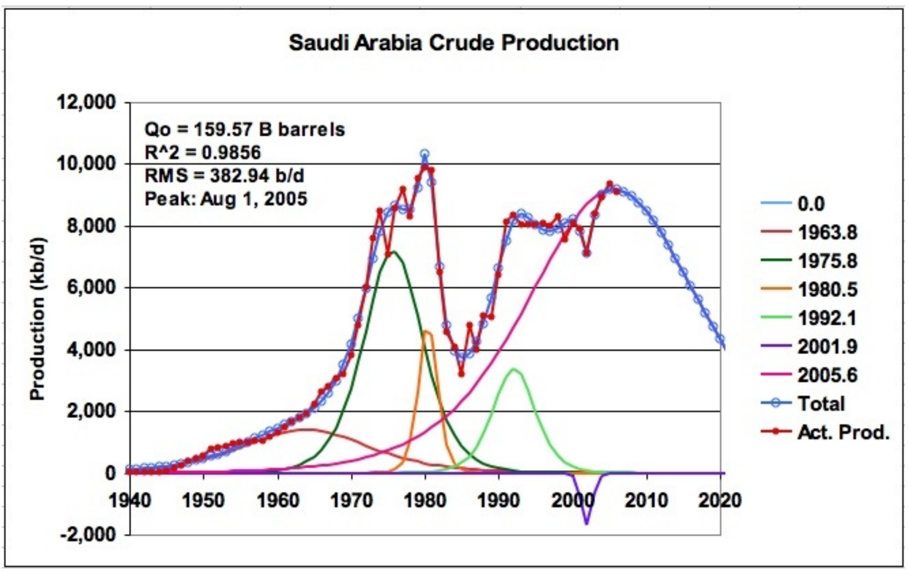
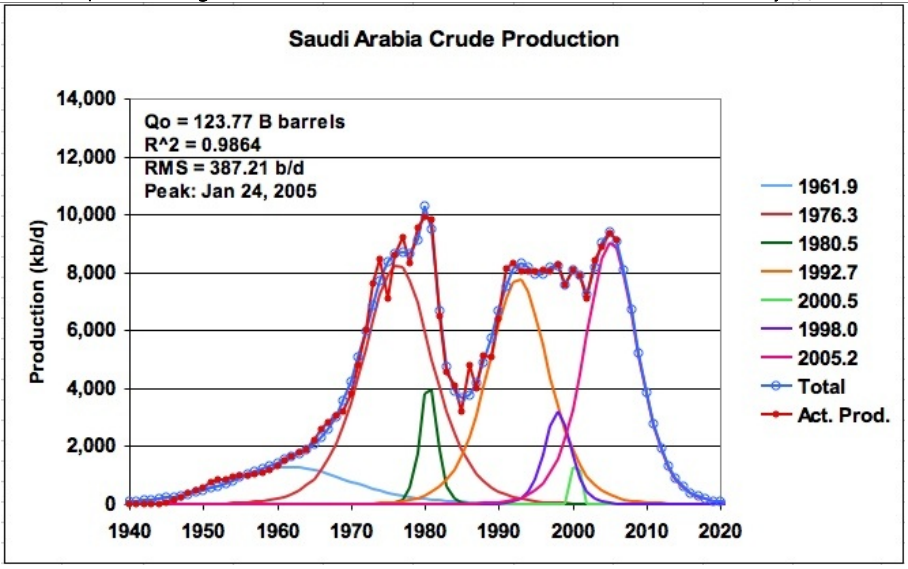


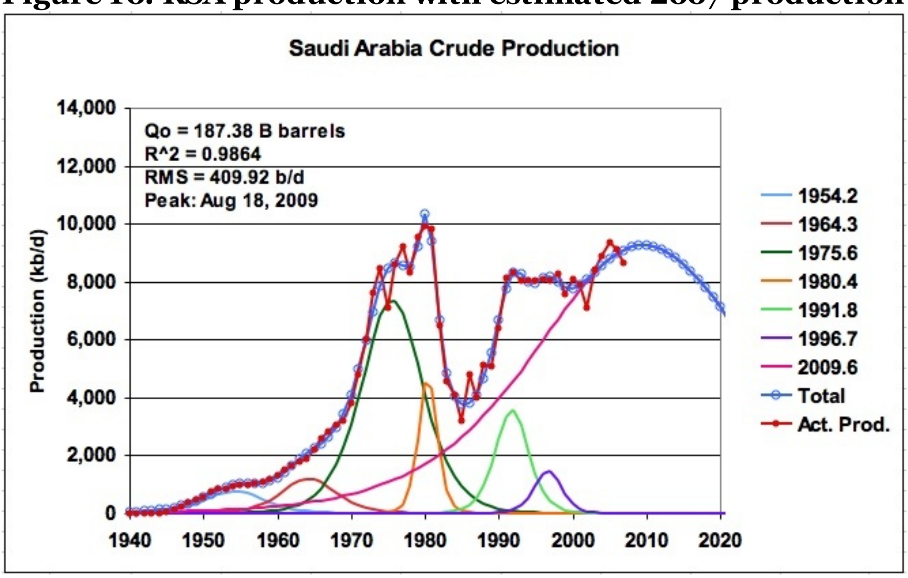
Figure 9: Effect of two Logistics to model the 2001 production decline



Another example of the difficulties and sensitivity associated with how to treat the last years can be obtained by projecting the average KSA oil production for 2007. The June 2007 OPEC Oil Market Report shows that for the first five month of 2007, KSA oil production has averaged 8553 Mb/d with a small increasing trend since March. If it is assumed that OPEC will not alter its target production until September and then permit production to increase in November and December, KSA could achieve an average production of approximately 8,625 Mb/d in 2007, if it increased its production by 250,000 b/d in the last two months.

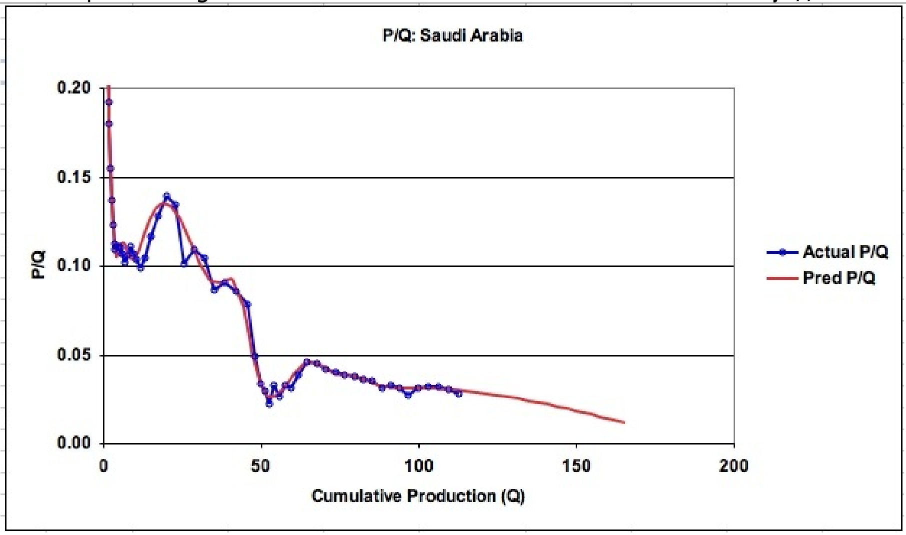
Adding this 2007 data point to the run that generated Figure 5, and using a model that averages the data over the latest years gives the result shown in Figure 10. Adding the projected 2007 data point reduces the URR by 100 B barrels to 187.4 B barrels and moves the peak production date forward to 2009. The P/Q graph is given in Figure 11.

Figure 10: KSA production with estimated 2007 production added



While it was hoped that this methodology could provide some additional insight into the URR of KSA, it only seems to have confirmed that there appears to be two possible solutions, either a URR of approximately 160 B barrels or 260 B barrels. Perhaps the KSA production profile is too difficult to model, whether one uses this methodology or Hubbert's HL method.

Figure 11: P/Q for KSA production with estimated 2007 production added



On the other hand, we must recognize that the KSA production during the years 1998 to 2003 was constrained intentionally by Saudi Aramco to address market factors. Consequently, it might be reasonable to assume that the models that averaged the production during that time frame are more realistic than those trying to follow the profile exactly. The models that averaged the production data in those last years indicate that a URR for KSA in the range of 260 B barrels and a production peak of approximately 12,000 kb/d may be plausible. If KSA production were to exceed 10.5 M b/d to 11.0 M b/d in the next 2 years, it would lend more credence to the 260 B barrel estimate.

It will be difficult to assess the KSA URR until the reason for the production decline that began in March 2006 can be ascertained. It appears that the continuing excellent detective work by Staniford and Mearns regarding potential future KSA production will definitely be needed help to resolve the KSA URR mystery. We will need to know whether the decline is due to inevitable natural depletion or deliberately constrained production. If it is natural depletion, the URR estimate of 160 B barrels may be closer to the mark.

4) Kuwait

Another country of interest is Kuwait and in particular the issue of whether their oil reserves (URR) are 48 B barrels or 99 B barrels. In January 2006, Petroleum Intelligence Weekly (PIW) reported that Kuwait's actual oil reserves, which are officially stated at around 99 billion barrels, might be closer to 48 billion barrels.

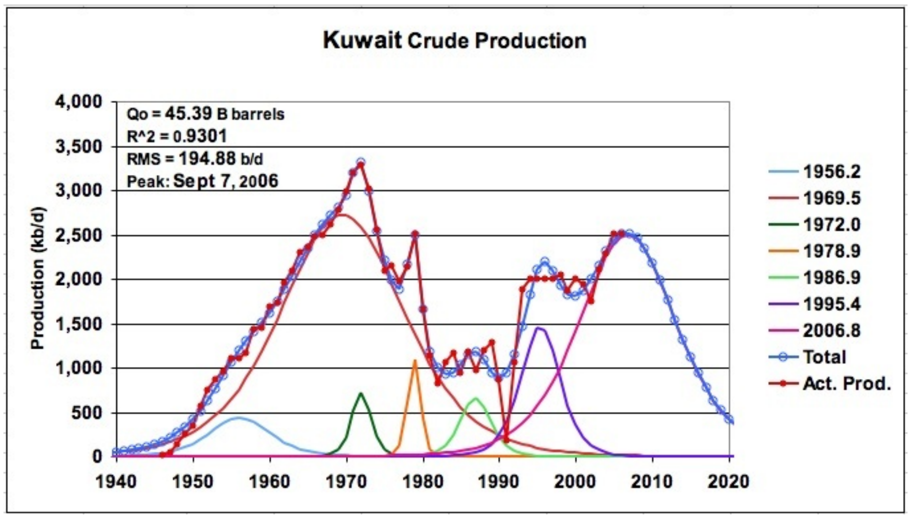
Since there are two estimates for Kuwait's reserves, modeling the oil production history would provide an indication of which estimate, high or low, was more consistent with the results of modeling. Also, since the production has been particularly erratic since 1970, including the decline to 185 kb/d in 1991 due to the disruption associated with the 1990 invasion of Kuwait and the ensuing war, it would provide another indication of the merits and limitations of this modeling methodology.

Kuwait's oil production data was taken from the 2005 OPEC Annual Statistical Bulletin for the years 1938 to 2004. This data includes ½ of the oil produced in the neutral zone. The 2005 and 2006 production numbers were taken from the May 2007 OPEC Oil Market Report. Seven logistic functions were used to model the average daily production from 1938 to 2006 (SA6_LS_Mult_Logistic). The result is shown in Figure 12.

After running a few cases with similar URRs, the model shown in Figure 12 was selected because it attempted to average the production over the last 8 years. The model predicts a URR of 45.39 B barrels and peak production rate of 2.52 M b/d on Sept 7, 2006. This solution is surprisingly close to the PIW article that reported Kuwait's reserves to be close to 48 B barrels. On May 15, 2007, the Kuwait Times published a similar article:

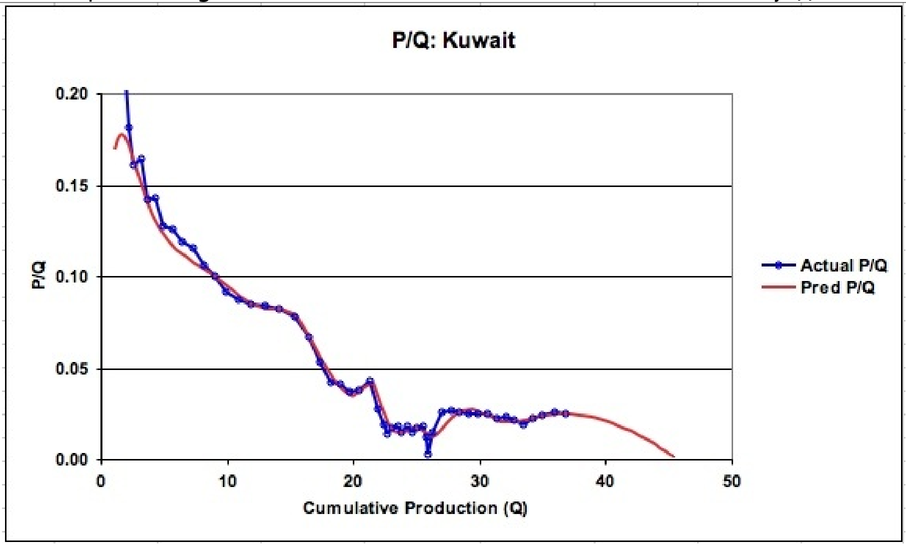
> KUWAIT: More than half of Kuwait's oil reserves will not be produced through cheap traditional methods, Deputy Director General of the Kuwait Institution for Scientific Research (KISR) Dr. Nader Al-Awadhi said yesterday. Kuwait's oil reserves are estimated at about 95 billion barrels, among the biggest worldwide. Most production, if not all, is being produced through traditional methods, Al-Awadhi told a KISR workshop on "Managing Carbon Dioxide for Improving Oil Production" that started yesterday.
>
> He expected that the traditional methods would produce 45 billion barrels, but could not be used for the rest (i.e. 50 billion barrels). Thus, emerges the necessity of developing new feasible environment-friendly methods for producing heavy oils, he said adding that oil production operations over the past years had focused on light oil.

Figure 12: Kuwait oil production



The Kuwait Times article appears to clear up the issue of the level of Kuwait's oil reserves (URR). It states that the traditional methods would produce 45 B barrels and indicates that the remaining oil is classified as heavy. Since the oil produced to date has used conventional methods, the modeling can only infer its URR estimate from this historical production data. The article provides a degree of confirmation for the predicted URR of 45.4 B barrels for Kuwait and possibly its future production profile for conventional oil. Since Kuwait has stated that its Burgan oil field has peaked, it is possible that this means that its conventional oil production also peaked in 2006 as the model and data indicate. The interesting question that comes to mind from reading the Kuwait Times article is whether the Kuwait and KSA "anomalous reporting" of increased oil reserves in the 1980s is related to the discovery/addition of "heavy oil". It is also interesting to note that Simmons in "Twilight in the Desert", P174, in describing eastern Ghawar mentions a "massive tar mat up to 500 feet thick lay between Arab D oil and the formation receiving injected water".

Figure 13: P/Q for Kuwait

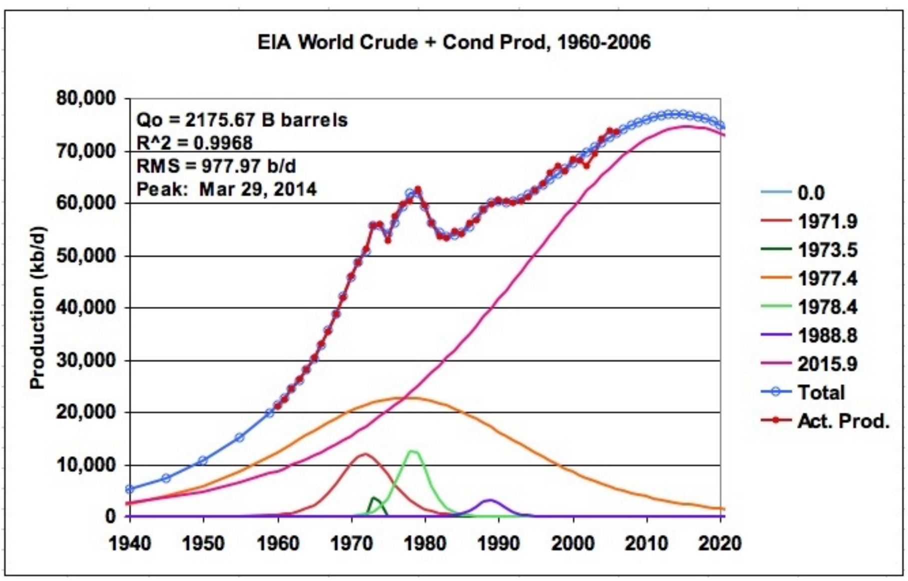


The P/Q graph for Kuwait is shown in Figure 13. As can be seen, there is a break in the linear portion of the data at a Q of 33.4 B barrels and one is left with the decision on how to deal with this using HL. The LS multi-logistic approach follows the break in the P/Q graph and heads for a URR of 45.4 B barrels. In this case we are fortunate to have the confirming statement from the Dr. Nader Al-Awadhi, "that the traditional methods would produce 45 billion barrels".

5) World Oil Supply

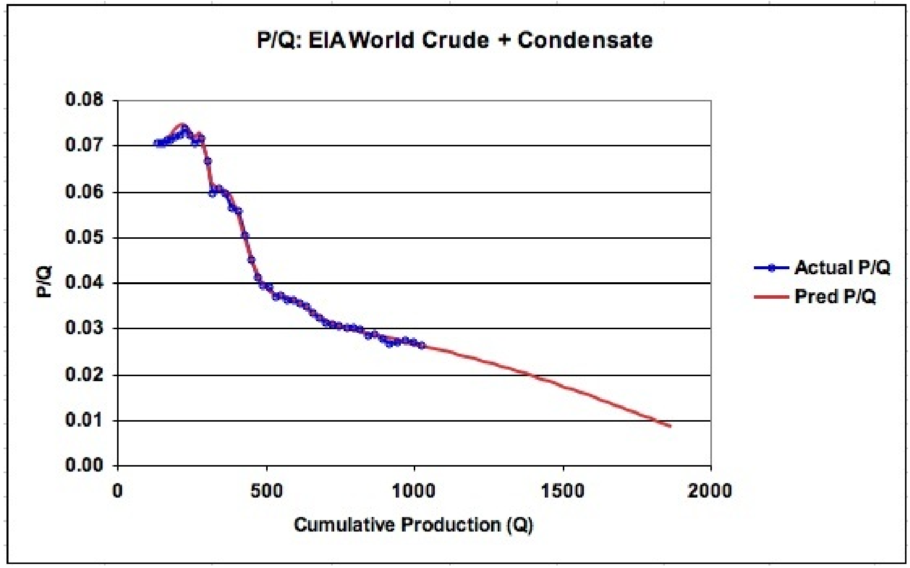
On April 17, 2007, Khebab updated The Shock Model in The Shock Model (Part II). One of the points mentioned by Khebab in his post was the inability of the logistic function to address the 1970 to 1980 production bump. While this is clearly true for a single logistic function, the foregoing work on KSA oil production indicated that this would not be the case for a methodology based on fitting multiple logistic functions and decided to apply the same procedure as above to world oil production.

Figure 14: EIA World production for crude plus condensate (six logistics)



The data source for world oil production was the EIA International Petroleum Monthly sheet for crude plus condensate, t41d, supplemented with data from Table 1.2 from the Transportation Energy Data book of the U.S. DOE. Table 1.2 provided data from 1960 to 1969 and the May 8, 2007 EIA data sheet t41d provided information for the years1970 to 2006. Note that the 2006 data is the EIAs preliminary estimate.

Figure 15: P/Q for EIA world production for crude plus condensate



The EIA world oil production data was modeled using six logistic functions. As before, we are left with the decision of how accurately to model the 2000 to 2006 production profile. The initial runs were allowed to average the latest years. One of the runs is shown in Figure 14 and the results are given in Tab EIA World-6-1 (from EIA_LS_Mult_Logistic, also available on request). This model predicts a world URR for crude plus condensate of 2176 B barrels with a peak production of 76.9 M b/d on March 29, 2014. The associated P/Q graph is shown in Figure 15. Notice how the predicted P/Q graph has a very gentle downward curvature as it heads toward a cumulative production point of 2176 B barrels rather than the straight line which would occur from using a single logistic function.

Table 2: Parameters defining 6 logistic functions for world C+C production

Qo	0.000	40.345	4.723	349.704	25.017	5.480	1750.402	2175.67
Const	6.25697	0.42997	6.29773	0.09497	0.74375	0.82988	0.06218	
Peak Yr	0.000	1971.948	1973.479	1977.413	1978.432	1988.834	2015.856	

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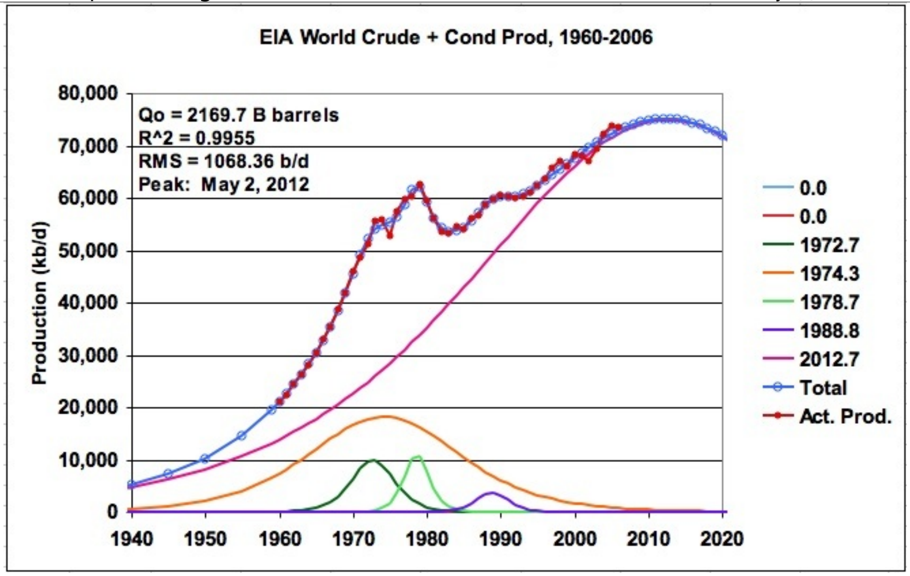
The parameters that define each of the six logistic functions shown in Figure 14 are given in Table 2. As can be seen, the logistic function centred in the year 2015.9 dominates all of the others and accounts for 80.4% of the URR.

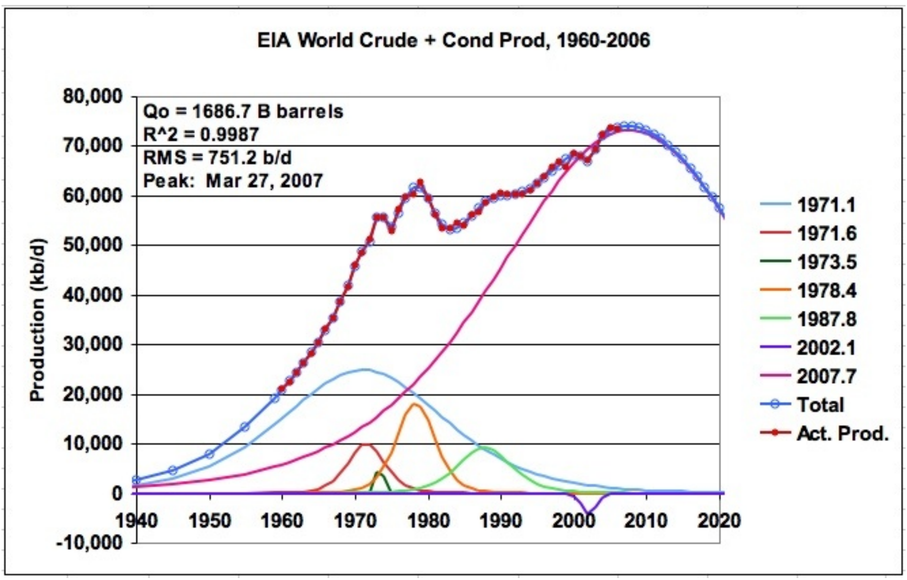
To get an idea of the potential variation in Qo, additional runs using the six logistic function model with different initial conditions yielded URRs between 2120 B barrels and 2222 B barrels.

Figure 16: EIA world production for crude plus condensate (five logistics)



Applying a five logistics model to the production profile yielded the results shown in Figure 16. This model yielded a URR of 2169.7 B barrels. While R^2 was slightly lower, the RMS error was about 12½% higher.

Figure 17: World production for crude plus condensate (seven logistics)



Again the lowest sum of squared errors was obtained with a logistic function with a small negative URR being placed at the year 2002.1. This seven logistic function model predicts a URR of 1686.7 B barrels with a peak production of 74 M b/d on Mar. 27, 2007 and is shown in Figure 17. Note that for this case, the URR is reduced by approximately 500 B barrels relative to the URR of 2175 B barrels shown in Figure 12.

As can be seen, multiple logistic models can follow world oil production very well and can address the 1970 to 1980 production bump along with the varying production profile during the years 1998 to 2004. However, one must question the validity of this result since a URR of 1686.7 B barrels seems too low, considering that Campbell, in the March 2007 ASPO letter, estimates the URR for regular conventional oil to be approximately 1900 B barrels.

The critical question that needs to be answered is whether the production profile in the years 2000 to 2004 should be averaged or modeled accurately. This is a rather critical question since the addition of the logistic function with a very small negative URR, which permitted a very accurate fit of the oil production profile during the years 2000 to 2004, resulted in a reduction in the URR of approximately 500 B barrels. As discussed in the KSA section, during this timeframe OPEC intentionally constrained oil production to address market factors. Consequently, at this time, the combination of the Campbell data and the OPEC production constraints suggests that a model that averages the data in the later years, rather than fits it precisely, appears to be more realistic and accurate for estimating URR and indicating future production.

The foregoing analysis has been focused on obtaining a realistic fit of the production profile using 5 to 7 logistic functions. However, in this type of curve fitting analysis, it is worthwhile to also investigate a looser or "averaging type" fit using only 2 logistic functions. This was not done for the KSA and Kuwait examples because of their non-logistic behaviour and the extreme variation in their production profiles.

The result of modeling the EIA data using two logistic functions is shown in Figure 18. This model increases the URR to 2244 B barrels and adds 69 B barrels to the six logistic model shown in Figure 14. However, it moves the peak date forward from 2014 to 2011. These two models are similar in that they both have one main logistic function to predict future production. The other logistic functions are smaller, track the deviations associated with historical crises and decay rapidly. By comparing the results from the "two logistic" model in Figure 18 with the very accurate fit using the "seven logistic" model shown in Figure 17, the six and five logistic models shown in Figures 14 and 16, respectively, can be considered as being a reasonable compromise between under fitting and over fitting the data.

Figure 18: EIA world production for crude plus condensate (two logistics)

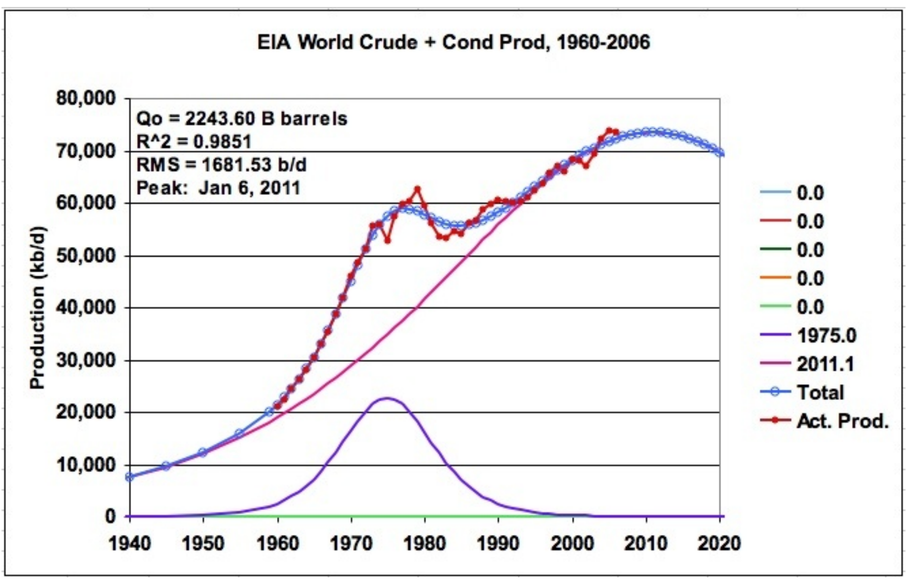
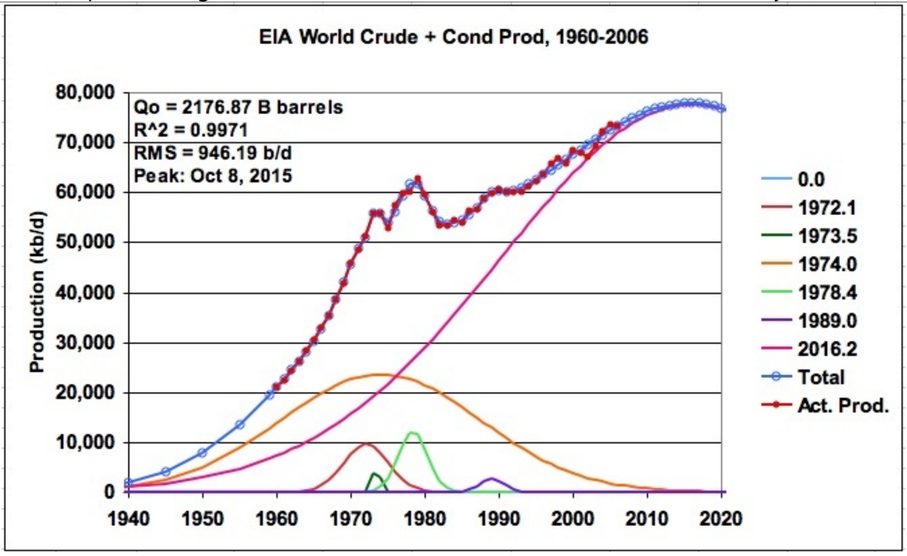


Figure 19: World production for C + C using the Gaussian distribution

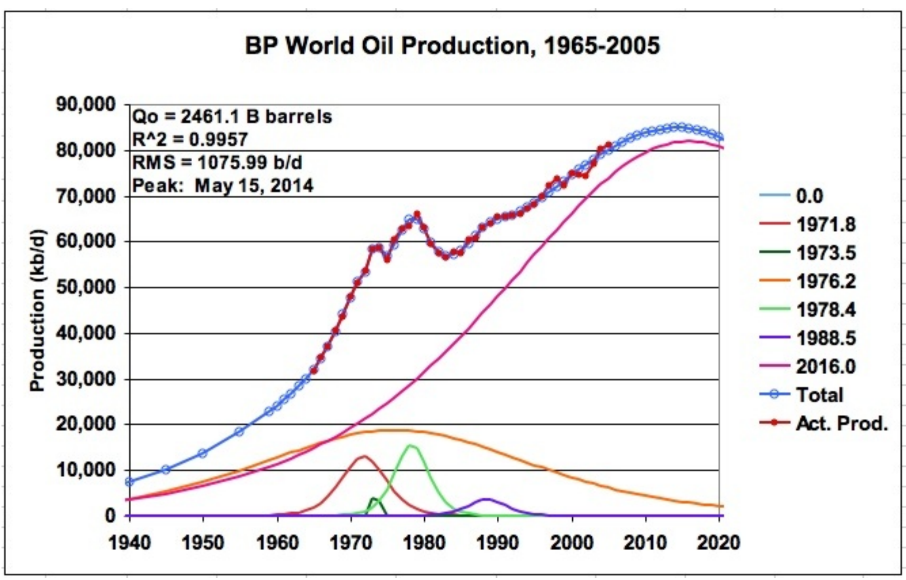


While the above analysis was undertaken using the logistic function, it is worthwhile to note that it could have equally been done using the Gaussian distribution. A Gaussian solution is shown in Figure 19. While it is similar to that shown in Figure 14, the peak date is pushed further out since the shape of the largest Gauss function is not as “peaky” as the logistic function. It should be noted that the Gaussian distribution is not typically used for modeling resource depletion. However, Deffeyes, in his book "Hubbert's Peak The Impending World Oil Shortage", used the Gaussian to model U.S. oil production history and then continued to use it to model world oil production data.

6) British Petroleum Data for World Oil Production

For a final example, BP’s world oil production data, which includes crude oil, oil sands and NGLs was modeled. The production data was taken from BP’s 2006 statistical review. Six logistic functions were used and the results are shown in Figure 20. The estimated URR is 2461 B barrels and the model indicates a peak production of 84.87 M b/d on May 15, 2014. While the peak production rate is different than that for the EIA C+C profile shown in Figure 14, due to the addition of the NGLs, the peak date is virtually the same when using six logistic functions.

Figure 20: British Petroleum’s data for world oil production (Six logistics)



Since the world oil production profile has a more regular nature, the BP data was also modeled using two logistic functions and is shown in Figure 21, Tab BP World-2-1 (BP_LS_Mult_Logistic, also available on request). This can be compared with the BP model in Figure 20, which shows a URR of 2461 B barrels. The 2 logistic model adds 138 B barrels to the URR, a 5.6% increase, and moves the peak date forward by about 20 months. As would be expected, the RMS error and R^2 are larger. The URRs of the two logistic functions are 119 B and 2480 B barrels respectively. Considering the simplicity of this two logistic model, it is not significantly different than the six logistic model.

In a [recent paper](#) by Phil Hart and Chris Skrebowski, they estimate the URR for world conventional oil and NGLs to be 2420 B barrels. Also the June 2007 ASPO letter estimates the URR for all liquids to be 2550 B barrels. The BP data modeled in Figure 20 shows a URR of 2461 B barrels, which falls in between these two estimates. While the all liquids data appears to be similar, it is not totally clear that the Hart-Skrewbowski data and the ASPO reserve data are reporting the same data as BP's Statistical Review.

Figure 21: British Petroleum's data for world oil production (Two logistics)

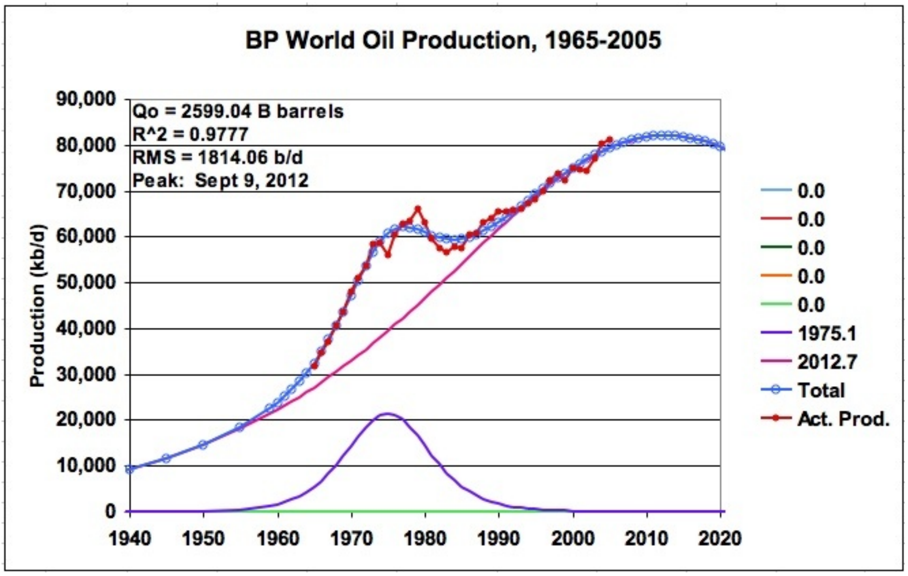
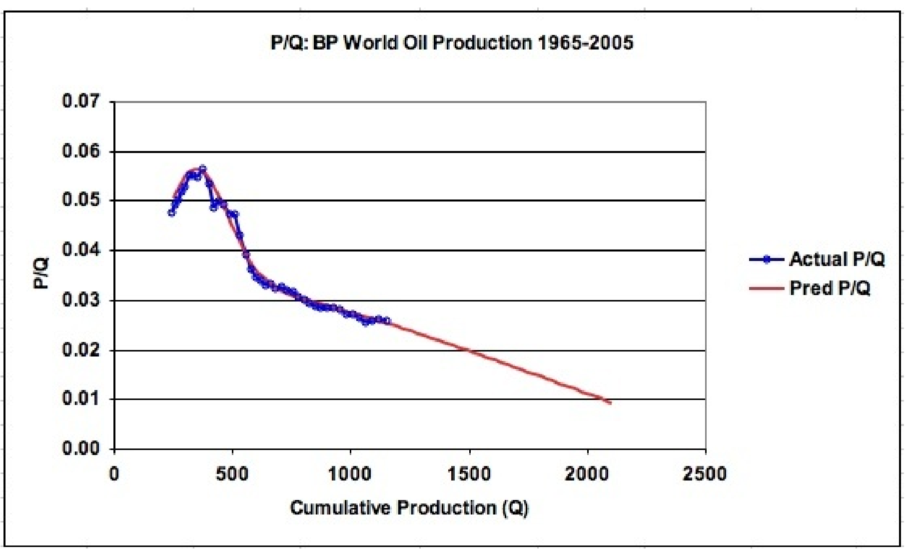


Figure 22: P/Q for BP's petroleum data for world oil production (Two logistics)



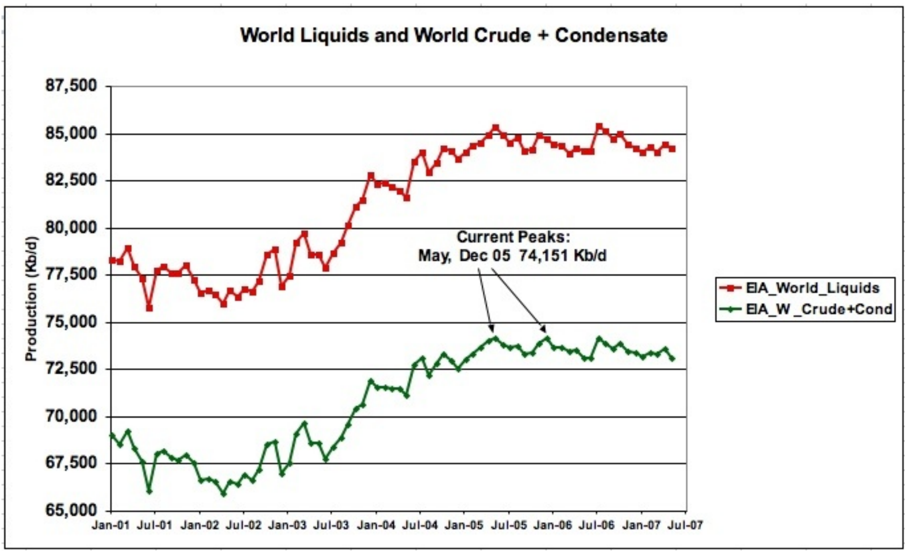
The P/Q graph for the two logistic BP model is given in Figure 22. As can be seen for this case, the projected P/Q is almost linear as would be expected for a case where there is one dominant logistic function that predicts future production.

7) Apparent Peak Oil

The foregoing analysis was focussed on estimating URR and when the peak in world oil production could occur using different modeling approaches (accurate vs averaging of latest years). The peaks ranged from the years 2007 to 2015. However, as the peak is approached and the annual change in the rate of oil supply decreases, another factor must be considered. In particular, it is necessary to consider the relationship between the annual supply rate of change (ROC) relative to the annual demand ROC.

Many are saying that world conventional oil production has peaked based on the EIA data for crude plus condensate shown in Figure 23. Recognizing that mandatory reductions in OPEC supply and additional difficulties in Nigeria are restricting production, it still may be too early to declare May 05 and Dec 05 as being the peaks for production of conventional oil.

Figure 23: EIA crude plus condensate monthly production

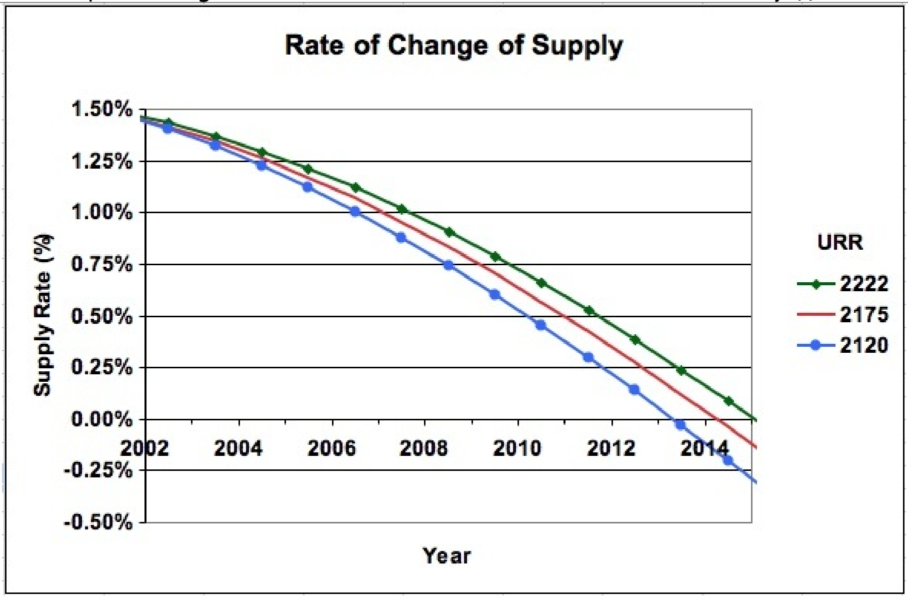


Nevertheless, the dramatic change in the slope of oil production from Jan 02 to May 05 compared to the production slope from May 05 to February 07, shown in Figure 23, does raise an interesting question/possibility. Is it possible that the world will see an "Apparent Peak" before the real peak is reached when supply cannot meet demand without an oil market correction? With supply and demand in relative balance as the peak is approached, the apparent peak could be defined by the point in time when the demand ROC for oil exceeds the supply ROC.

For 2007, the EIA is predicting an increase in demand of 1.6 % over 2006 while the IEA is predicting 1.8% increase. According to the IEA, the demand ROCs for the years 2003 to 2007 are 2.3%. 3.8%, 1.6%, 0.9% and 1.8% respectively. The average demand ROC for the last three years suggests that the supply graphs should be examined to determine when the supply ROC will begin to fall below approximately 1.4%. In the May 2007 edition of the U.S. Energy Information Administration "International Energy Outlook 2007", it states "World use of petroleum and other liquids grows from 83 million barrels oil equivalent per day in 2004 to 97 million barrels per day in 2015. This represents an average annual demand ROC of 1.1%.

The annual supply ROC is plotted in Figure 24 for the three EIA cases that gave solutions for URRs between 2120 B and 2222 B barrels and peak years from 2013 to 2015. The ROC of the BP data was also calculated and it coincided with the URR 2175 graph.

Figure 24: Annual Change in the supply ROC for various URRs (six logistics)



As can be seen, a supply ROC of 1.4% occurred around the year 2003 and during that time there was sufficient real world spare capacity to meet the even larger demand ROC of 2.3% that occurred that year. However, looking forward to the supply ROC for 2007 in Figure 24, it is between 1% and 1.1% for the three given URR scenarios. It drops below 1% after 2008. If the IEA's and EIA's 2007 tentative predictions for demand ROCs of 1.8% and 1.6% respectively are accurate, and the models developed in this paper are reasonable approximations for future real world oil production, the predicted gap between the decreasing supply ROC and the IEA's and EIA's projected demand ROC will either challenge the world's ability to increase supply at a reasonable price or demand destruction will be required to balance supply and demand.

5) Conclusions

The above analysis has provided another curve fitting methodology to estimate the URR for a country or the world. However, the variation in results associated with the accuracy of modeling the latest years shows the necessity of having factual/better reservoir/geological knowledge to complement any modeling. From the above results for Saudi Arabia, Kuwait and world oil production, it is clear that good modeling requires a mix of good mathematics and physical data.

In the case of Saudi Arabia, along with many other countries, verified estimates concerning URR and reserve production capacity are not readily/currently available. Ironically, such information will likely only be made available after a country's production has peaked; the fields have entered their irreversible period of decline; and reported oil production data from the IEA and EIA reveals the facts to the world.

While the issue of the dearth of information on oil reserves applies to many countries, the recent revelation from Kuwait regarding their reserves indicates this trend may change. As each country begins to meet the ever increasing challenge of trying to increase oil production against nature's inevitable natural depletion, they will have to come forth with better production/reserve information.

While most of the modeling analysis focused on determining a country's URR and the world peak production date, the analysis on supply ROC showed that the peak production date might not be the most critical time to pinpoint. A more critical time to pinpoint might be the "Apparent Peak", i.e. the point in time when the demand rate of change for oil exceeds the supply rate of change. The results from the foregoing analysis show that there is the potential to reach the "Apparent Peak" in oil production beginning as early as this year, 2007, or possibly 2008. If we are now in this critical time period, the world's ability to increase oil supplies at a reasonable price will be tested in a very short time or else demand destruction will be needed to balance supply and demand.