USING THE HUBBERT CURVE TO FORECAST OIL PRODUCTION TRENDS WORLDWIDE

A Thesis

by

JASSIM M. ALMULLA

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

May 2007

Major Subject: Petroleum Engineering

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Chair of Committee, Richard A. Startzman
Committee Members, Wayne M. Ahr
Jerome J. Schubert
Head of Department, Stephen A. Holditch

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ABSTRACT

Using the Hubbert Curve to Forecast Oil Production Trends

Worldwide. (May 2007)

Jassim M. Almulla, B.S., University of Louisiana at Lafayette

Chair of Advisory Committee: Dr. Richard A. Startzman

Crude oil is by far the most important commodity to humans after water and food. Having a continuous and affordable supply of oil is considered a basic human right in this day and age. That is the main reason oil companies are in a constant search of cost effective ways and technologies that allow for an improved oil recovery rate. This would improve profitability as well.

What almost everyone knows and dreads at the same time is that oil is an exhaustible resource. This means that as more oil is being produced every day, the amount of oil that remains to be produced shrinks even more. With almost all big oil fields worldwide having already been discovered, the challenge of finding new reserves grows harder and harder.

A question that has always been asked is “when are we going to run out of oil?” Given the available technologies and techniques, no one could give an exact answer and if someone does, he/she would not be 100% sure of that answer. This study tries to approximate future oil production rates to the year 2050 using the Hubbert model. There are different models or tools to estimate future oil production rates, but the

reason that the Hubbert model was chosen for this study is its simplicity and data availability.

As any forecast, this study depends heavily on past trends but also factors in the current conditions. It is safe to say that this forecast (study) is as any other forecast, in which it will probably not mirror exactly what will happen in the future. Still, forecasts have to be done, especially for such an important commodity.

This study predicts that the total oil to be recovered is 4.1 trillion barrels. It also shows that most major oil-producing countries are either passed or about to pass their peaks.

DEDICATION

This work is dedicated:

To my parents who I would be nothing without; they showed me the way and still do;

To my beautiful wife who had to go through a lot just so I could get my degree; I love you Salma;

To my kids who give me the strength to continue just by remembering their smiles; and

To all my brothers, sisters, and extended family members who gave me a lot of support.

ACKNOWLEDGEMENTS

Praise and gratitude be to the Almighty, Allah, the Creator and Governor of the Universe and his Prophet Mohammed, peace be upon him.

Thanks to my parents for all that they have provided me with. Thanks to my wife for being so supportive and patient while I finish my studies. Thanks to my kids that have been living without their father so he could get this degree. Thanks to my brothers and sisters back home for all their support and kind words. Thanks for my father in-law who has provided my wife and kids with a lot while I was away.

I wish to express my sincere appreciation to Saudi Aramco for giving me this opportunity to achieve my dream by getting such a degree from a prestigious university, Texas A&M.

I would like to thank the chairman of my graduate advisory committee, Dr. Richard A. Startzman, for his unlimited support without which this research could have never been completed.

I, also, would like to thank Dr. Jerome J. Schubert and Dr. Wayne M. Ahr for serving as members of my advisory committee.

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CHAPTER I

INTRODUCTION

M. King Hubbert was an American geophysicist working for Shell Oil Company. The base of his theory is that given any geographical area the trend of oil production out of this area tends to fit a bell-shaped curve. This theory was presented by Hubbert to the American Petroleum Institute in 1956 in San Antonio. He predicted that the USA would hit its oil peak in the early 1970's. Most experts during this time rubbished this notion. Then in 1970 the U.S. production rate started falling and everyone realized that Hubbert was right.[1]

All the production data used in this study were obtained from *Twentieth Century Petroleum Statistics*.[2]

1.1 Hubbert Curve

As mentioned before, Hubbert suggests that production rate in any given area should fit a bell-shaped curve (see Fig. 1.1). All the production rates available are plotted against time. So, the Hubbert curve represents the best fit of all the historical data and then the extension beyond the provided data is a look at how production most likely would look out of the region.

This thesis follows the style of *SPE Journal*.

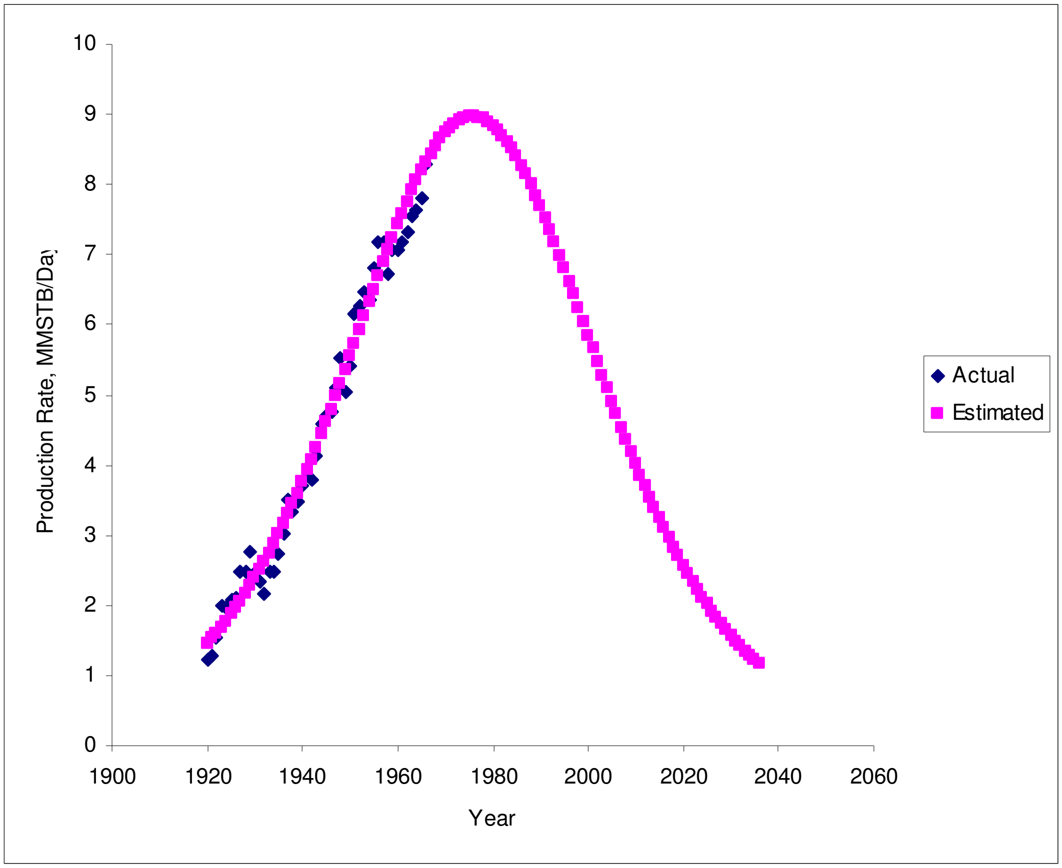

Fig. 1.1 A Basic Hubbert Bell-Shaped Curve

The highest point in the curve represents the production peak. After that the production starts to decline until it eventually would get to zero.

1.2 Hubbert Concept

The concept starts with the parabola:

$$q(t) = \frac{dN_p}{dt} = a\ N_p + b\ N_p^2 \quad \text{..1.1}$$

In this equation, *a* and *b* are constants and *a* is also called the growth factor. Figure 1.2 shows what a curve would look like using Eq.1.1.

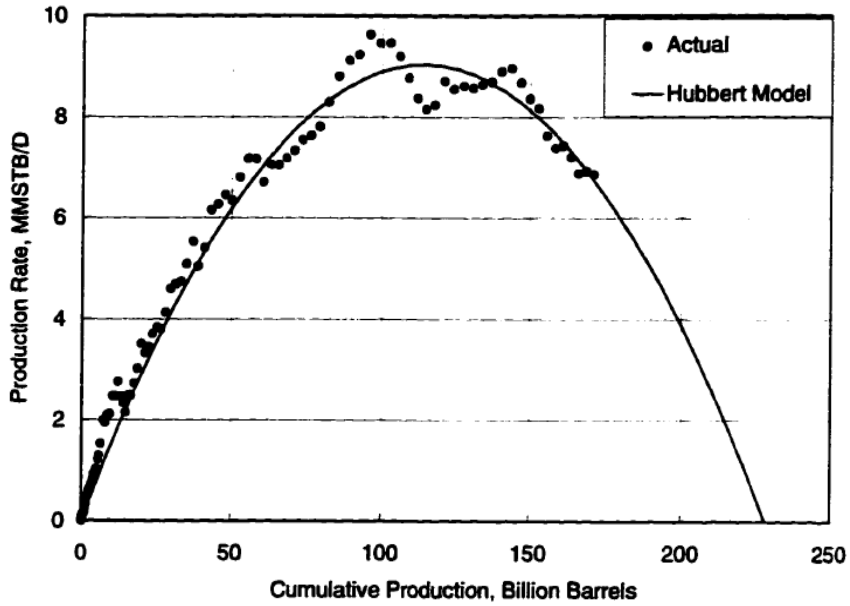

Fig. 1.2 Illustration of Eq.1.1 as a Curve (after Al-Jarri). [3]

When t = 0 or when $t \rightarrow \infty$, then the rate (q or dN_p/dt) is equal to zero. This on the other hand means that $N_p = 0$ at t = 0. It also indicates that $N_p = N_{p,u}$ when $t \rightarrow \infty$. $N_{p,u}$ is the cumulative ultimate production recovered. Considering all that, $b = -a / N_{p,u}$. As a result, substituting for b with rearrangement and integration of Eq.1.1 would yield:

$$N_{p,t} = \frac{N_{p,u}}{\left(1 + N_D e^{-a(t-t_o)}\right)} \quad \ldots\ldots 1.2$$

In the previous equation (Eq.1.2) N_D is a cumulative dimensionless factor giving by:

$$N_D = \frac{N_{p,u} - N_{p,o}}{N_{p,o}} \quad \ldots\ldots 1.3$$

$N_{p,o}$ is the cumulative production at any given time, t_0.

Differentiating Eq.1.2 would give the production rate as a function of time (dN_p/dt) in the following equation:

$$q(t) = \frac{dN_p}{dt} = N_{p,u} \frac{a\, N_D\, e^{-a(t-t_o)}}{[\, 1 + N_D\, e^{-a(t-t_o)}\,]^2} \quad \ldots\ldots 1.4$$

So, now Eq.1.1 includes a time factor and that could be observed in Figure 1.3.[3]

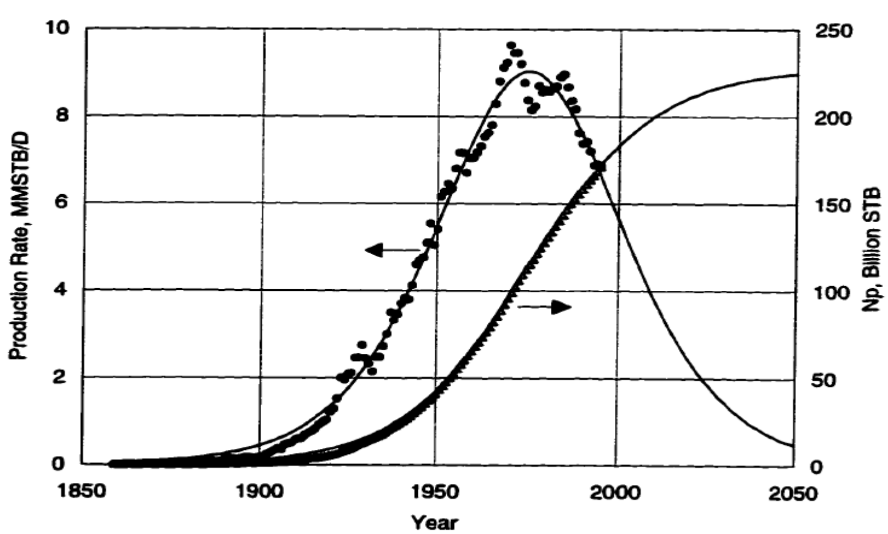

Fig. 1.3 Hubbert Model after Including Time (after Al-Jarri). [3]

1.3 Curve Fitting

Hubbert equation parameters of each country were obtained by evaluating the best curve fit of the Hubbert equation using the available production data. The best fit was obtained using the software Polymath™ 6.10. All curve fitting software work on the principle of minimizing the least squares of the produced fit. In the background of the software, a minimization problem is solved using a non-linear program whose objective function is a sum of squares of nonlinear functions. The default minimization algorithm used in Polymath is the Levenberg-Marquardt (LM) algorithm. [4]

To find the least square of the best fit, an initial guess of the fit parameters is required. In the case of low nonlinearity, any random guess is sufficient to retrieve the optimum values of the parameters. However, in the case of highly nonlinear equations, such as the Hubbert correlation, the initial guess has to be realistic and within the proximity of the expected optimal parameters. In order to comply with this requirement, the following procedure was followed.

A point of the actual data is nominated as a potential peak of the Hubbert curve. The derivative of a curve at its peak is always zero which represents the slope of the tangent to the curve at that point. The derivative of Hubbert equation is given by:

$$\frac{dq(t)}{dt} = \frac{d^2q(t)}{dt^2} = \frac{N_{p,u}\, N_D\, a^2\, [-e^{-a(t-t_o)} + N_D e^{-2a(t-t_o)}]}{\left[1 + N_D\, e^{-a(t-t_o)}\right]^3} \quad \text{.........................1.5}$$

At the peak (i.e. t_{max}) the derivative is zero. Equating the numerator to zero will yield:

$$N_D e^{-a(t_{max}-t_o)} - 1 = 0 \quad \text{……………………..…………………………..………1.6}$$

Solving for t_{max}:

$$t_{max} = t_o + \frac{\ln(N_D)}{a} \quad \text{……………………………………………..……..……1.7}$$

At t = t_{max}, production rate is q_{max} and the total amount produced is $N_{p,max}$. Because of the symmetry of Hubbert curve around the peak, $N_{p,max}$ which represents the area under the curve from t = 0 to t = t_{max} has to be half the ultimate production, hence:

$$N_{p,u} = 2\, N_{p,max} \quad \text{…………………………………………………………...……...1.8}$$

But from Eq.1.1:

$$q_{max}(t_{max}) = a\, N_{p,max} + b\, N_{p,max}^2 = a\frac{N_{p,u}}{2} + b\frac{N_{p,u}^2}{4} \quad \text{……………………………..1.9}$$

Substituting for b = -a/ $N_{p,u}$ and solving for a:

$$a = \frac{4\,q_{\max}}{N_{p,u}} \quad \text{..........} 1.10$$

Once the potential peak is selected, $N_{p,u}$ and a are determined using Eq.1.8 and Eq. 1.10 respectively.

Any point can be selected to evaluate t_o and $N_{p,o}$. Having these parameters fed to the software, the optimum value at which the least squares value is minimal will then be retrieved along with the correlation coefficient.

1.4 Hubbertarians Vs. Anti-Hubbert

As any theory, the Hubbert model has its supporters and its opposers. The supporters seem to admit to the theory's known flaws, but on the other hand they use it because it has stood strong and proved that it could be a valuable tool for a long time. [5]

Most of the opposers seem to focus on the few places were the Hubbert model did not work and try to ignore that Hubbert model actually performed adequately in most countries in the world. [6]

1.5 Objectives

This study will try to approximate future oil production rates to the year 2050 using the Hubbert model. There are different models or tools to estimate future oil production rates, but the reason that the Hubbert model was chosen for this study is for its simplicity and data availability.

A similar study was published by Abdulrahman Al-Jarri (Ph. D dissertation, Texas A&M) back in 1997 using the Hubbert model as well. So, another objective of this thesis is to compare the two studies.

1.6 Organization of Thesis

This thesis includes four chapters organized as follows:

Chapter I explains the bases of the Hubbert model and the curve fitting model followed. The other chapters organized as the following:

Chapter II discusses the results generated by this study in detail.

Chapter III compares this study to a similar one conducted by Abdulrahman Al-Jarri as part of his Ph. D studies here in Texas A&M.

Chapter IV presents the conclusions.

Finally, the nomenclature, references, and appendixes developed in this research are introduced.

CHAPTER II

DISCUSSION OF RESULTS

Curves of all oil-producing countries have been generated. Each curve displays the country's historic production data and a Hubbert curve that tries to match the data and forecast the future trend all the way to the year 2050 (see Figure 2.1 as an example). Parameters of each country that have been calculated are tabulated below as well (see Table 2.1).

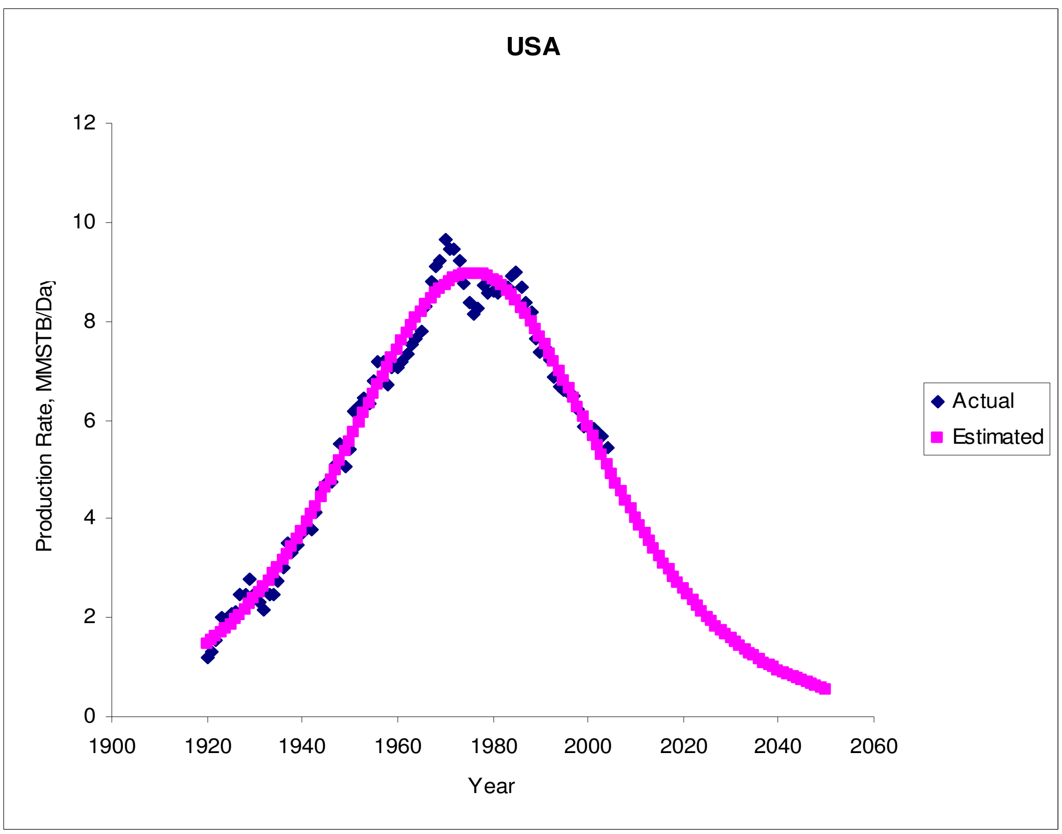

Fig. 2.1 Illustration of the Plot Using USA Production

Table 2.1-Parameters of the Hubbert Models for each Country

Country	$N_{p,u}$ MMSTB	t_o Year	N_{po} MMSTB	a 1/Year	N_D	R^2	R_{msd} MMSTB/D	q_{max} MMSTB/D	t_{max} Year
Albania	489.59	1960	0.058	0.154	8445.625	0.88	0.006425	18.865	2019
Algeria*	26497.47	1960	5.264	0.073	5033.125	0.90	0.1769	484.299	2077
Angola*	13200.88	1991	5.047	0.107	2614.809	0.98	0.04413	352.947	2065
Argentina	21002.10	1859	0.016	0.055	1354973.194	0.94	0.057	287.214	2117
Australia	9751.32	1975	3.755	0.090	2596.020	0.80	0.090017	219.447	2062
Austria	839.01	1951	0.442	0.093	1896.357	0.70	0.009572	19.544	2032
Bahrain	1202.21	2013	3.106	0.072	386.028	0.80	0.00768	21.712	2095
Bolivia	642.95	2035	1.695	0.069	378.294	0.62	0.0092	11.053	2121
Brazil	1624493.46	1990	7.727	0.073	210247.011	0.98	0.0587	29480.170	2159
Brunei	14651.58	1976	4.146	0.090	3532.924	0.99	0.03446	328.311	2067
Bulgaria	84.41	1964	0.079	0.104	1072.126	0.42	0.002054	2.196	2031
Cameroon	1138.76	1981	0.390	0.212	2916.661	0.73	0.02522	60.330	2019
Canada	47776.57	1939	2.931	0.061	16301.896	0.92	0.2037	730.599	2098
Chile	468.38	1948	0.061	0.112	7639.291	0.70	0.00691	13.089	2028
China	47815.84	1983	25.381	0.102	1882.955	0.96	0.2558	1219.423	2057
Colombia	1020576.14	1953	1.856	0.043	550007.291	0.87	0.069	10977.062	2260
Congo	2954.15	1992	1.839	0.125	1605.812	0.97	0.01498	92.511	2051
Cuba	50625.17	1977	0.052	0.093	976945.486	0.98	0.00222	1178.965	2125
Denmark	3974.36	1996	1.896	0.151	2094.816	0.99	0.01539	150.303	2047
Ecuador	6576.03	1992	5.164	0.093	1272.377	0.95	0.0337	152.453	2069
Egypt	11338.65	2025	30.417	0.119	371.776	0.98	0.04298	336.504	2075
F.S.U.	172721.94	1968	74.370	0.098	2321.460	0.94	1.07557	4244.327	2047
Former Czechoslovakia	14611.80	1975	0.084	0.031	173041.972	0.67	0.0011849	111.800	2369
Former Yugoslavia	1065.69	1969	0.479	0.120	2225.064	0.97	0.00504	32.044	2033
France	987.51	1946	0.158	0.071	6234.315	0.68	0.01235	17.544	2069
Gabon	5258.42	1913	0.010	0.085	524006.603	0.78	0.048787	111.772	2068
Germany	1576.16	1959	0.557	0.148	2826.674	0.75	0.02554	58.429	2013
Greece	63.91	1986	0.045	0.565	1420.059	0.12	0.007709	9.021	1999
Hungary	877.91	2035	2.360	0.072	370.940	0.89	0.004161	15.705	2118
India	8723.28	1979	2.688	0.118	3243.752	0.97	0.04529	256.582	2048
Indonesia*	29026.89	2040	78.119	0.080	370.575	0.98	0.3374	578.953	2114
Iran*	84176.15	2050	226.121	0.065	371.261	0.67	1.0153	1360.455	2142
Iraq*	35157.58	2026	92.663	0.077	378.415	0.60	0.5747	678.645	2103
Israel	257.01	1967	0.053	0.694	4844.773	0.74	0.0207	44.618	1979
Italy	1133.34	1976	0.226	0.122	5004.468	0.87	0.01243	34.426	2046
Japan	365.38	1814	0.000	0.048	870581.833	0.51	0.002629	4.366	2100
Kuwait*	50156.37	1956	25.551	0.063	1961.957	0.28	0.6817	785.540	2077
Libya*	35920.54	1996	75.080	0.071	477.431	0.37	0.61728	637.568	2083
Mexico	49917.87	1998	63.379	0.094	786.603	0.94	0.2899	1168.236	2069
Morocco	20.97	1951	0.004	0.217	5226.678	0.83	0.00047978	1.140	1990
Myanmar	25516.92	448	22.903	0.001	1113.121	0.11	0.00772	9.448	5184
Netherlands	1274.87	1948	0.206	0.066	6184.512	0.60	0.013778	20.944	2081
New Guinea	545.78	1993	0.502	0.261	1087.152	0.60	0.01572	35.628	2020
New Zealand	365.65	1978	0.048	0.175	7550.350	0.96	0.0033	16.003	2029
Nigeria*	42881.40	1997	57.434	0.073	745.620	0.66	0.4741	778.277	2088
Norway	26506.22	1990	11.589	0.176	2286.276	0.99	0.0940356	1168.804	2034
Oman	14365.11	1934	0.085	0.090	169228.630	0.92	0.0688	324.885	2067
Pakistan	654.97	2002	1.138	0.137	574.717	0.93	0.005376	22.475	2048
Peru	2781.41	1938	0.190	0.075	14647.637	0.77	0.0245	52.348	2065
Philippines	114.68	1997	0.237	0.105	482.131	0.31	0.00636	3.020	2056
Poland	27709.19	1465	20.129	0.012	1375.581	0.18	0.00416	79.792	2092
Qatar*	611094.68	1912	1.768	0.029	345577.653	0.73	0.1046	4442.429	2351
Romania	5975.56	1916	0.488	0.063	12244.875	0.72	0.042598	94.014	2066
Saudi Arabia*	162067.26	1974	80.988	0.074	2000.132	0.79	1.6056	2993.366	2077
Spain	266.43	1985	0.409	0.207	649.656	0.70	0.00798	13.788	2016
Syria	5083.20	1972	0.250	0.161	20352.374	0.91	0.0549	204.059	2034
Taiwan	23.03	1968	0.003	0.275	6911.427	0.76	0.00065	1.586	2000
Thiland	2185.30	1981	0.087	0.133	25160.780	0.97	0.007574	72.603	2057
Trinidad and Tobago	3802.12	2034	10.205	0.072	371.591	0.92	0.001776	68.683	2116
Tunisia	1820.29	1993	3.276	0.090	554.677	0.73	0.01082	40.858	2063
Turkey	1221.04	1948	0.132	0.079	9217.825	0.61	0.01462	24.021	2064
UK	28434.54	1977	6.294	0.134	4516.913	0.91	0.3101	950.954	2040
UAE*	45600.33	1966	10.544	0.072	4323.917	0.76	0.3568	826.130	2082
USA	234010.66	1938	68.128	0.056	3433.862	0.98	0.3374	3273.511	2084
Venezuela*	71997.20	2020	181.424	0.059	395.846	0.86	0.625	1056.764	2122
Vietnam	1922.50	1995	0.653	0.271	2943.167	0.98	0.01678	130.477	2024
Yemen	3469.85	1996	2.328	0.189	1489.301	0.92	0.0376	163.550	2035
Zaire	367.79	1987	0.419	0.124	876.563	0.52	0.005394	11.436	2041

*OPEC Members

2.1 Classical Hubbert Curves

This study analyzed production from sixty eight oil-producing countries world wide. A Hubbert curve has been generated for each country. This section will discuss the curves that fitted the Hubbert model as expected. These curves were classified as the Classical Hubbert Curves.

Most of these countries have been relatively in stable conditions for an extended amount of time. Some of these countries represented a flawless fit to the Hubbert model such as Angola and Norway as could be seen in figures 2.2 and 2.3 respectively.

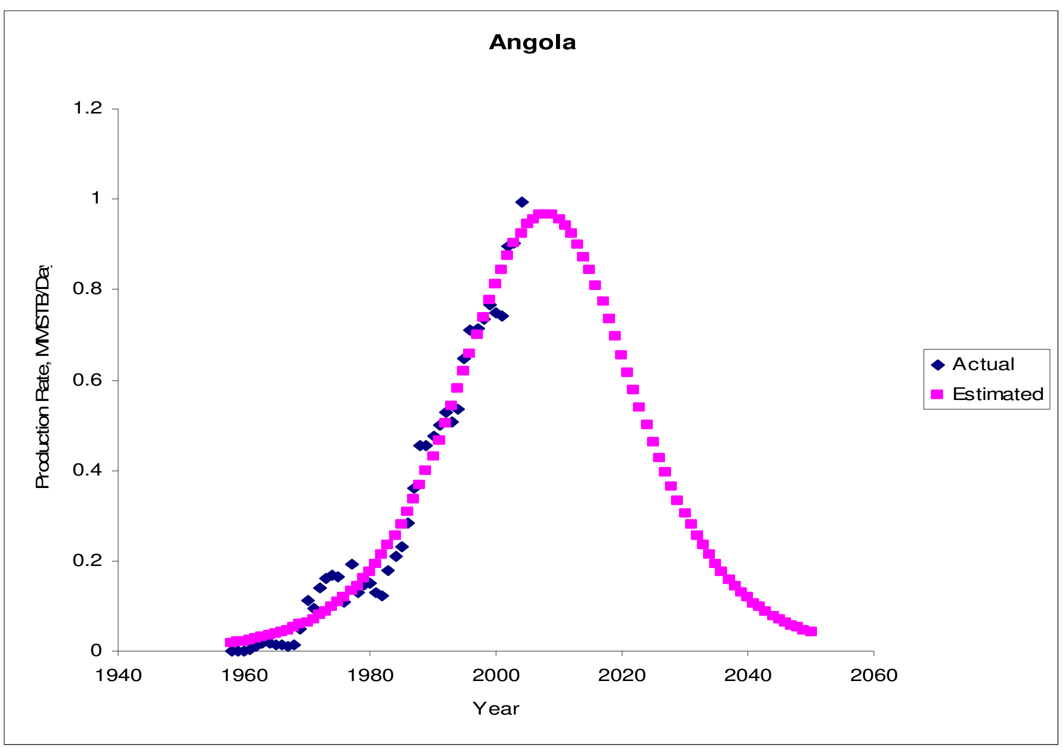

Fig. 2.2 Angola Production Curve

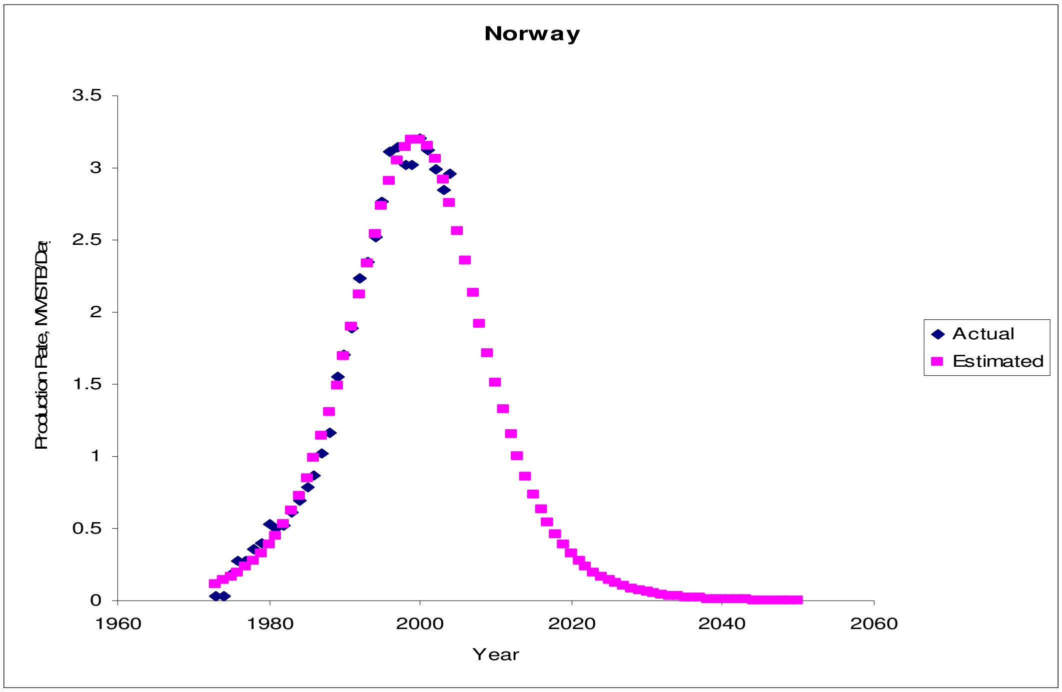

Fig. 2.3 Norway Production Curve

2.2 Unclassifiable Curves

This section discusses the curves that did not seem to fit the Hubbert model. All curves plotted represented a Hubbert model curve in a way. After longer analysis and study, these curves seemed to fit the model but in an unexpected or unorthodox manner. These curves were classified as Unclassifiable Curves. This section will go over each curve that did not fit the model in a satisfactory way and try to reason the findings.

2.2.1 Brazil

Brazil is one of the biggest oil producers in South America. Figure 2.4 shows the Hubbert curve of Brazil.

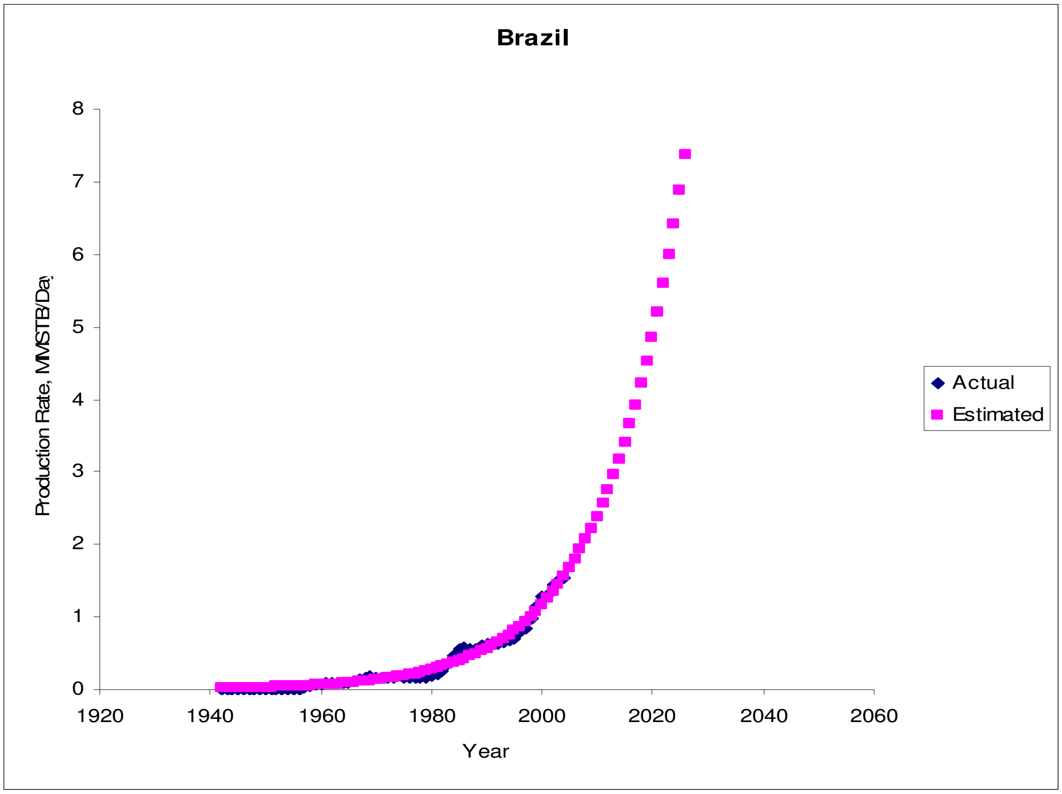

Fig. 2.4 Brazil Production Curve

As it could be noticed in this figure, Brazil is still far from hitting its oil peak. According to this study, Brazil is supposed to hit its oil peak around 2078. Although it might be possible that this is actually true, still it is very unlikely. The reason behind this "mistake" is the misleading data.

Most of Brazil's production comes from offshore fields. In a recent study, 70% of the areas that were granted permission for oil activities in Brazil were located offshore. The biggest offshore prospect in Brazil is the Campos basin which is located in deep waters. The recent availability of this big prospect given the new technologies and the recent oil prices allowed Brazil to increase its production rate in recent years.

Another minor factor that helped Brazil increase its producing potential is heavy oils which have become real feasible to produce.[7, 8]

This relatively late increase in potential caused the model to react as can be seen in the previous figure. This shows the importance of dealing with the Hubbert curve carefully. It could be real misleading in such a case.

2.2.2 Colombia

Colombia reacted very similarly to Brazil as can be seen in figure 2.5 but for different yet similar reasons.

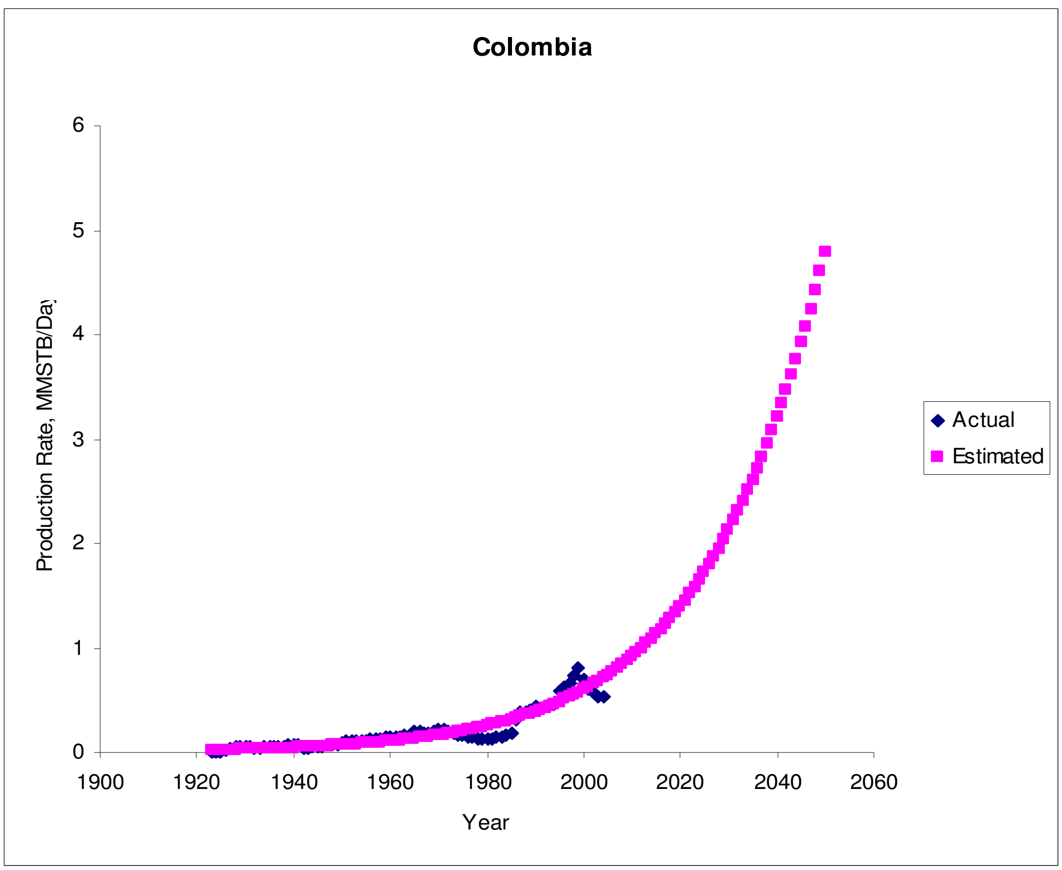

Fig. 2.5 Colombia Production Curve

As can be seen from the figure, the production rate in Colombia has seen a significant increase starting in the mid to late 80's. This could be attributed to more than one reason.

Most of the Colombian fields are located in the rugged rainforest areas. Until recently, these areas were off limits because of its rugged nature which made it real difficult to explore and conduct operations. With improved resources, this problem has been solved now. Hence, new horizons to produce more oil in these areas are now very achievable. [9]

Another reason is more political that natural. Much of these rainforests are located in an area that is unsafe to work in because of the guerillas and the drug cartels. In recent years, the local government has been able to somehow better control these areas which helped developing these fields. [9, 10]

Finally, better roads and driving conditions have contributed to the recent development. Companies, especially foreign ones, are better prepared to road and driving conditions now than when they first got there. [11]

All these factors contributed to the sudden hike in production rate in the late 80's. Such a hike caused the Hubbert model to overestimate Colombia's oil peak which is similar to Brazil's case.

2.2.3 Qatar

The Qatar curve showed an overestimate of peak oil as well as can be seen in figure 2.6 below.

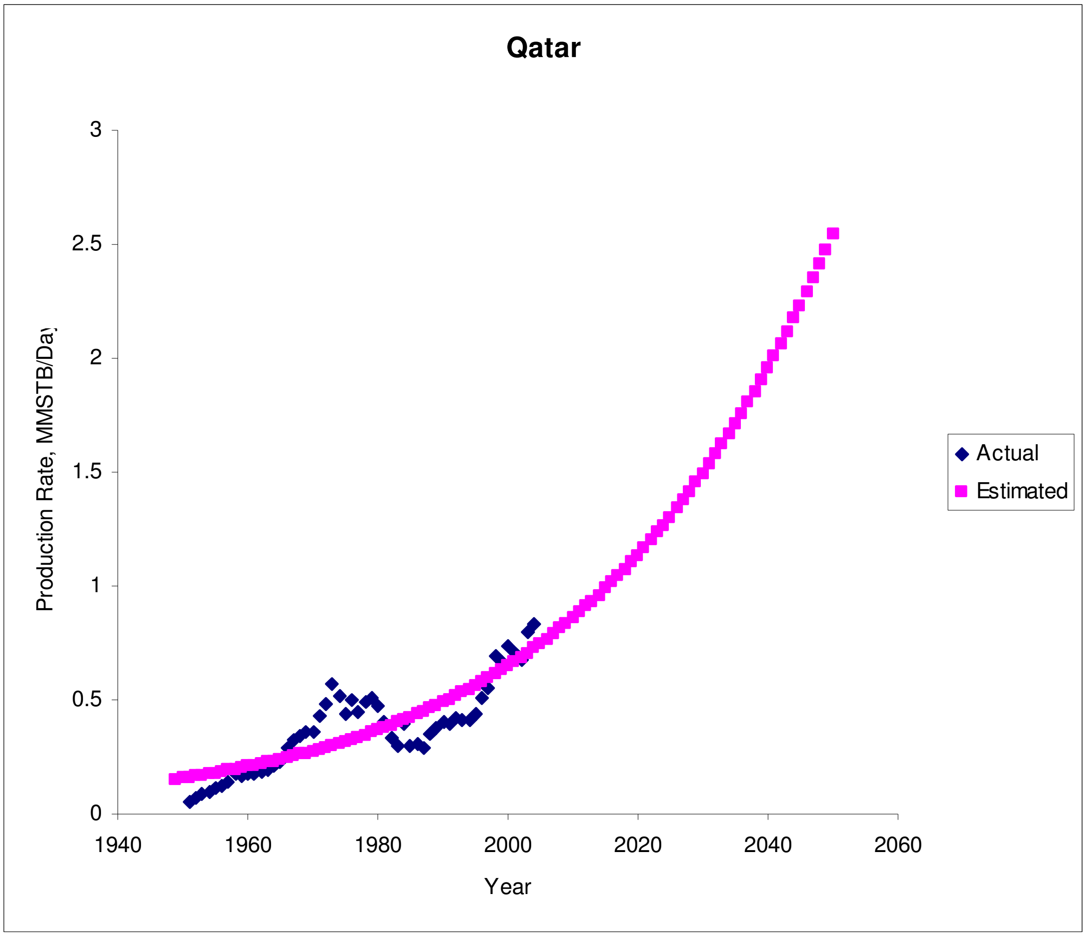

Fig. 2.6 Qatar Production Curve

Qatar has always been known as a major gas producer. Still, it has always been considered as an important oil producer in the gulf area. Starting in the early 90's, Qatar started focusing more on improving its oil production potential. A clear example of that is the giant Al Shaheen field. The field was first discovered back in 1974. The field was deemed not feasible economically for production. The reason behind that simply was that oil only existed in low permeability thin carbonate sheets. With the availability of new cost-effective technologies in regards to drilling, completion, and production, producing and developing Al Shaheen field has become feasible. A similar situation was encountered in the Al Khalij field. [12, 13]

The development of these fields and other smaller fields are the main reason why a spike in production can be seen in the Qatar curve. This as a result contributed to the Hubbert model overestimation.

2.2.4 Cuba

The following figure (Fig. 2.7) shows that the Hubbert model has overestimated Cuba's peak just like the previously mentioned countries. Cuba's case is less significant due to its low potential compared to Brazil, Colombia, and Qatar.

Most of Cuba's production has been coming for the last 30 years out of the area along the north cost between Havana and Varadero. In 1992, a major facelift of the Cuban oil operation was been conducted by a Canadian company called Sherritt. Being an expert in producing heavy oils, Sherritt has rejuvenated the Cuban oil production. [14]

As a result of the improved efficiency in producing the heavy oil, Cuba has improved its potential significantly. With the current high demand (and prices), producing these heavy-oil fields makes more economical sense than in years past.

All these factors could be blamed for the big overestimate of Cuba's oil peak. According to this study, Cuba will get to this peak in the year 2062 with an estimated rate of 3.2 MMSTB/D.

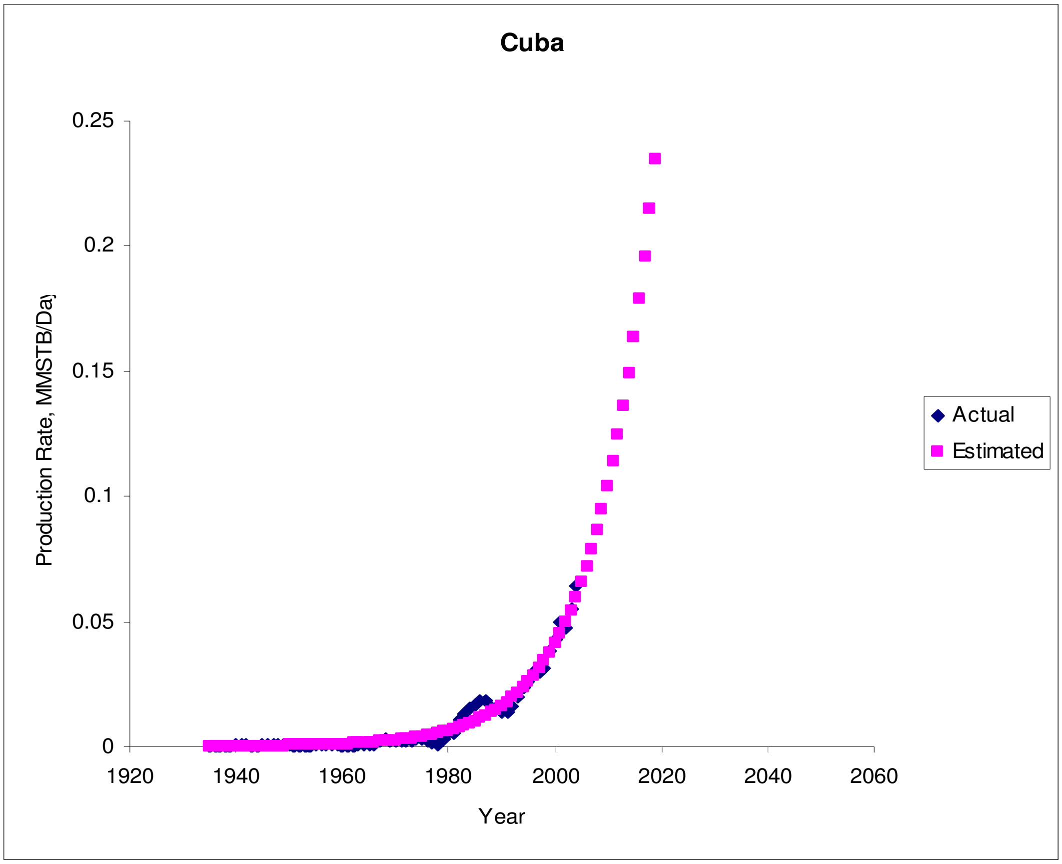

Fig. 2.7 Cuba Production Curve

2.2.5 Former Czechoslovakia

Former Czechoslovakia was one of the former U.S.S.R. allies in Eastern Europe. It used to depend heavily on the former Soviet Union to satisfy its oil needs. In 1989, the former Soviet Union faced its first drop in oil production after a constant yearly growth. That made the former Soviet Union drop its "oil" support to its allies considerably. Then the collapse of the Soviet Union came and brought with it a crunching economical struggle to the new Russia. Looking to overcome this, Russia started to look for hard currency in exchange for oil. This made the former Czechoslovakia reconsider the situation and that led to development of Czechoslovakia's oil fields. [15]

That is the main reason behind the very noticeable increase in production rate in former Czechoslovakia starting with the early 90's as can be seen in figure 2.8 below.

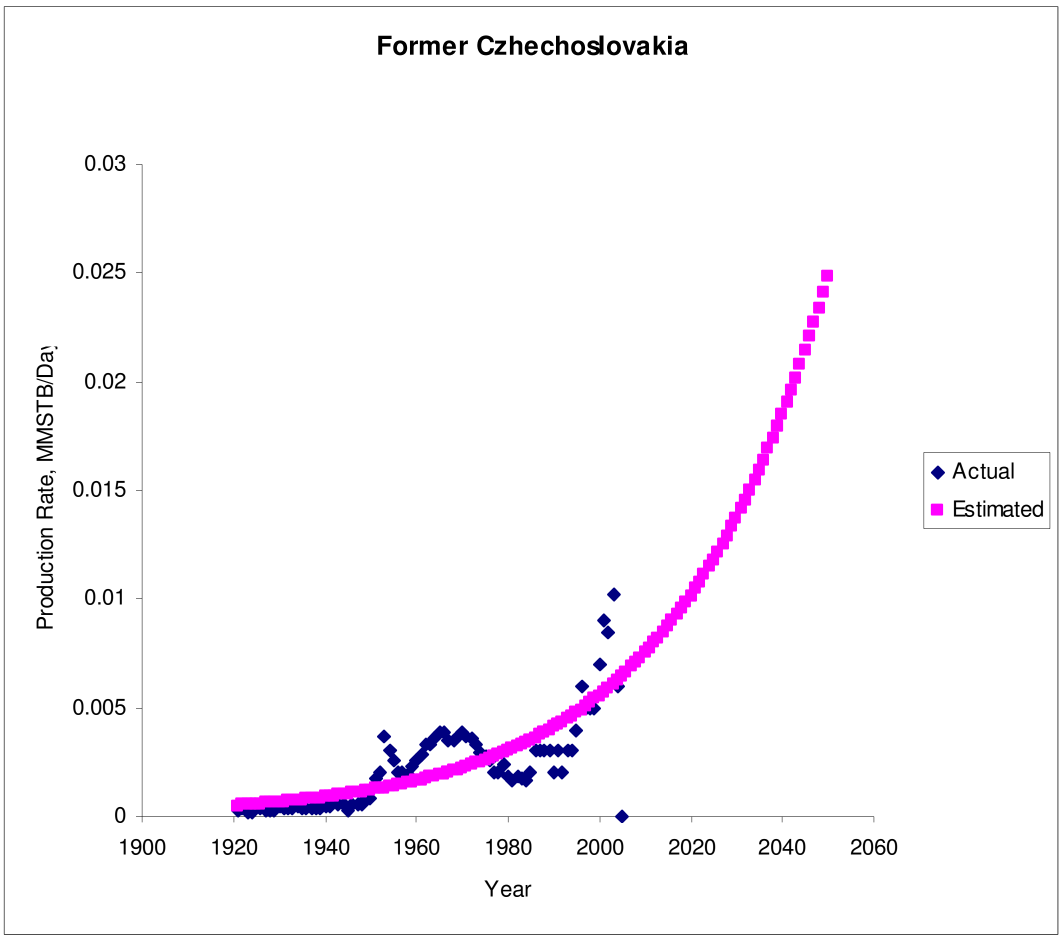

Fig. 2.8 Former Czechoslovakia Production Curve

Still, this hike has no big significance because of the relatively low potential of the country.

2.2.6 Myanmar

A first glimpse at Myanmar's curve (see Fig. 2.9) would not suggest that it represent a Hubbert curve at all. After further review, it was obvious that it indeed represent "a part" of a bigger Hubbert curve. Because of the scattered production data and trying to figure out the pattern, the model interprets the available points as the last segment of the curve. In other words, the estimated line is representing the period in which production is approaching zero.

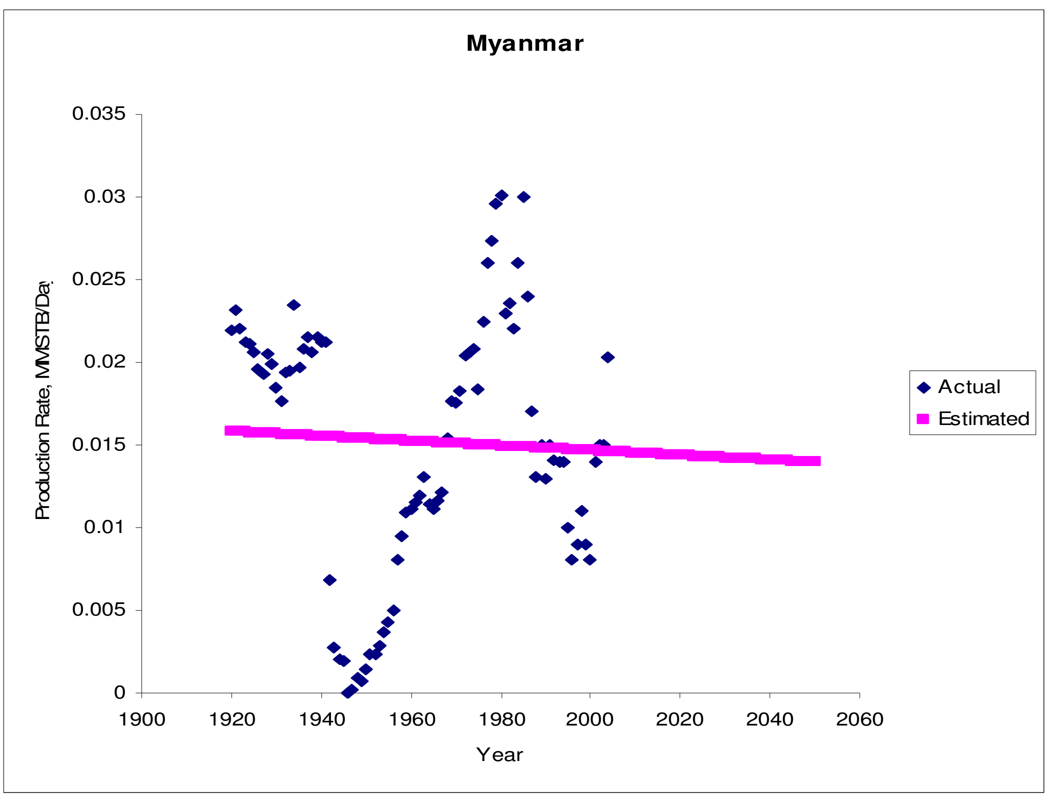

Fig. 2.9 Myanmar Production Curve

All this is attributed to the nature of the data which has an unorthodox nature to it. Given the circumstances that Myanmar has gone through over the years, this is considered very logical. Myanmar is a country that has always been far from being stable. It is a country that had and is still having more than its fair share of war and turmoil. All the wars that Myanmar went through had its obvious affect on the oil industry which explains its Hubbert model.

2.2.7 Poland

Poland, another country of the former communist East Europe block, has a similar curve to Myanmar (see Fig. 2.10). The estimated curve that represents the Hubbert model in the figure is seemed to be approaching zero.

Just like former Czechoslovakia, Poland used to depend on the former Soviet Union for its oil needs. That is why a sharp increase in oil production can be seen in the figure starting from the early 90's. Still the very scattered data prior to this date is main reason to blame for having a non-representing Hubbert model.

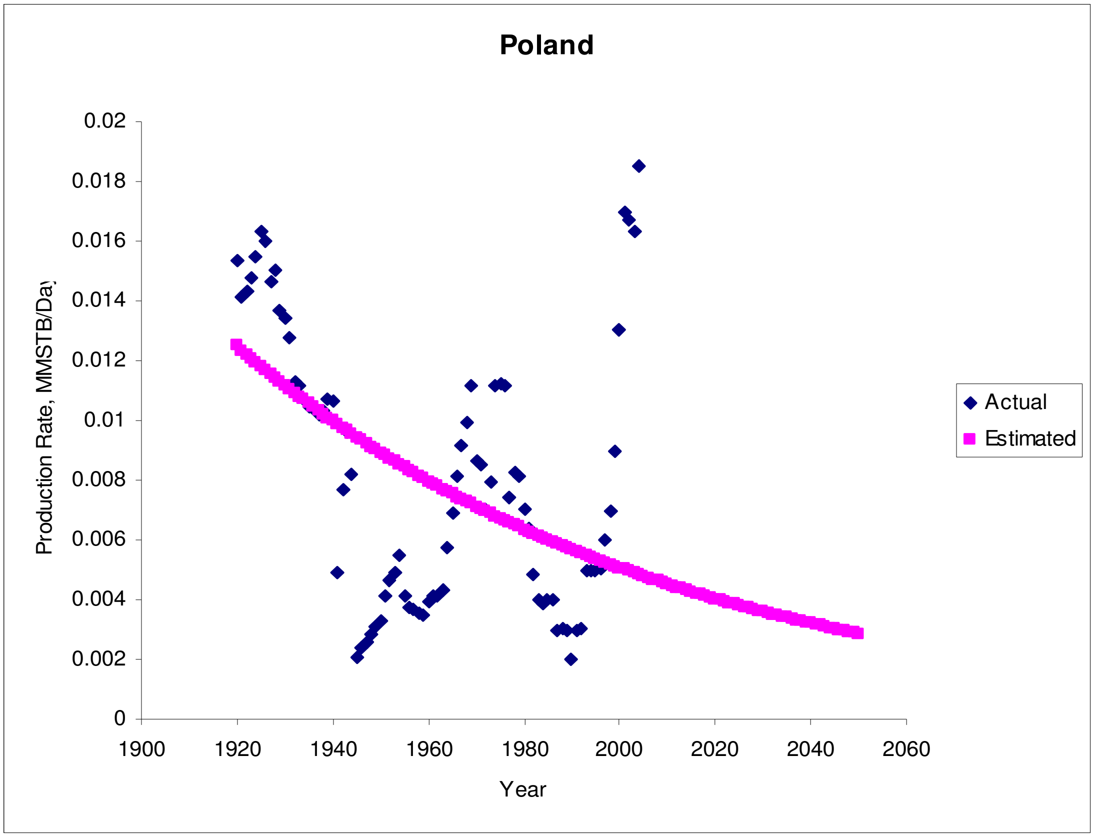

Fig. 2.10 Poland Production Curve

2.3 Hubbert with Outliers Curves

In some other cases, the Hubbert curve would be good but not as good as these previous cases. That might be due to fluctuation in production rates through the years. This could be seen in some of the OPEC countries because of their controlled production.

As can be seen in the Saudi Arabia curve in figure 2.11, the model does not fit the production data because of the controlled production policy that Saudi Arabia follows as a member of OPEC.

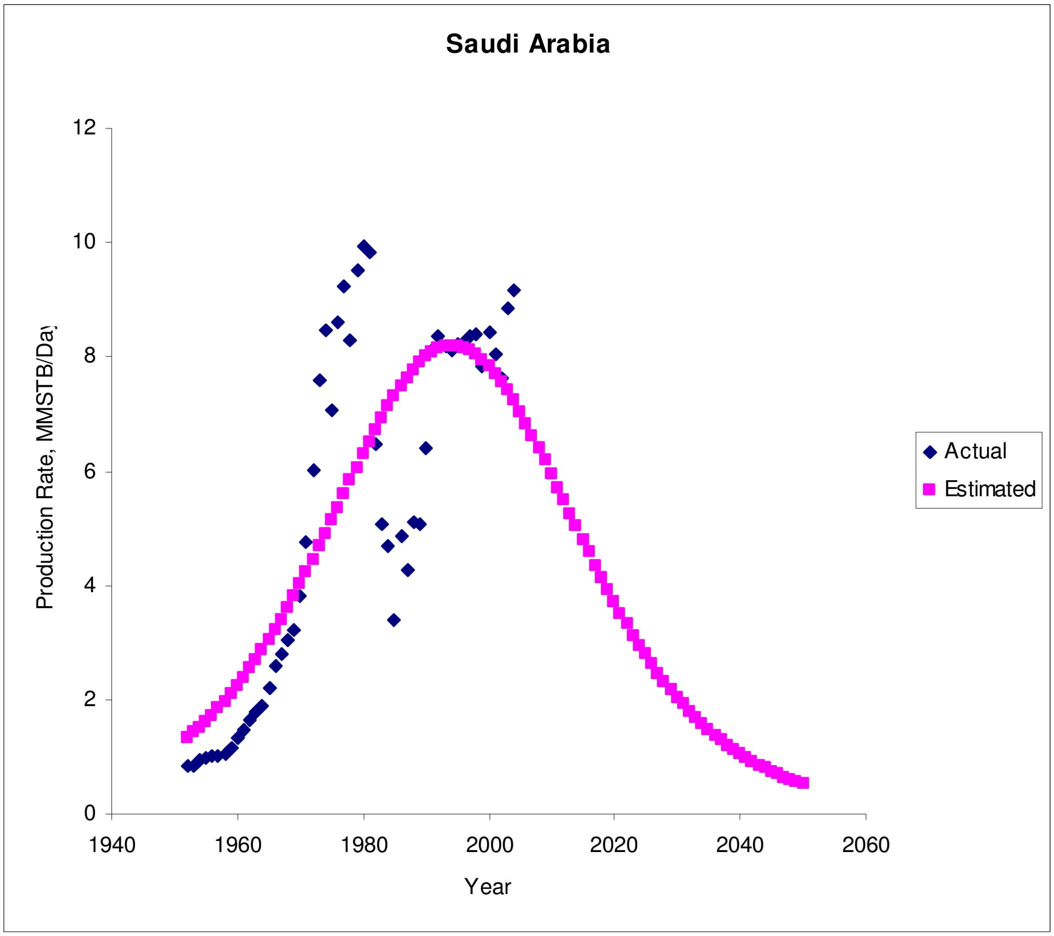

Fig. 2.11 Saudi Arabia Production Curve

Another reason to have these countries with outliers is wars. All countries that have gone through wars have suffered great losses in terms of production potential. Most, if not all, of these countries have not been able to regain their pre-war potential. One of the clearest examples could be provided by Iran. In 1974, Iran had an average of 6.0 MMSTB/D. This average gradually shrunk and then fell sharply with the Iranian revolution in 1979 and then the first Gulf War in 1980 (see Fig. 2.12).

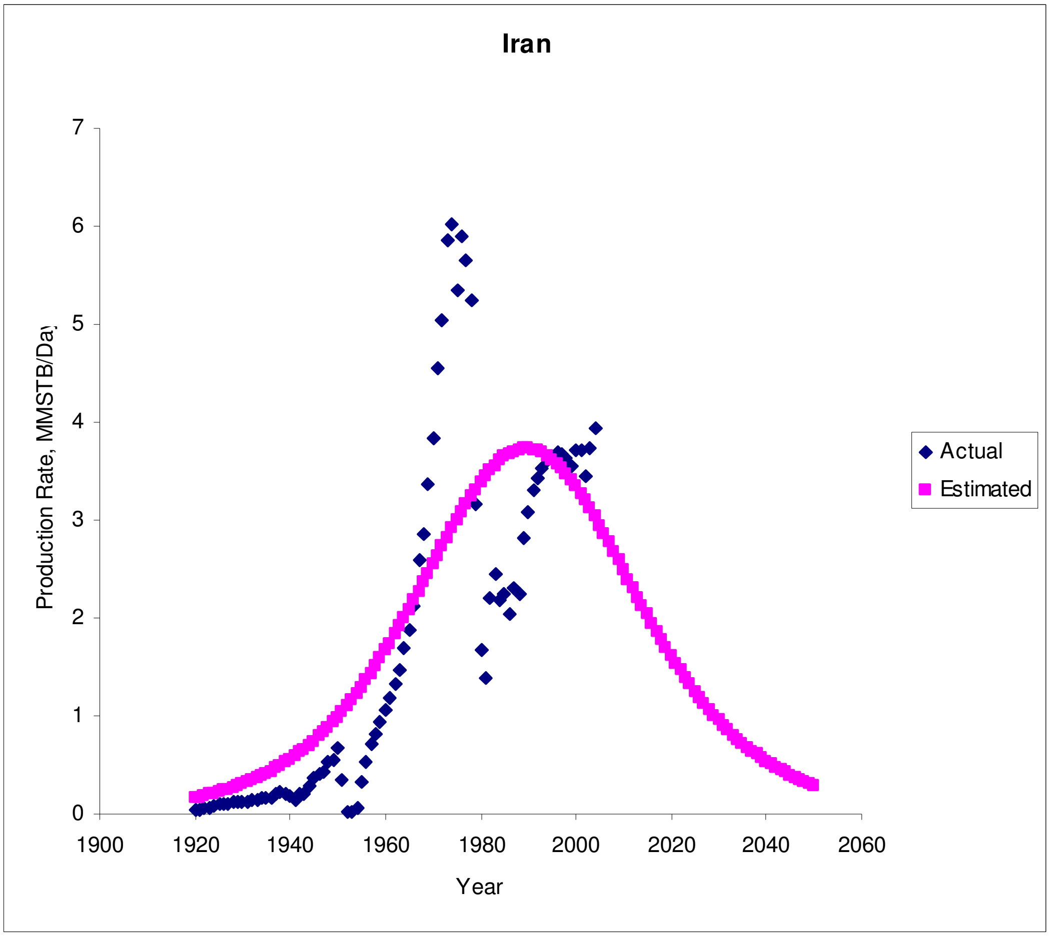

Fig. 2.12 Iran Production Curve

Iran's potential started to go up again in the later years of the war. It started to really pick up after the end of the year in 1988.

2.4 World Curves

Two world curves were created in this study using two different methodologies. The first curve was created by adding production rates of all countries. Then the curve was generated in the same way as if it was another country. The resulting curve seems to be real satisfactory as can be seen in figure 2.13 below.

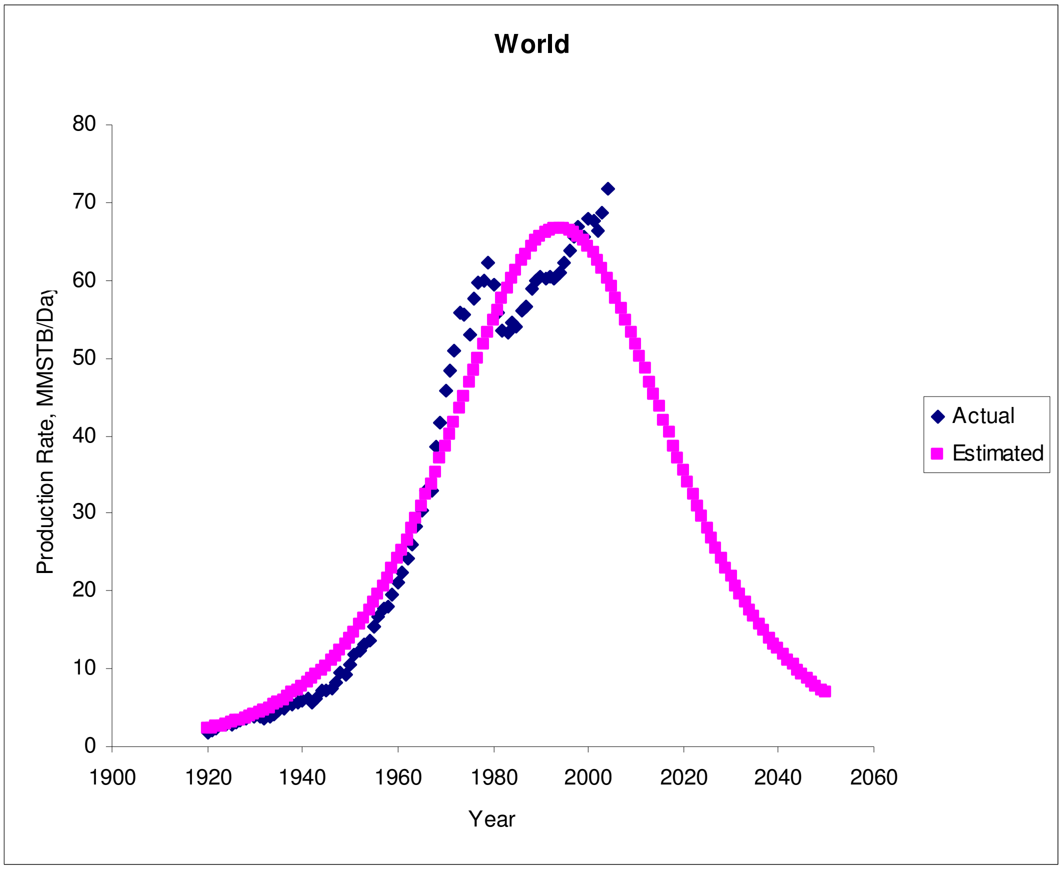

Fig. 2.13 World Production Curve

The Hubbert model seems to fit the production data real well especially in the years between 1918 and 1975. the world oil peak, which have passed according to this curve, appears to occur prematurely if we consider the last two production points. Overall, this curve seems to give a good representation to what is going on in the oil world.

The second curve was created using the curve adding technique. All the Hubbert curves were added to create one "World" curve as can be seen in figure 2.14.

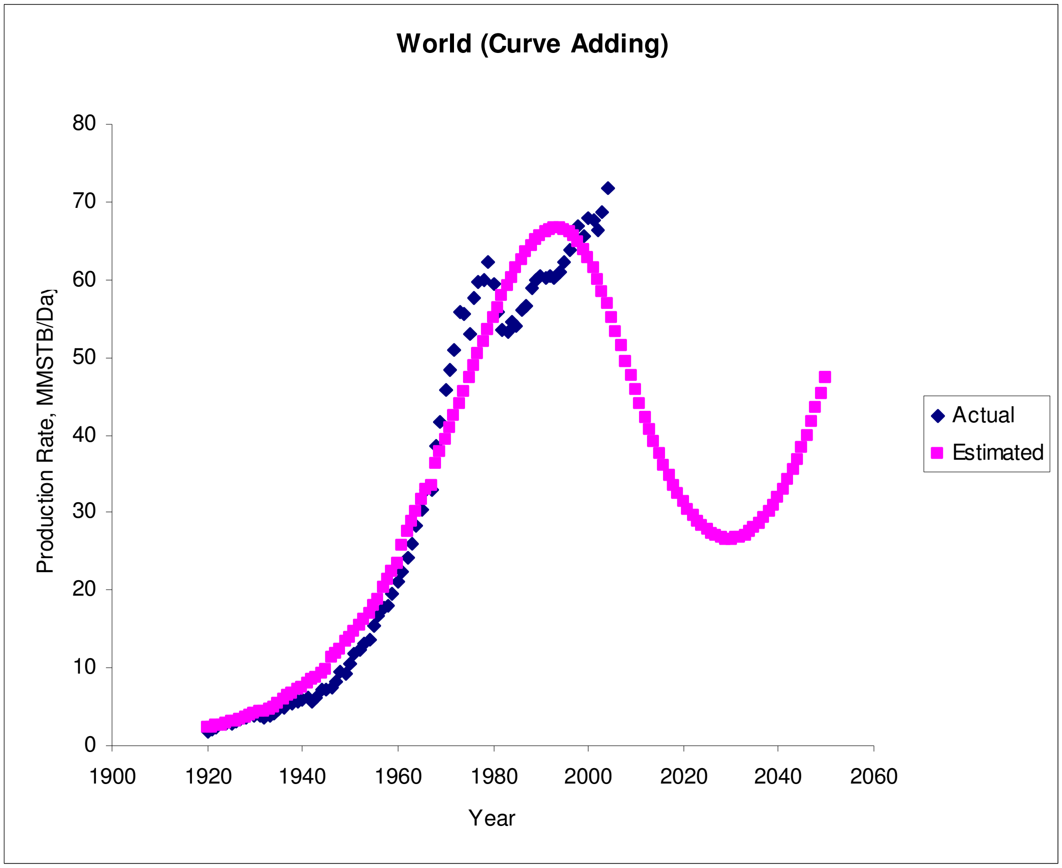

Fig. 2.14 World Production Curve (Curve Adding)

The second world curve started almost identical to the previous one. Then it started to go up again in the year 2031. The reason behind this sudden increase is the previously mentioned "unorthodox" curves of Brazil, Colombia, Qatar, Cuba, and the former Czechoslovakia. To prove this theory a new curve was created (Fig. 2.15) without these countries that can be seen below.

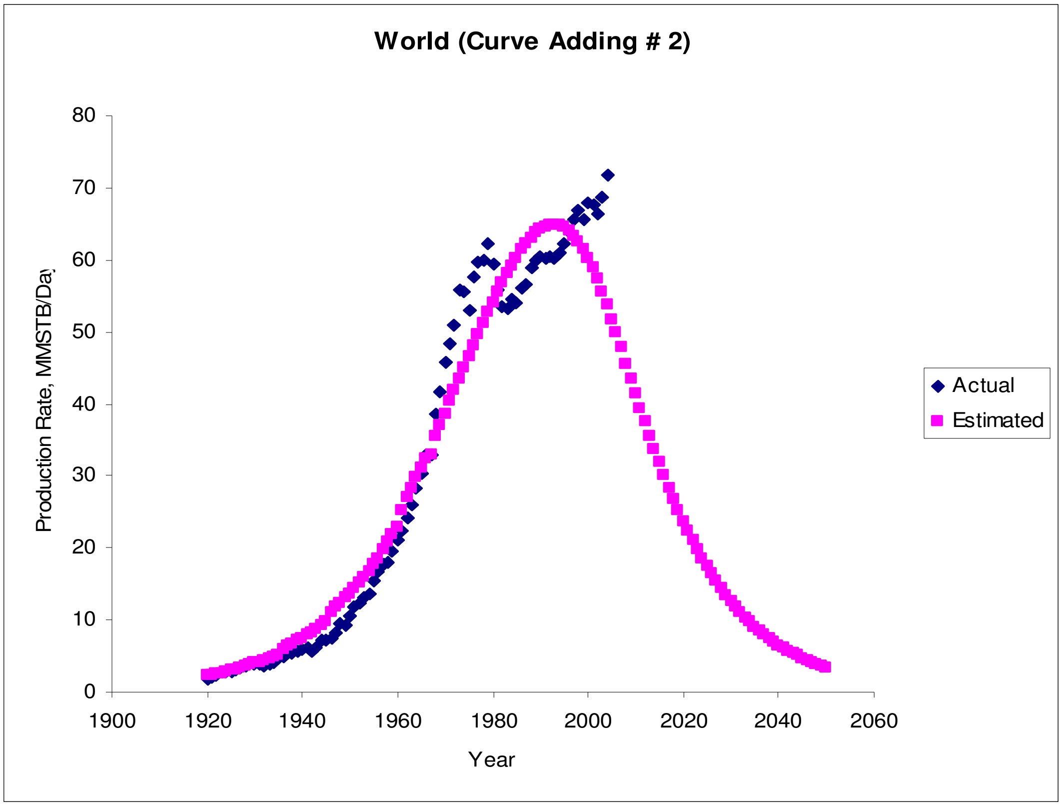

Fig. 2.15 World Production Curve (Curve Adding # 2)

CHAPTER III

COMPARISON WITH AL-JARRI'S STUDY

A Ph. D. dissertation was written by Abdulrahman Al-Jarri back in 1997. Al-Jarri's study was similar to this one. It also tried to use the Hubbert model as a method to forecast oil production. This chapter will try to compare the results or findings of the two studies.

3.1 Seven More Points

The obvious advantage that this study possesses over Al-Jarri's is the availability of more production data or production "points". This advantage contributed to two major differences; it either overestimated or underestimated some of the countries.

Most of Al-Jarri curves were an underestimate of the actual production points that were collected after the study. This is very understandable given the new technologies that have been implemented in the oil field since 1997 to the present. This improvement meant improved production rates. As a result, Al-Jarri underestimated these rates. This is something that Al-Jarri could not predict back then.

Some of these countries that have been underestimated were Algeria, Angola, and Canada which could be seen in figures 3.1, 3.2, and 3.3.

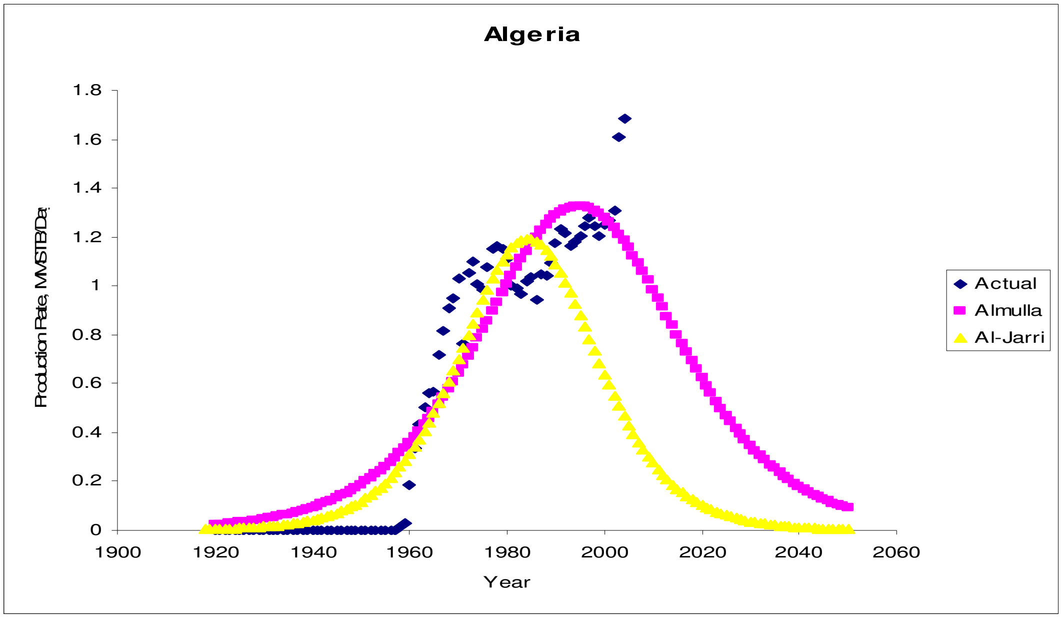

Fig. 3.1 Algeria Production Curves

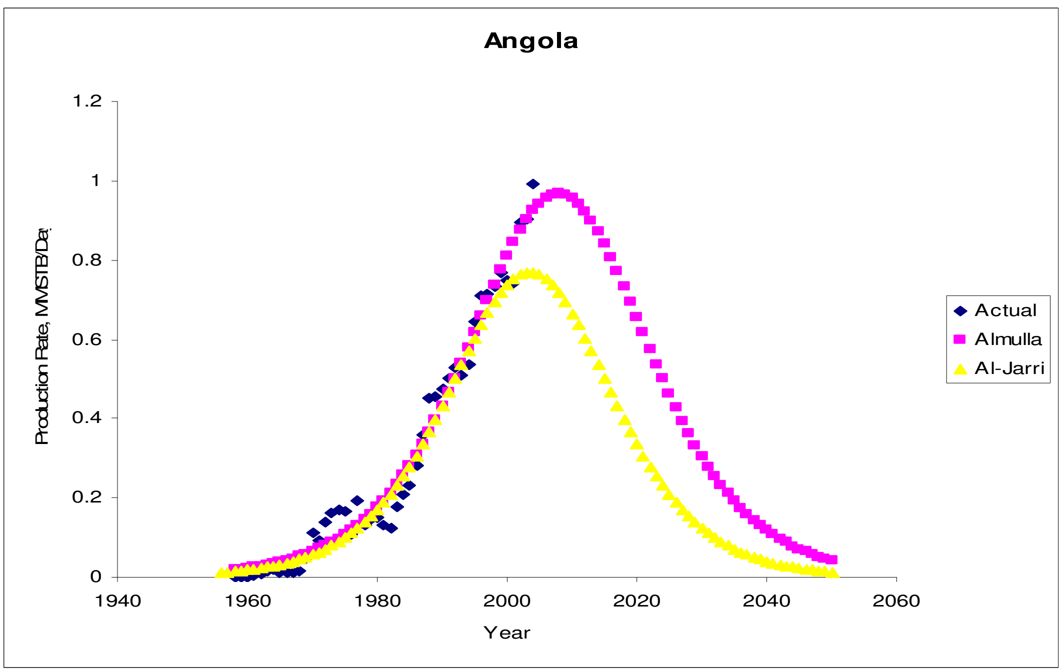

Fig. 3.2 Angola Production Curves

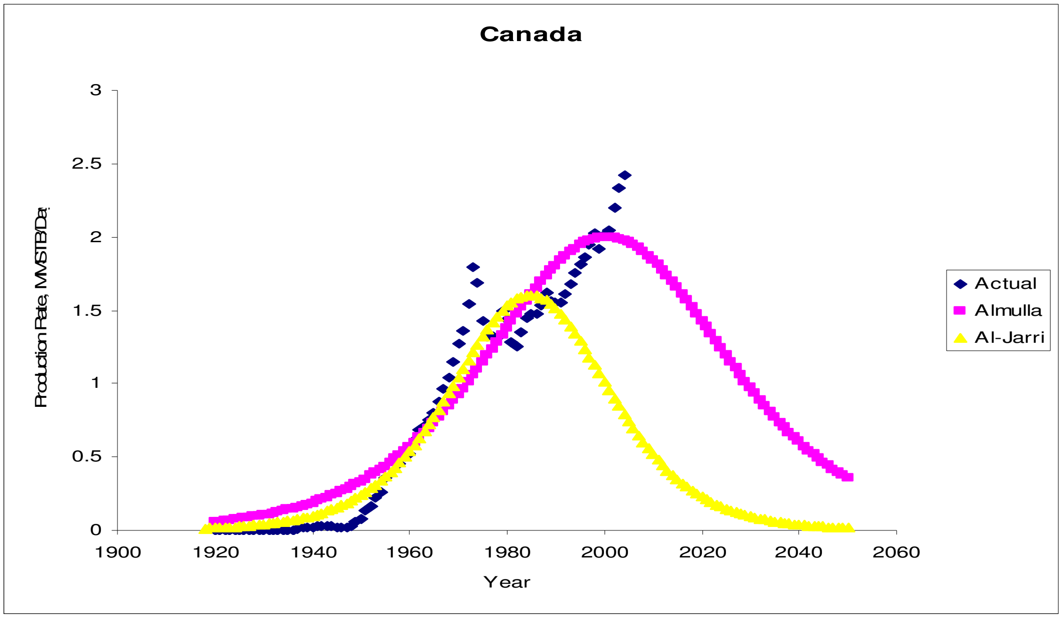

Fig. 3.3 Canada Production Curves

Some of the curves have overestimated what actually happened in later years. This is obviously caused by sudden drop in production in these years. This could be due to natural causes like drop in potential or could be because of controlled production. The latter is more likely specially that most of these overestimated countries were OPEC countries.

As an example of these overestimated countries, the figures of Oman, Saudi Arabia, and U.A.E. are shown below (Fig. 3.4, 3.5, and 3.6).

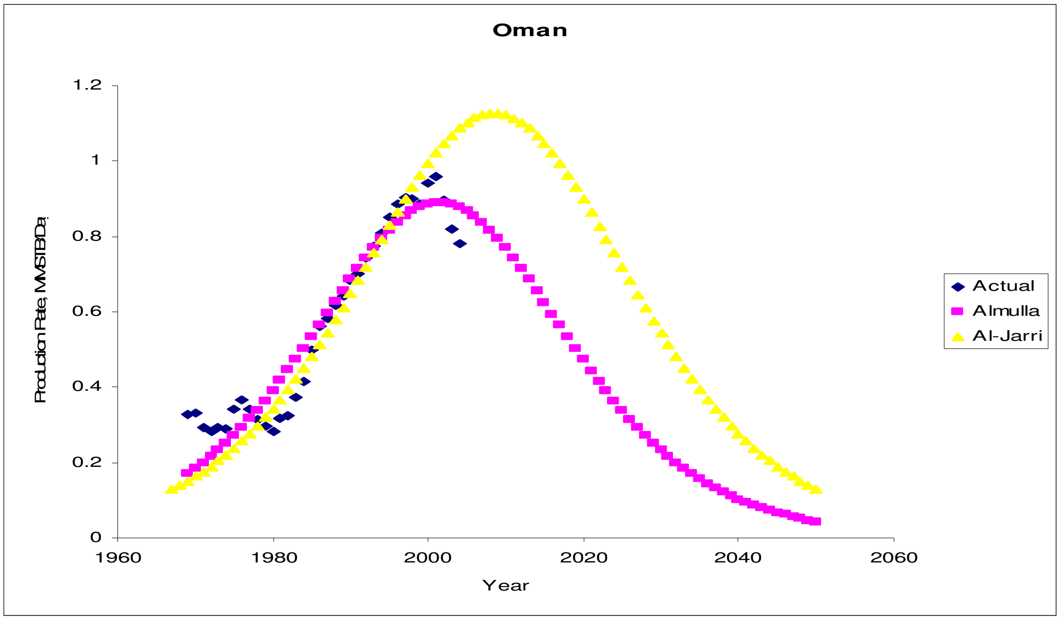

Fig. 3.4 Oman Production Curves

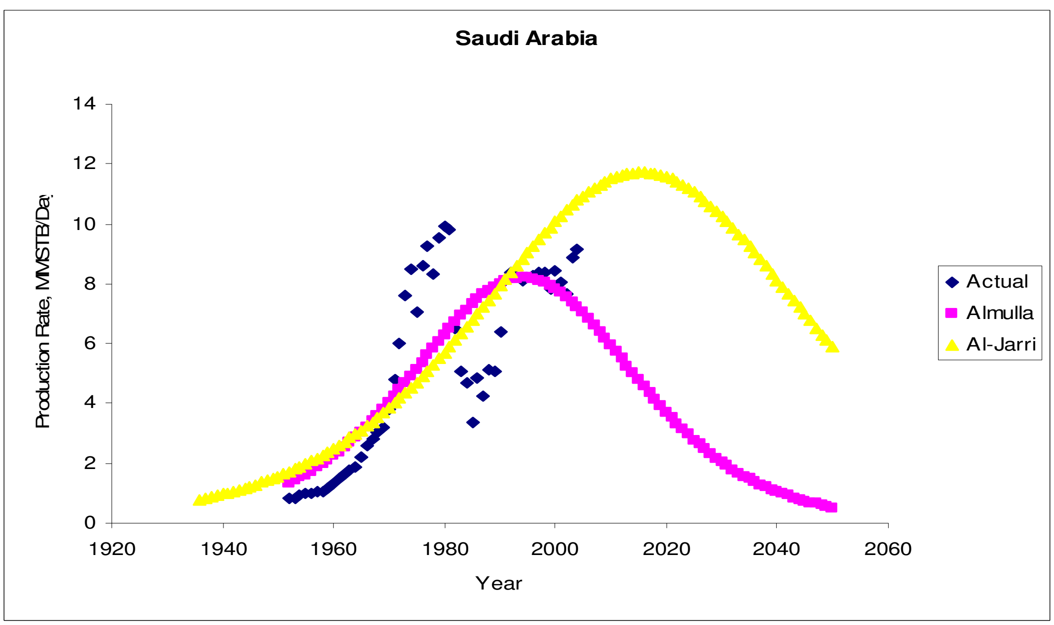

Fig. 3.5 Saudi Arabia Production Curves

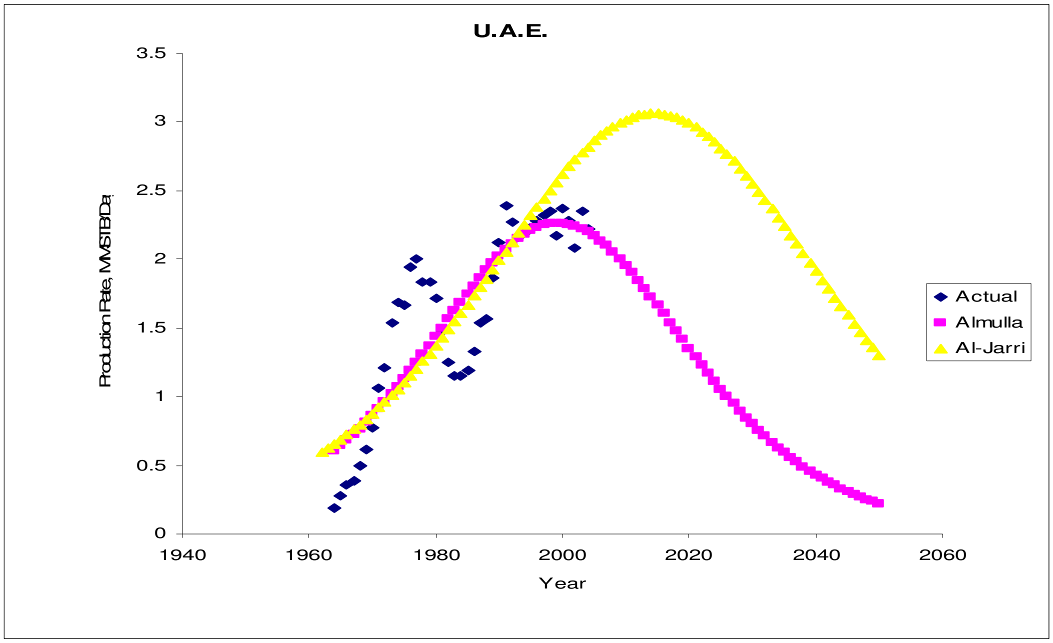

Fig. 3.6 U.A.E. Production Curves

Few were the cases with matching curves generated by the two studies. Below are three examples of Brunei, Former Yugoslavia, and USA that generated almost a perfect match in figures 3.7, 3.8 and 3.9.

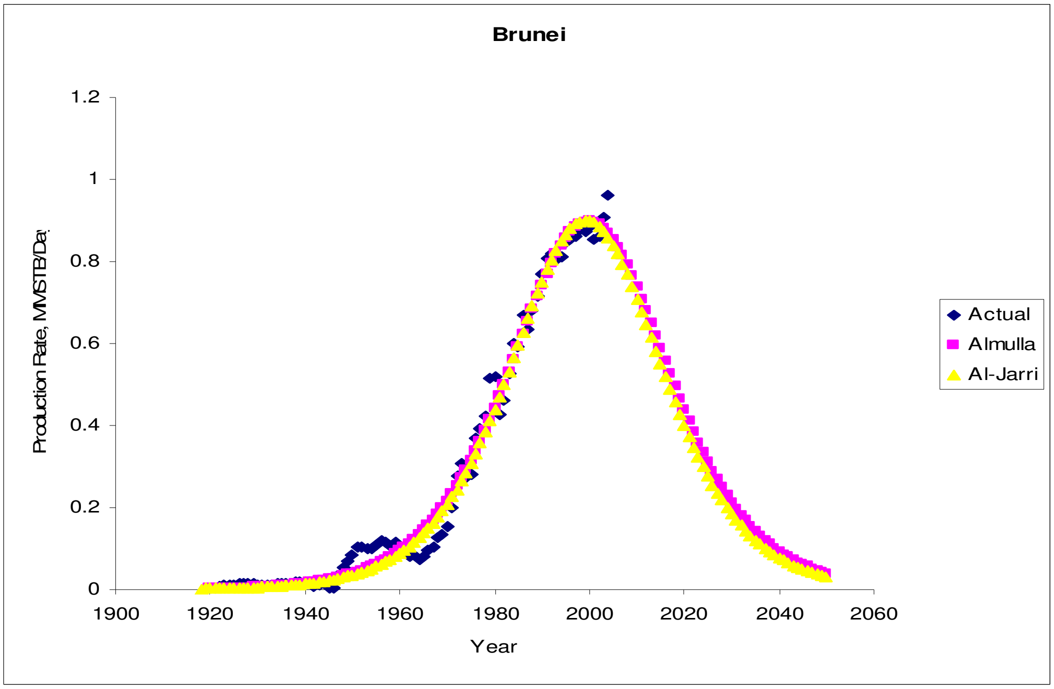

Fig. 3.7 Brunei Production Curves

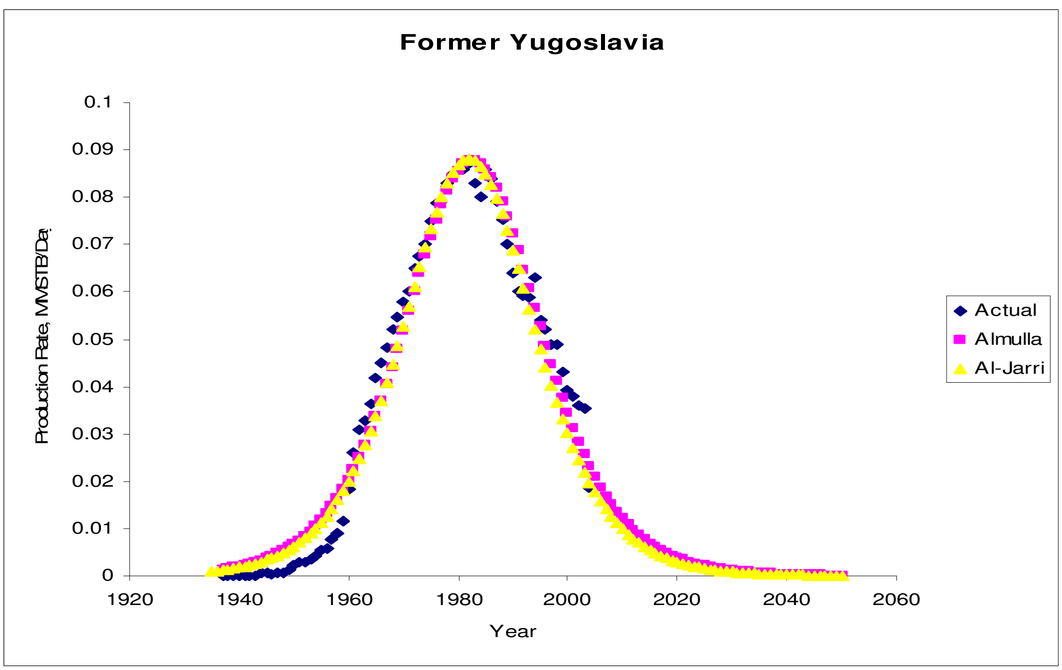

Fig. 3.8 Former Yugoslavia Production Curves

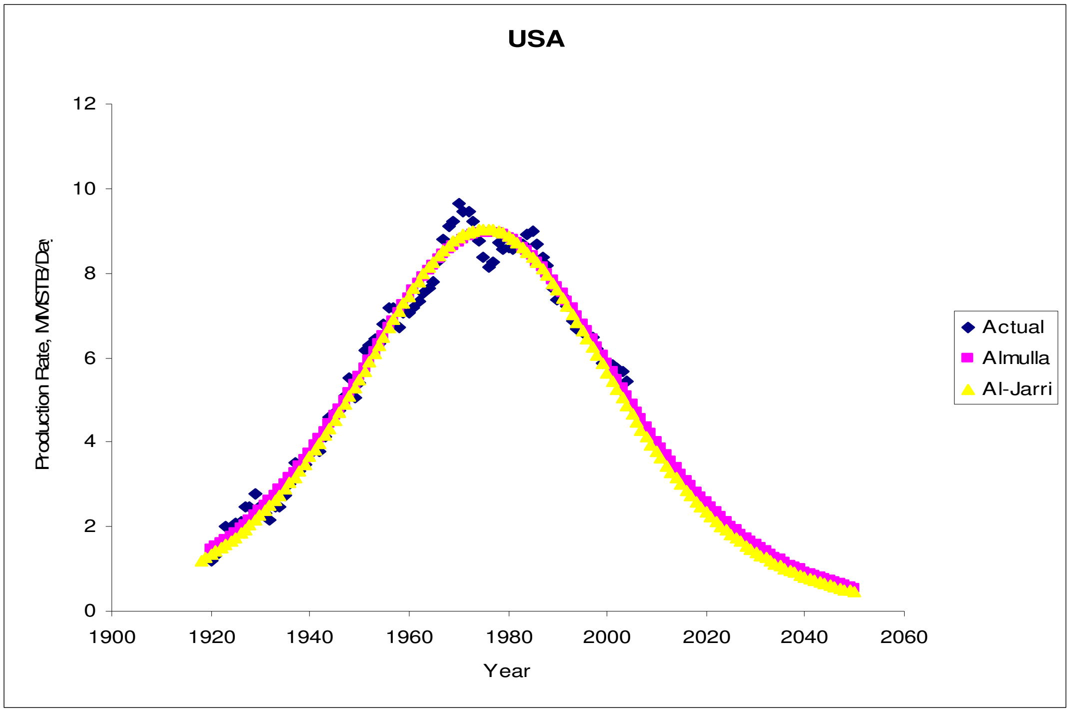

Fig. 3.9 USA Production Curves

The above mentioned differences or similarity does not add or take away any credibility of both studies. As mentioned before, any oil forecast will never mirror exactly what will happen in the future. It is just a tool to evaluate and have an idea of how the future could look like.

3.2 Different Software

A major contributor to the differences that were discussed is that each study used different software to curve fit the data. Al-Jarri used Solver™ while this study used Polymath™. That caused the big difference regarding the unclassifiable curves. Al-Jarri was able to have a better Hubbert like fit for these countries as you can see in his Brazil plot in figure 3.10.

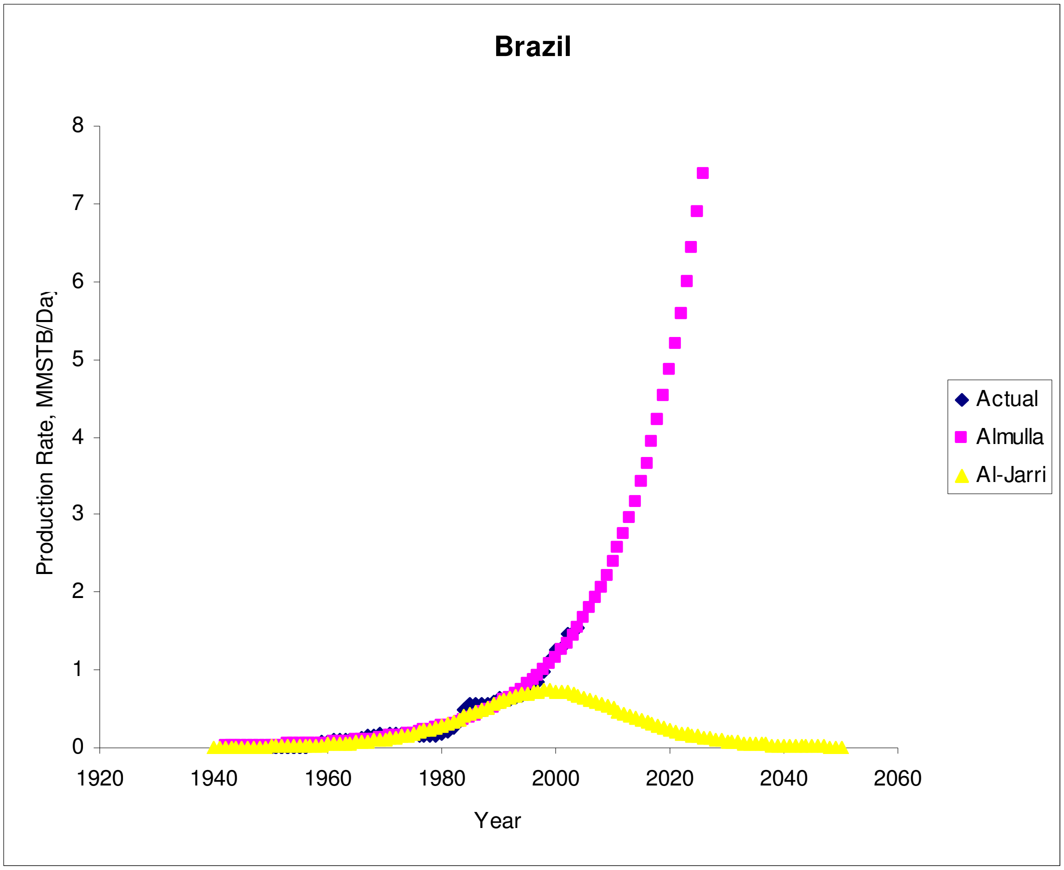

Fig 3.10 Brazil Production Curves

The previous figure shows a more realistic fit to the Hubbert model than the one generated by this study and was discussed in the previous chapter.

Other than these considerably minor differences, both studies have similar findings in terms of results overall. The major shape of the curves seemed to have real similarities. This gives the Hubbert Peak Theory even more creditability as a valid and proven theory in normal circumstances.

3.3 Al-Jarri World Curve

Just like this study, Al-Jarri generated a world curve. The method used in generating the world curve was curve adding (see Fig. 3.11).

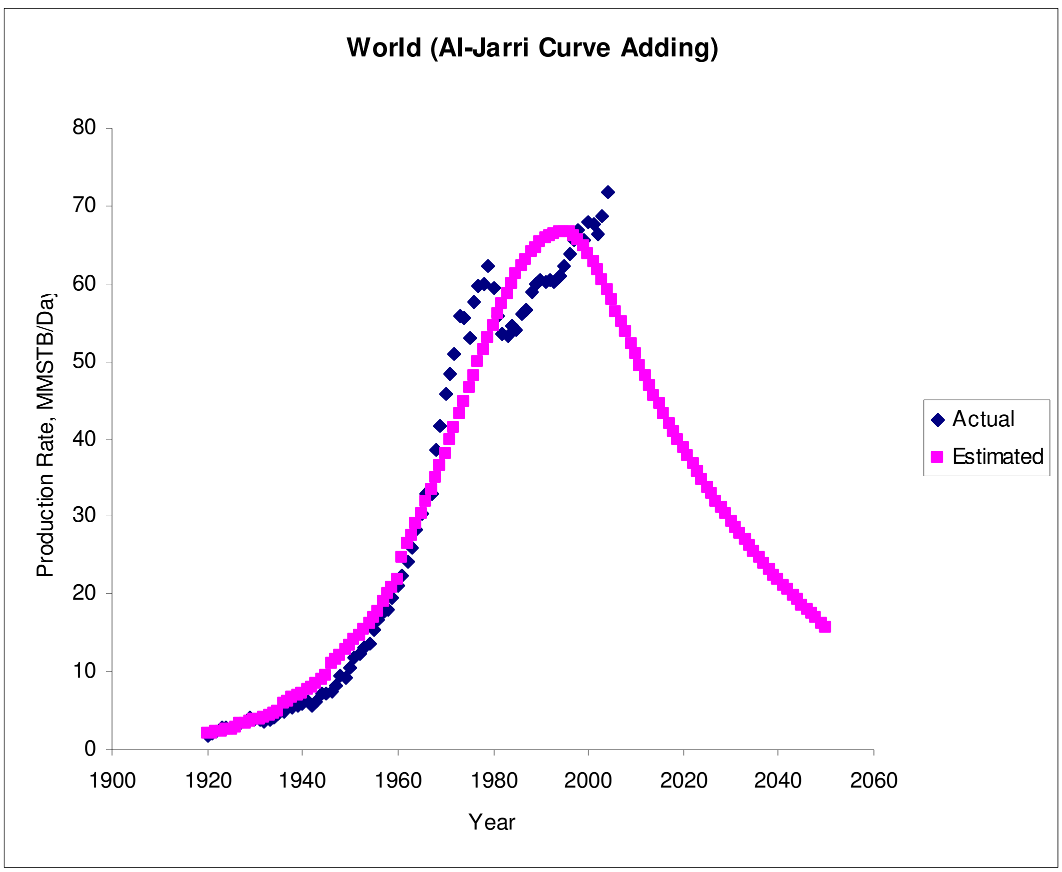

Fig 3.11 World Curve (After Al-Jarri) [3]

The model fits the data points real nicely to the point in time were the curve was plotted in 1997. After that, it is apparent that the model underestimated the world production and had a premature peak.

To compare Al-Jarri's world curve to the world curves generated in this study, all the curves were put on the same plot in the figure below.

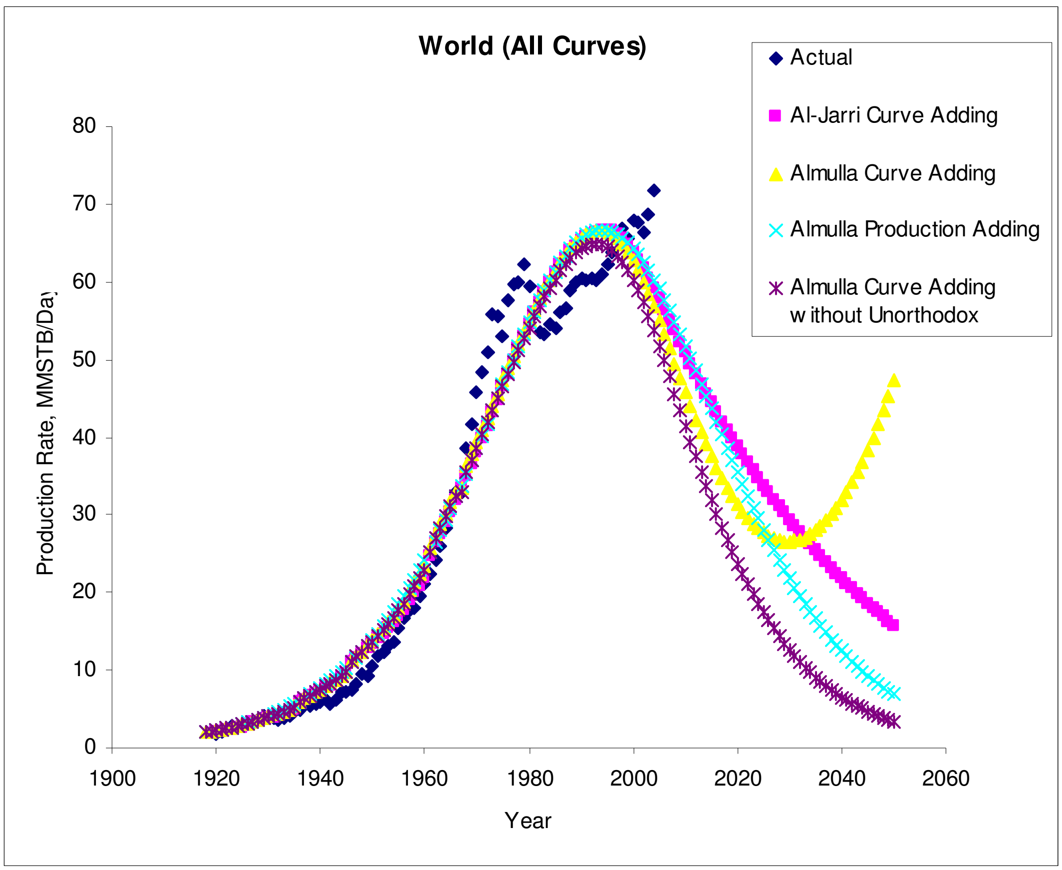

Fig. 3.12 World Curves

So, even the curves generated by this study had a premature world peak. All the curves match perfectly in the period before the peak. Then, each curve gave a different forecast. This is because of the different methodology used in generating each curve. Looking at the curves in a world-wide scale gives the impression that these curves are real close to each other in terms of shape and peak.

CHAPTER IV

CONCLUSIONS

4.1 Conclusions

The following could be concluded at the end of this study:

1. Hubbert assumes that production rates from any geographical area fit a bell-shaped curve.
2. The unclassifiable curves were caused by sudden increases in production or unstable production conditions.
3. Historical events such as wars could easily be pointed out by looking at the historical production rate of any region and its corresponding Hubbert model.
4. In comparison with Al-Jarri study, most curves generated by Al-Jarri underestimated production in later years. On a large scale, the two studies related well.

NOMENCLATURE

q	Oil Rate, MMSTB/D
dN_p/dt	Oil Rate, MMSTB/D
a	growth factor
b	constant
N_p	Cumulative Production, MMSTB
$N_{p,u}$	Ultimate Cumulative Production, MMSTB
t	Time, year
t_o	Arbitrary Time, year
$N_{p,o}$	Cumulative Production at any Given Arbitrary Time, MMSTB
N_D	Cumulative Dimensionless Factor
q_{max}	Peak Production, MMSTB/D
t_{max}	*Time of Peak Production, year*

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15. Balabanov, T.: "Prospects of the Soviet Oil and Gas Industry," paper SPE 24477. Available from SPE. Richardson, Texas (1992).

APPENDIX A

COUNTRIES PRODUCTION CURVES

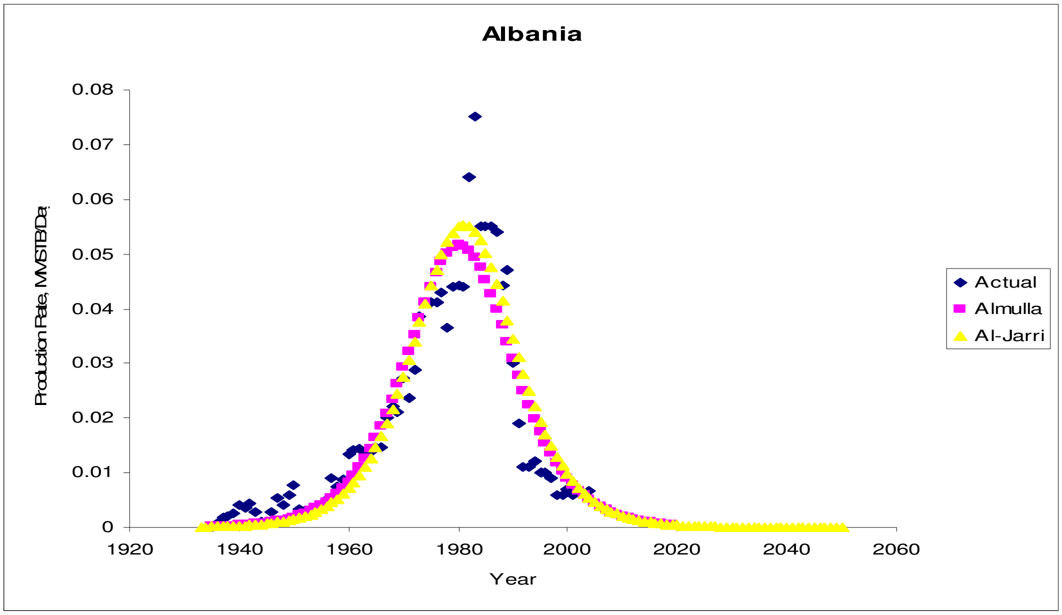

Fig A.1 Albania Production Curve

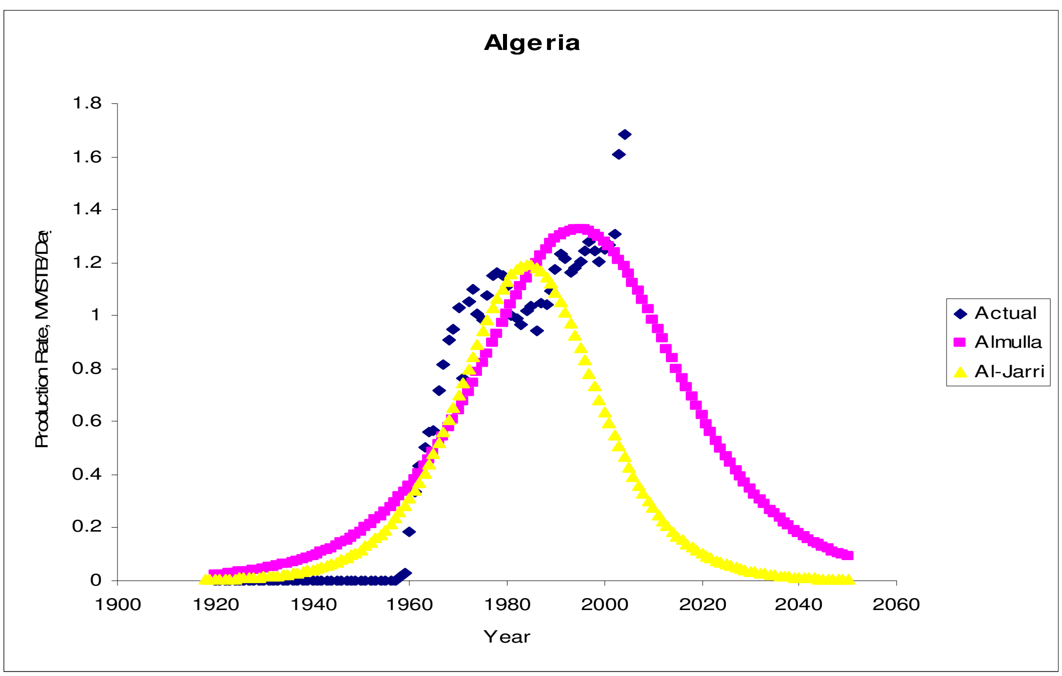

Fig A.2 Algeria Production Curve

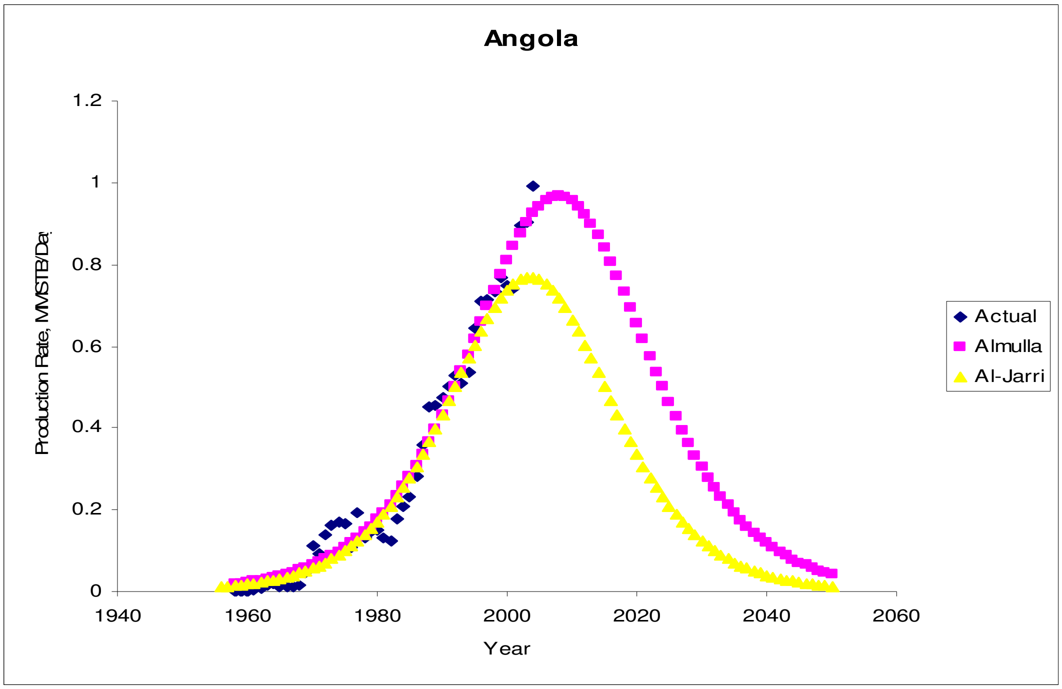

Fig A.3 Angola Production Curve

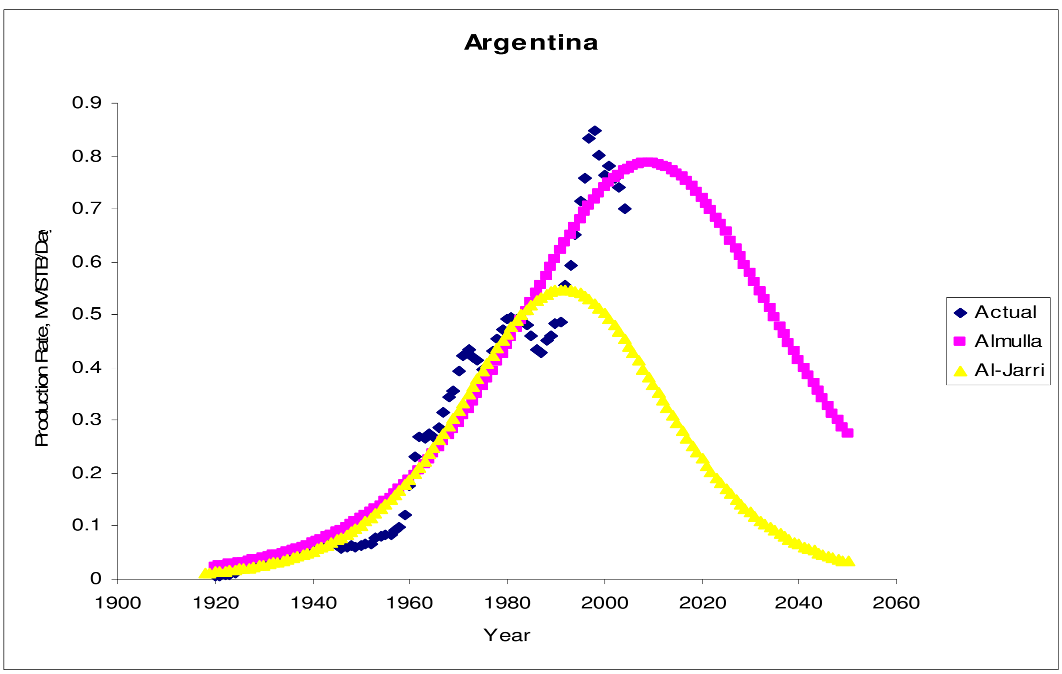

Fig A.4 Argentina Production Curve

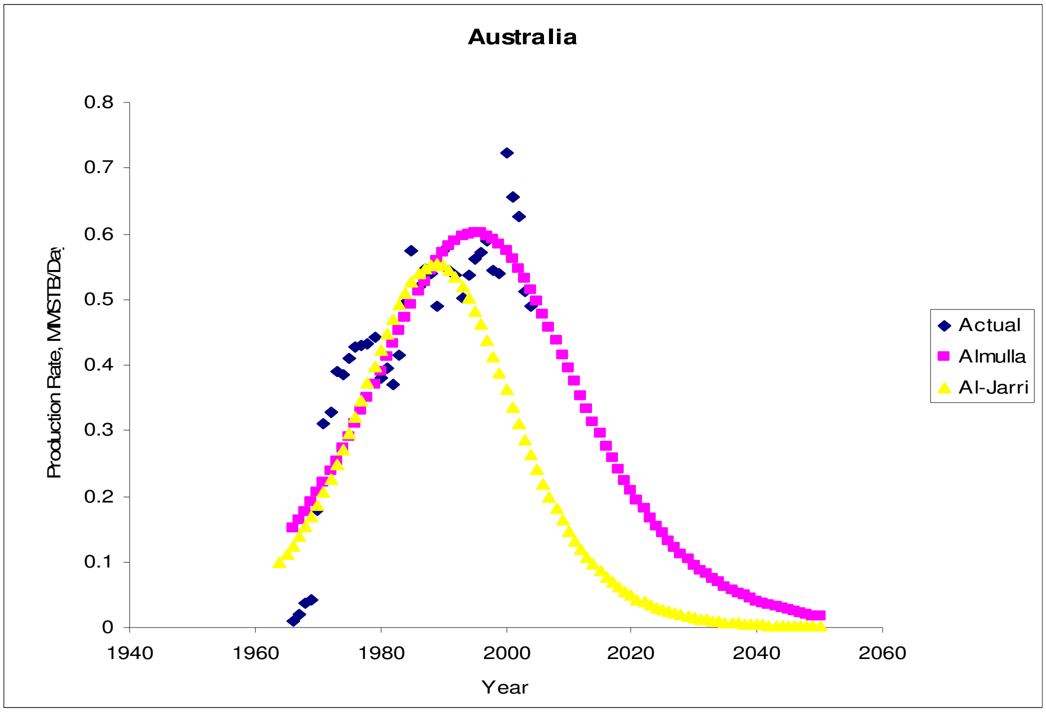

Fig A.5 Australia Production Curve

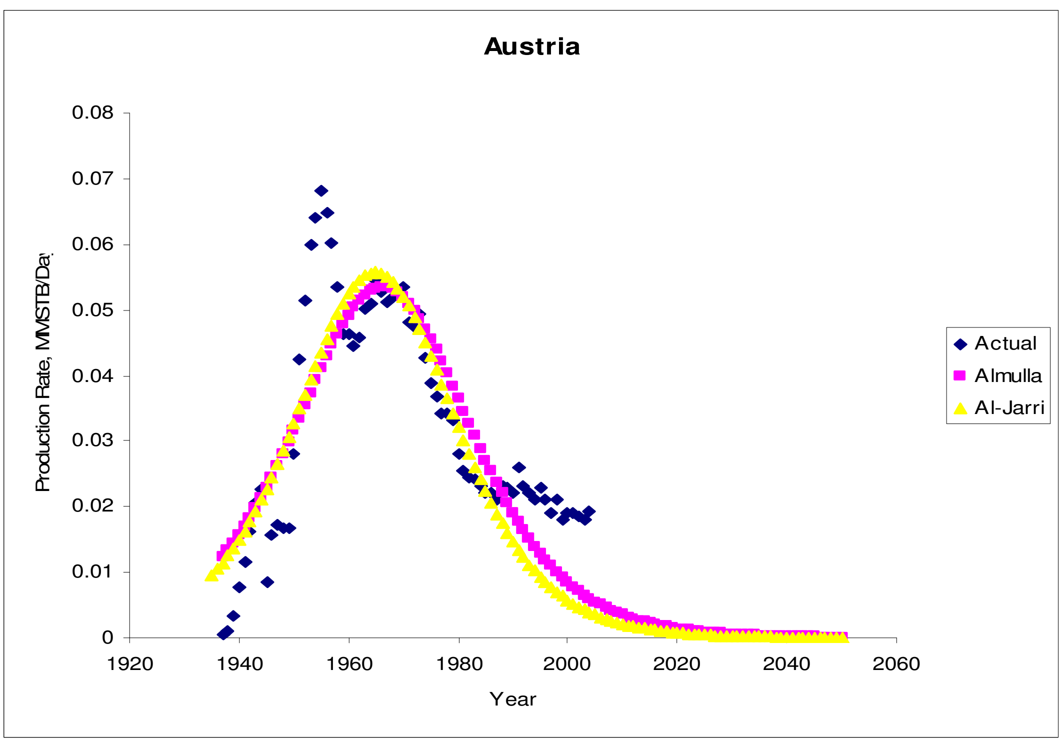

Fig A.6 Austria Production Curve

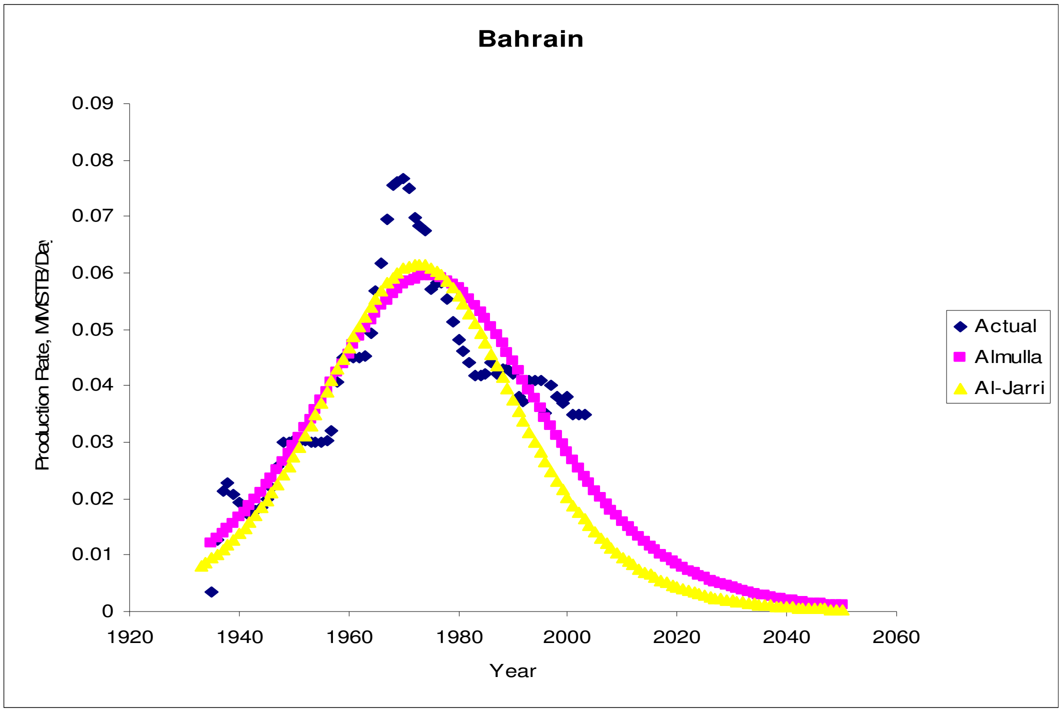

Fig A.7 Bahrain Production Curve

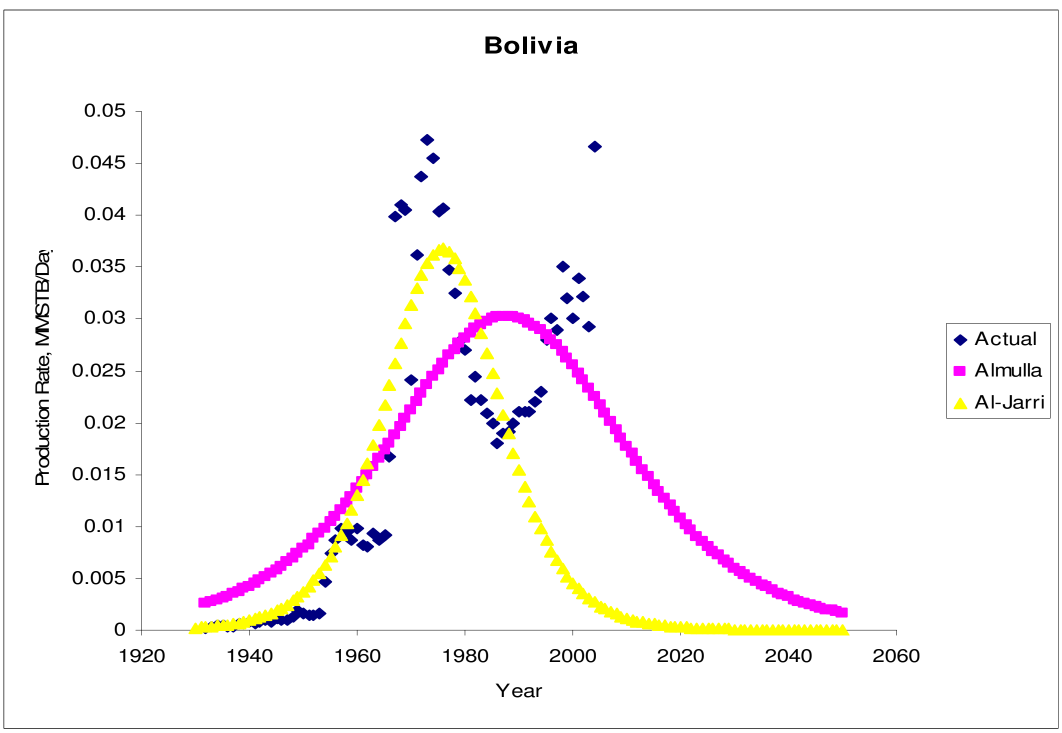

Fig A.8 Bolivia Production Curve

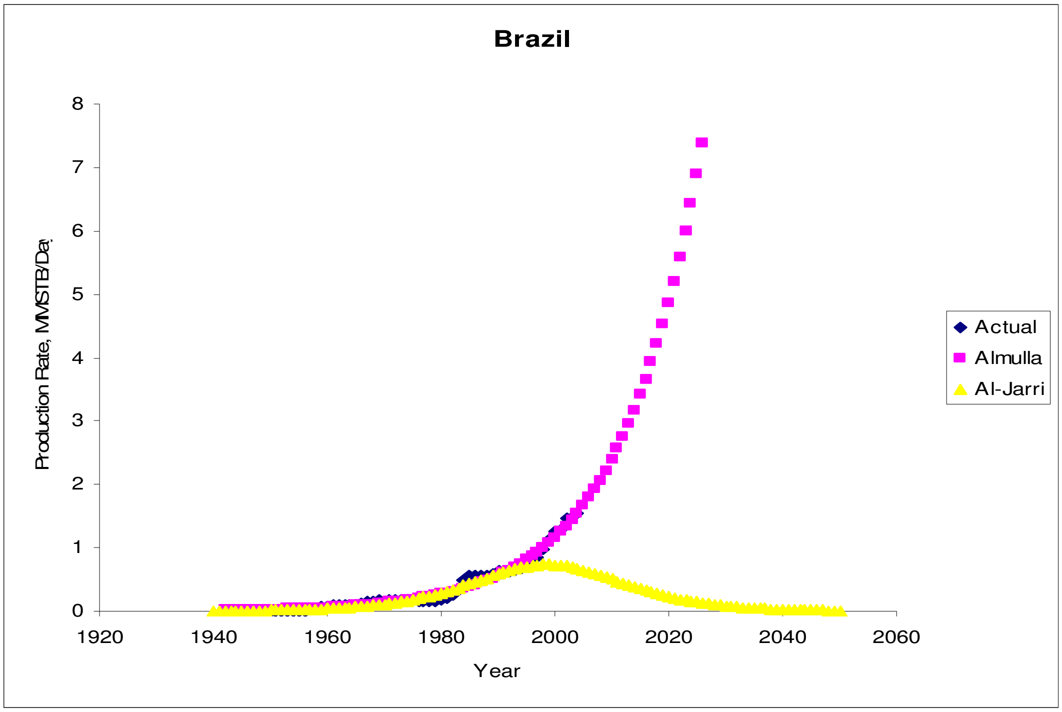

Fig A.9 Brazil Production Curve

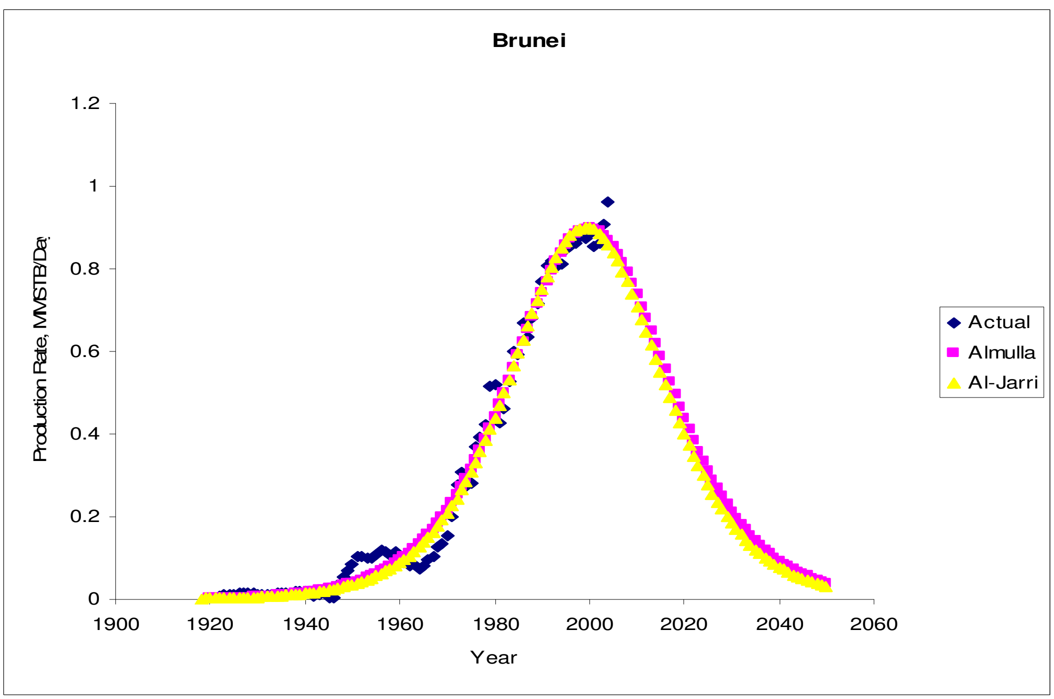

Fig A.10 Brunei Production Curve

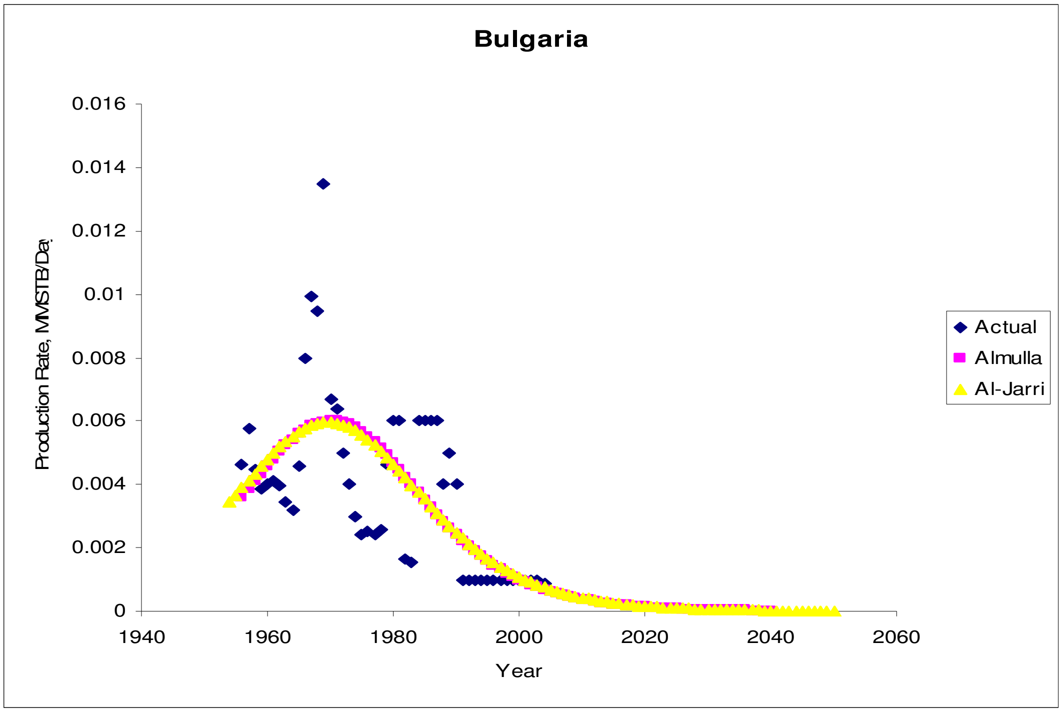

Fig A.11 Bulgaria Production Curve

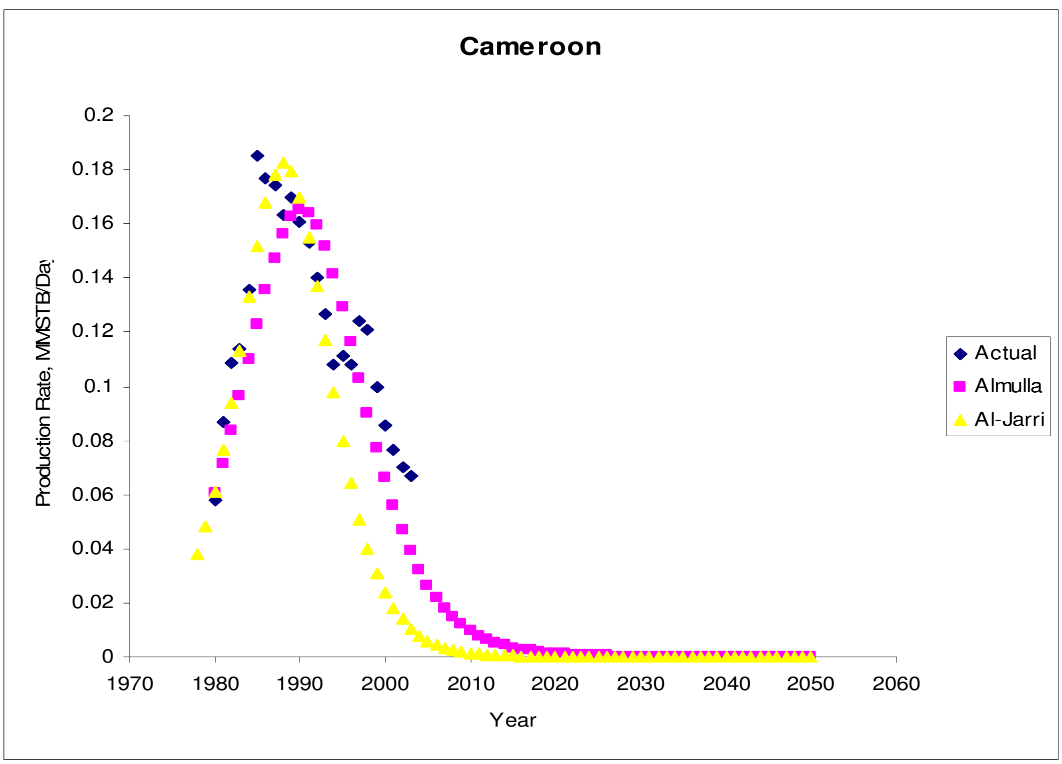

Fig A.12 Cameroon Production Curve

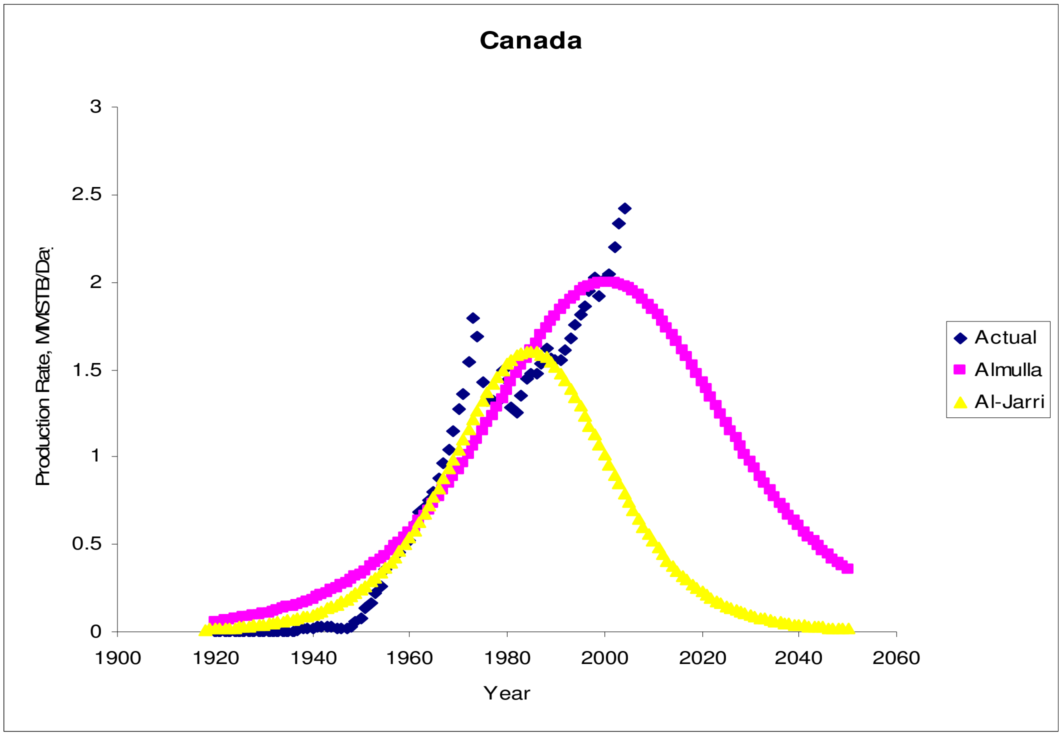

Fig A.13 Canada Production Curve

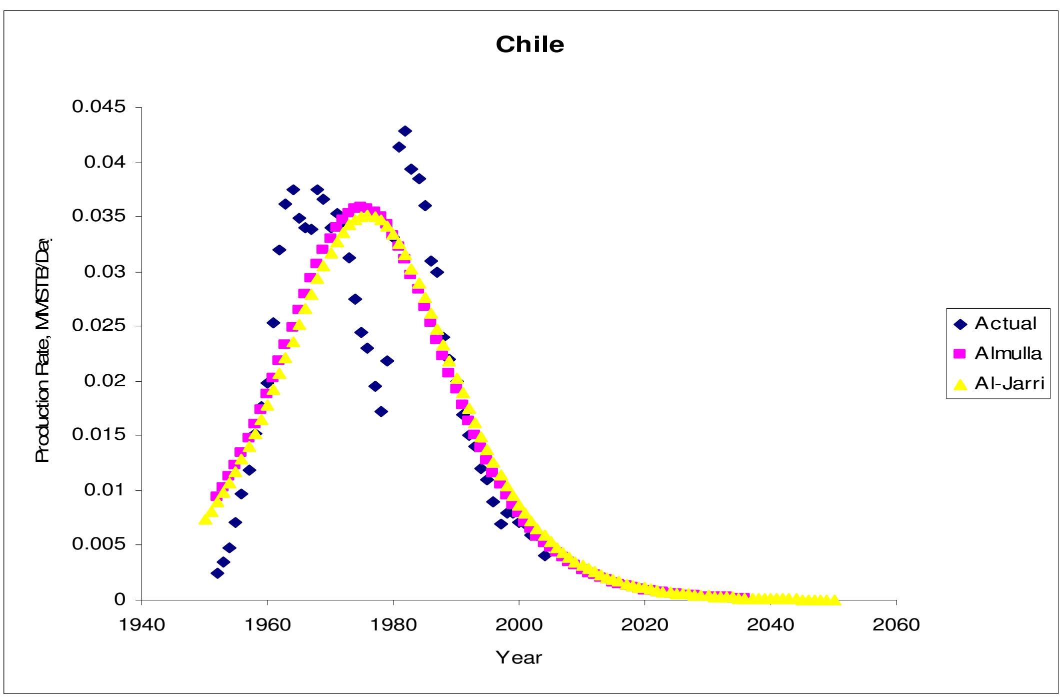

Fig A.14 Chile Production Curve

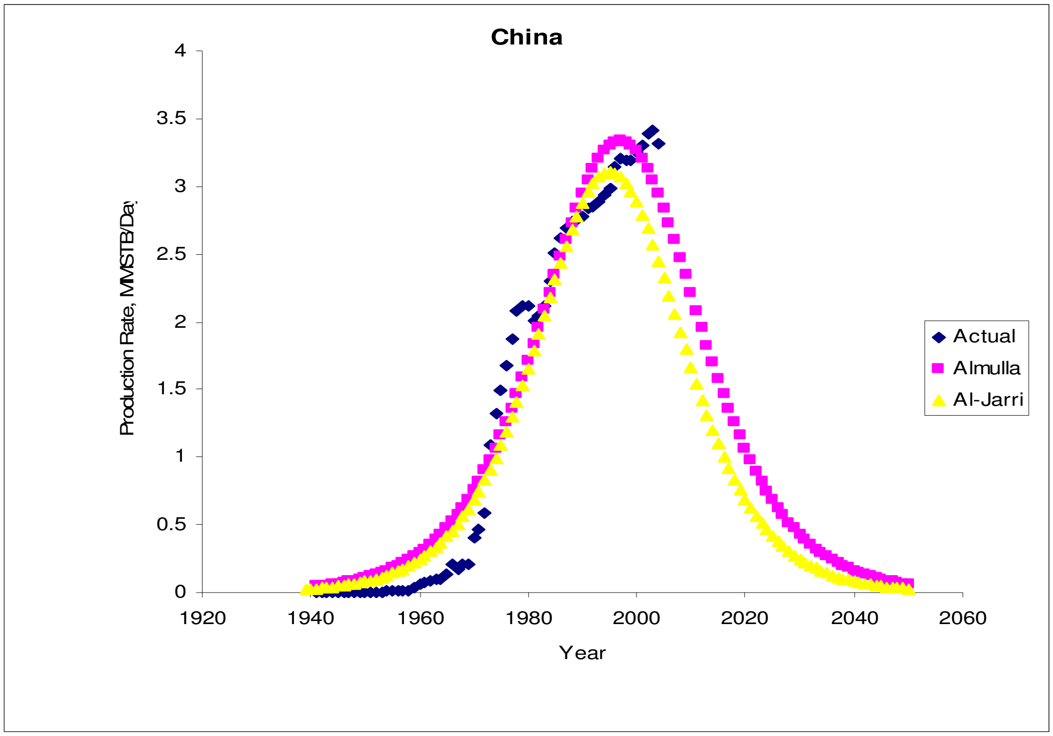

Fig A.15 China Production Curve

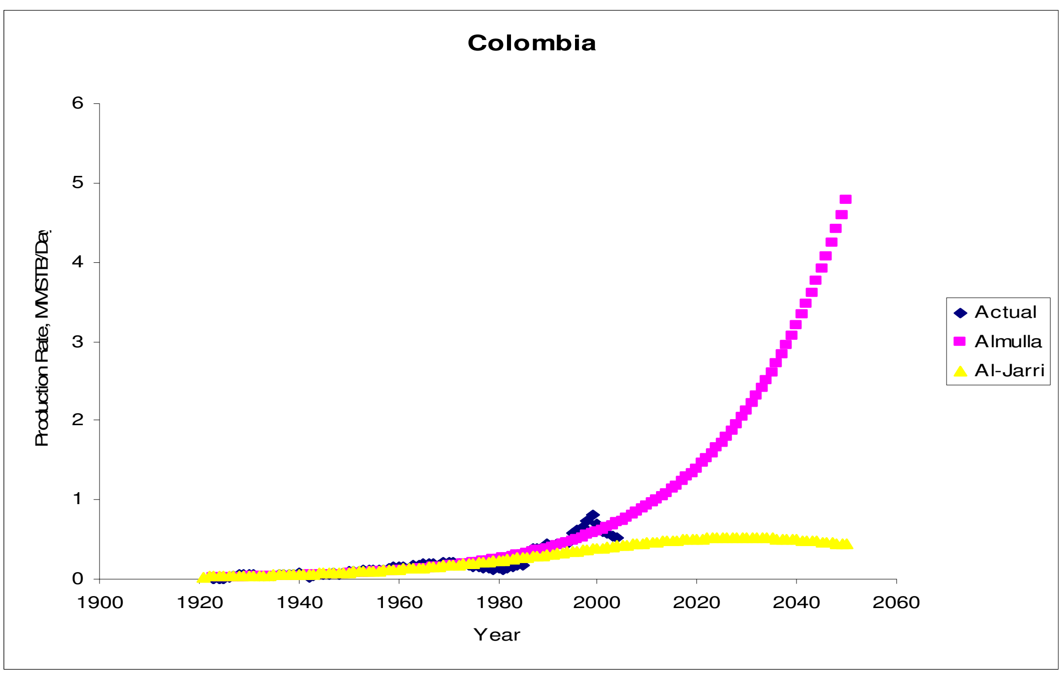

Fig A.16 Colombia Production Curve

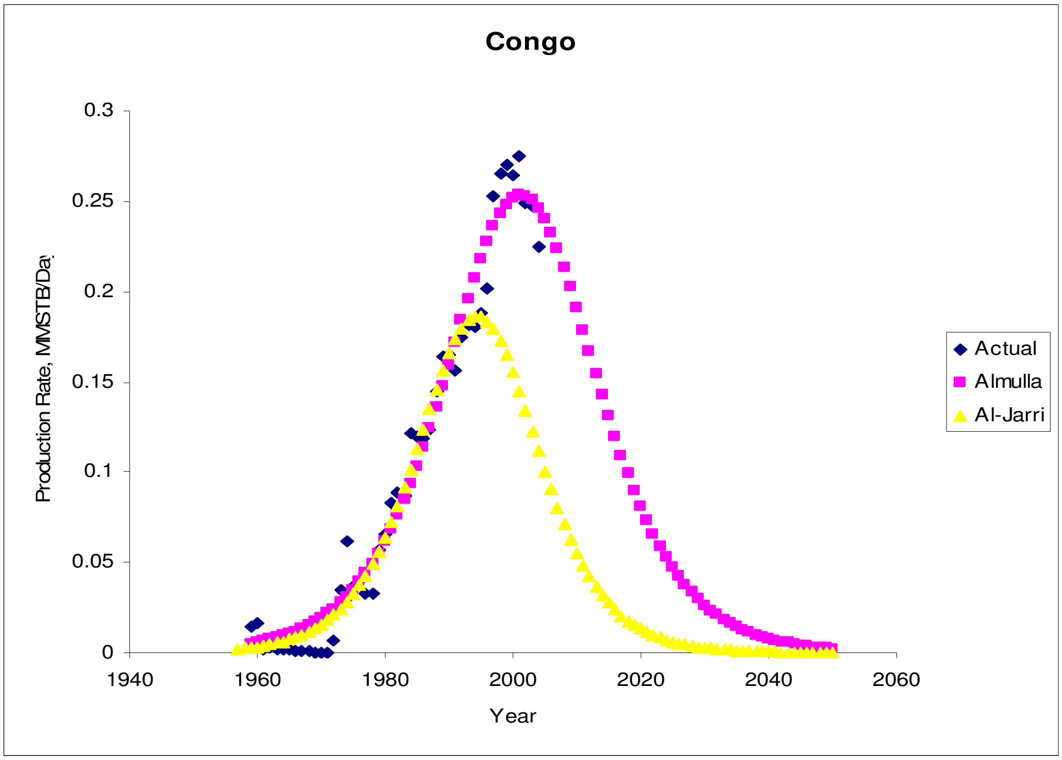

Fig A.17 Congo Production Curve

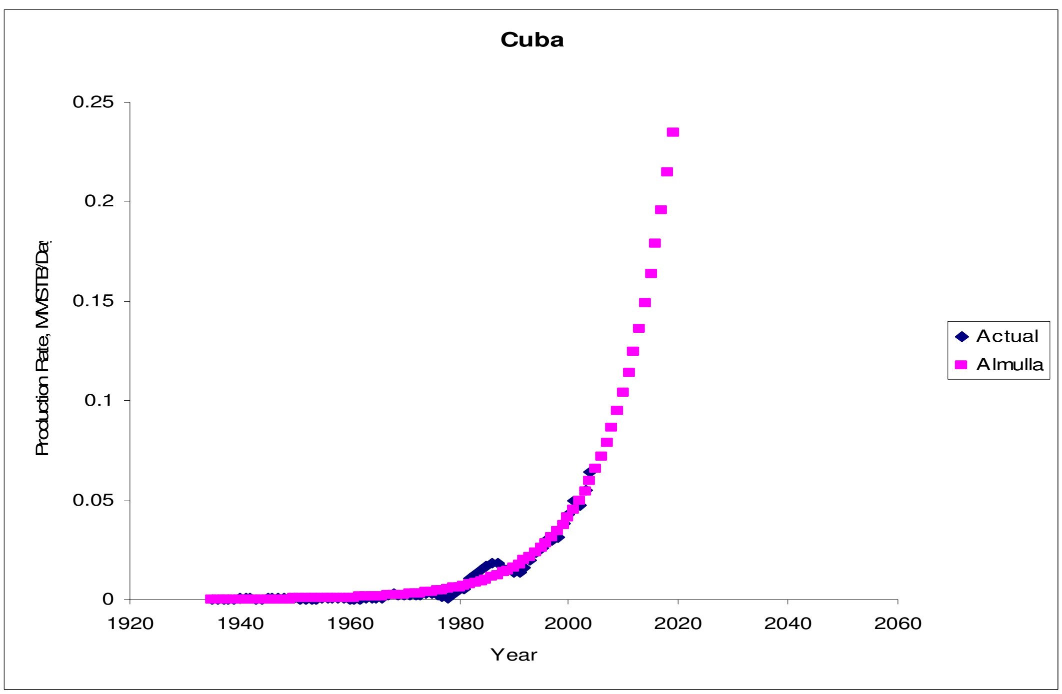

Fig A.18 Cuba Production Curve

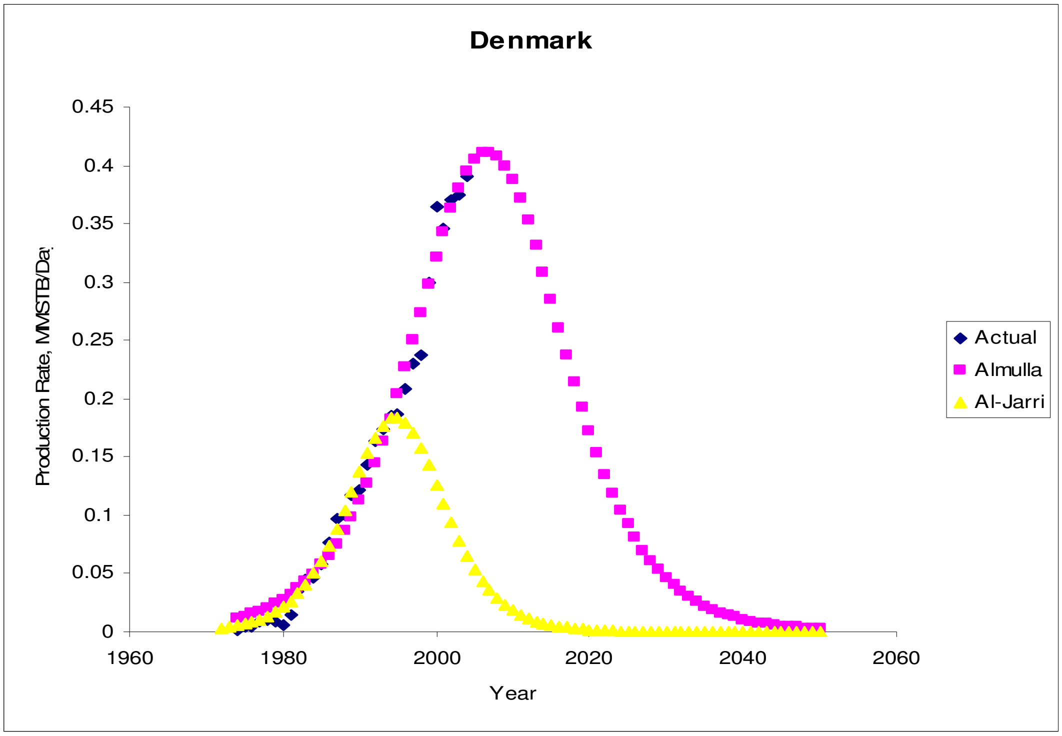

Fig A.19 Denmark Production Curve

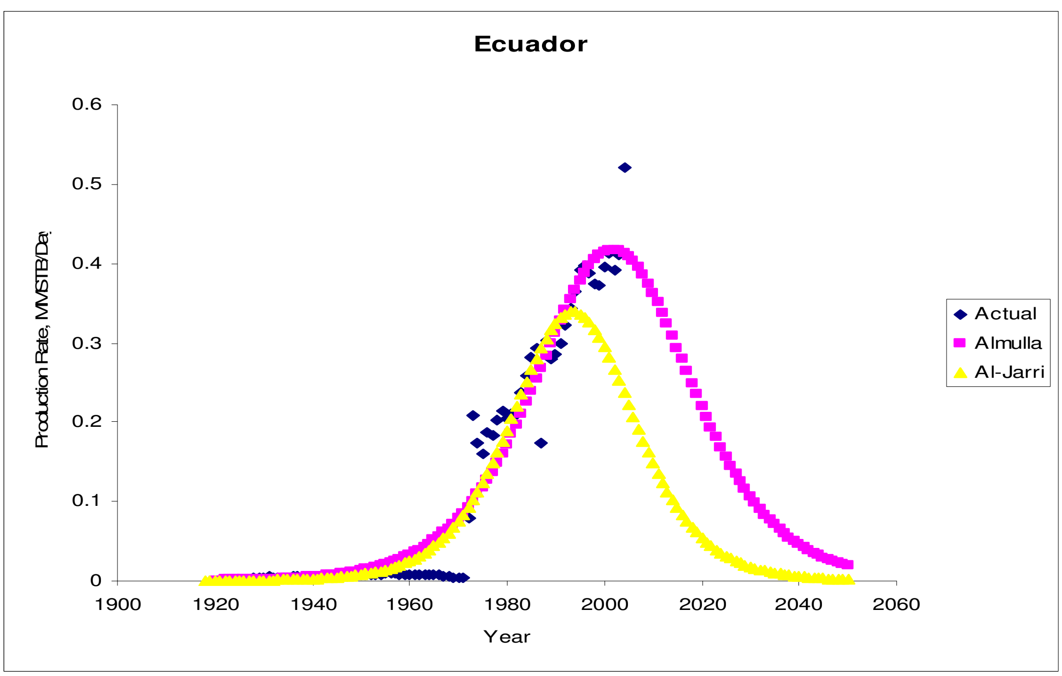

Fig A.20 Ecuador Production Curve

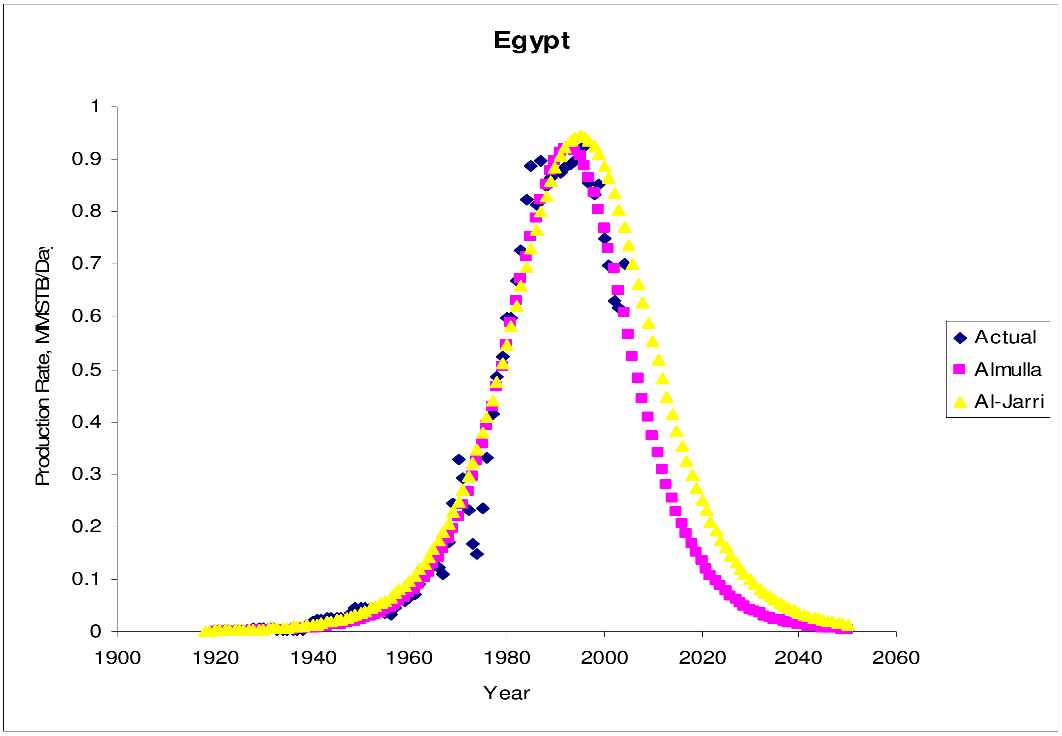

Fig A.21 Egypt Production Curve

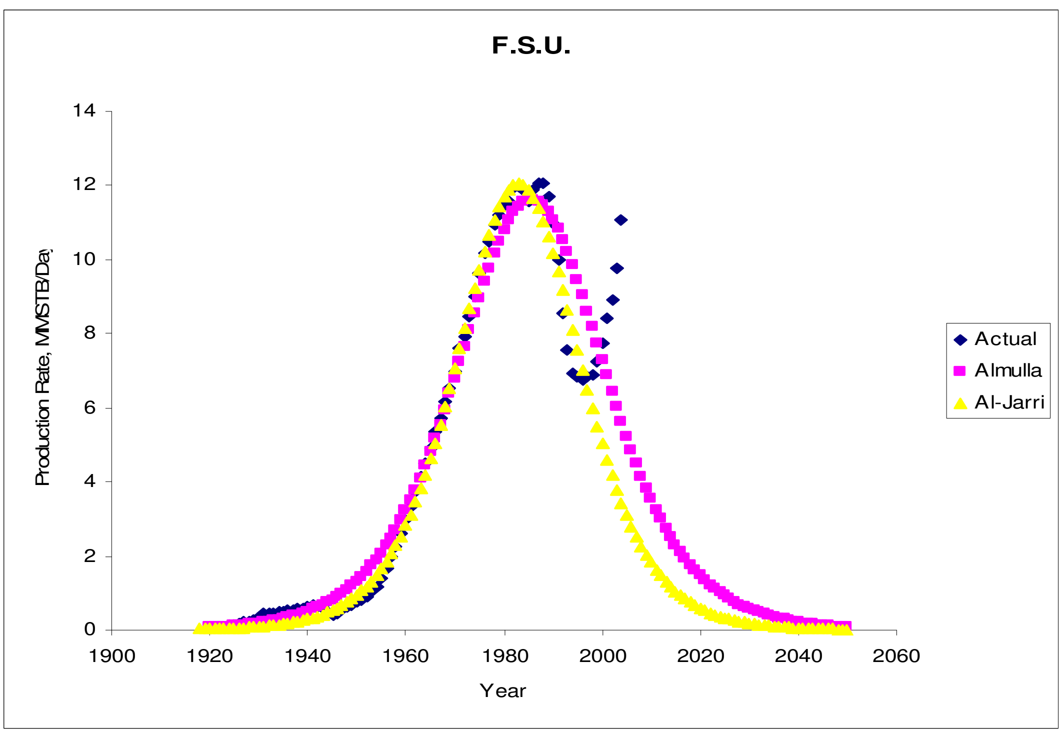

Fig A.22 Former Soviet Union Production Curve

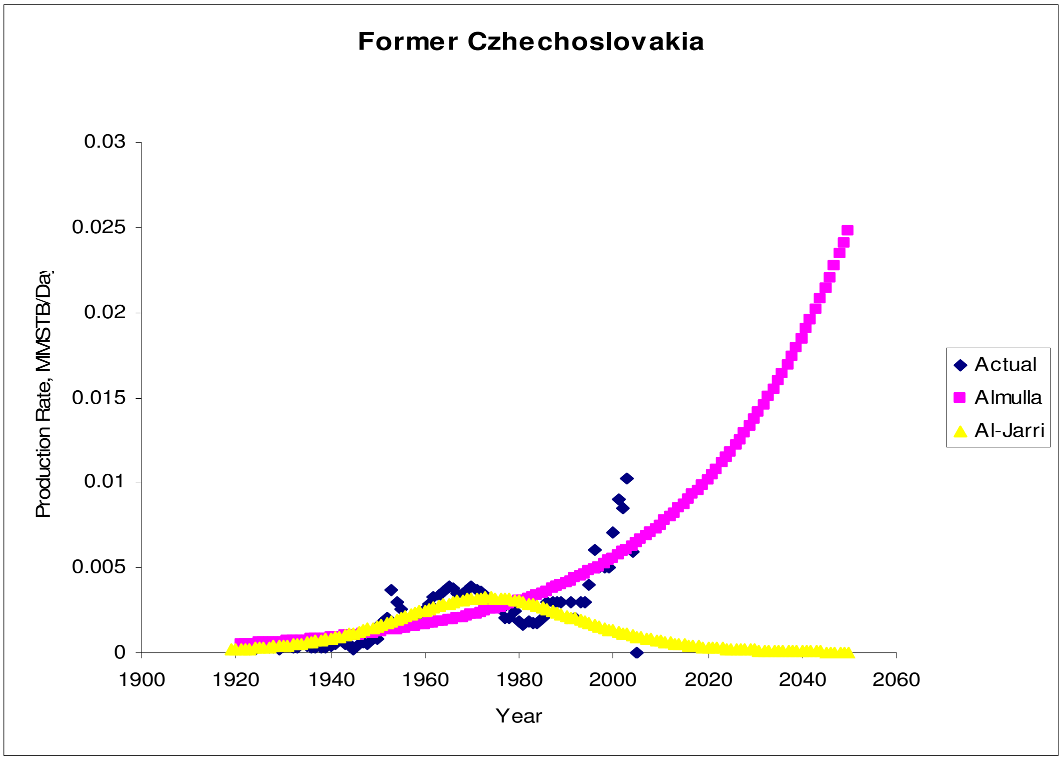

Fig A.23 Former Czechoslovakia Production Curve

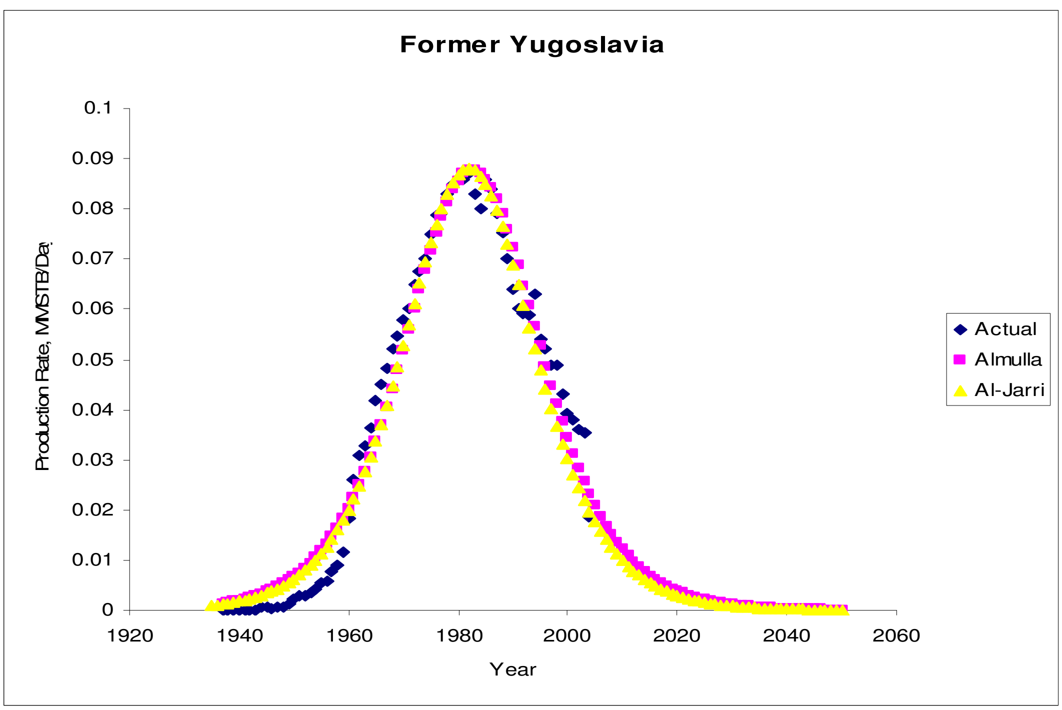

Fig A.24 Former Yugoslavia Production Curve

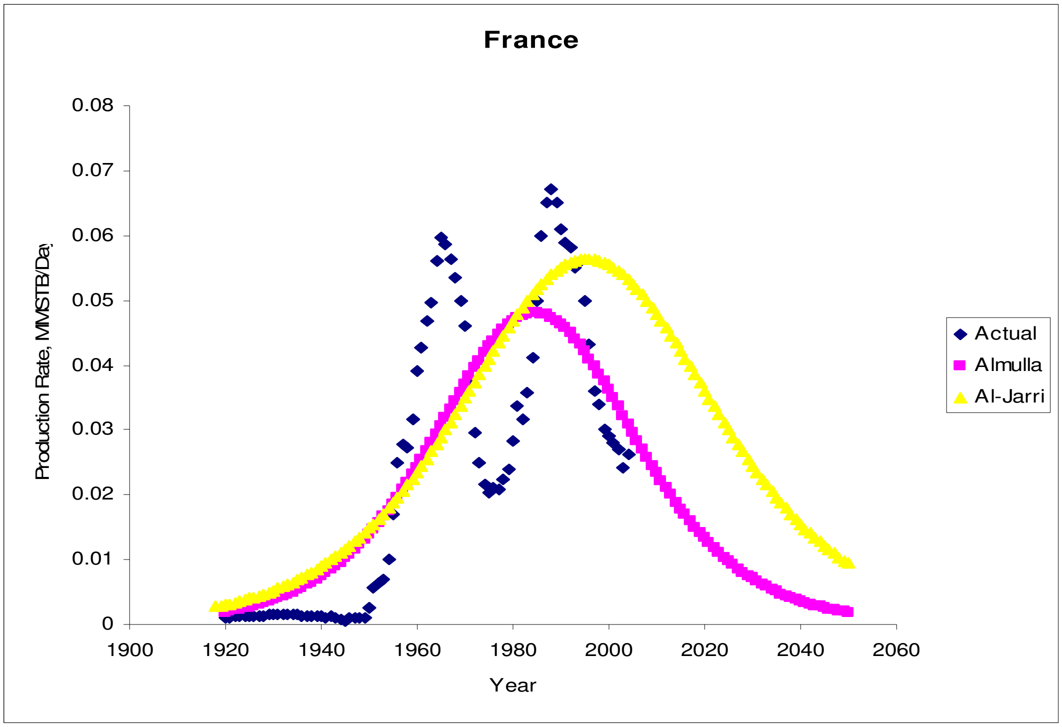

Fig A.25 France Production Curve

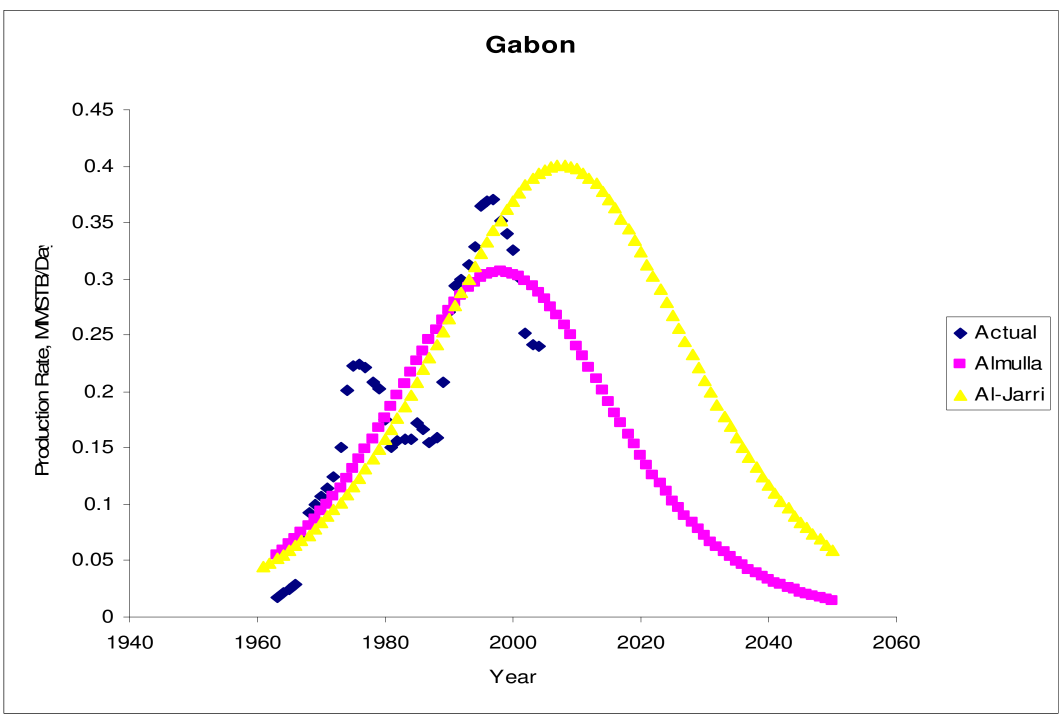

Fig A.26 Gabon Production Curve

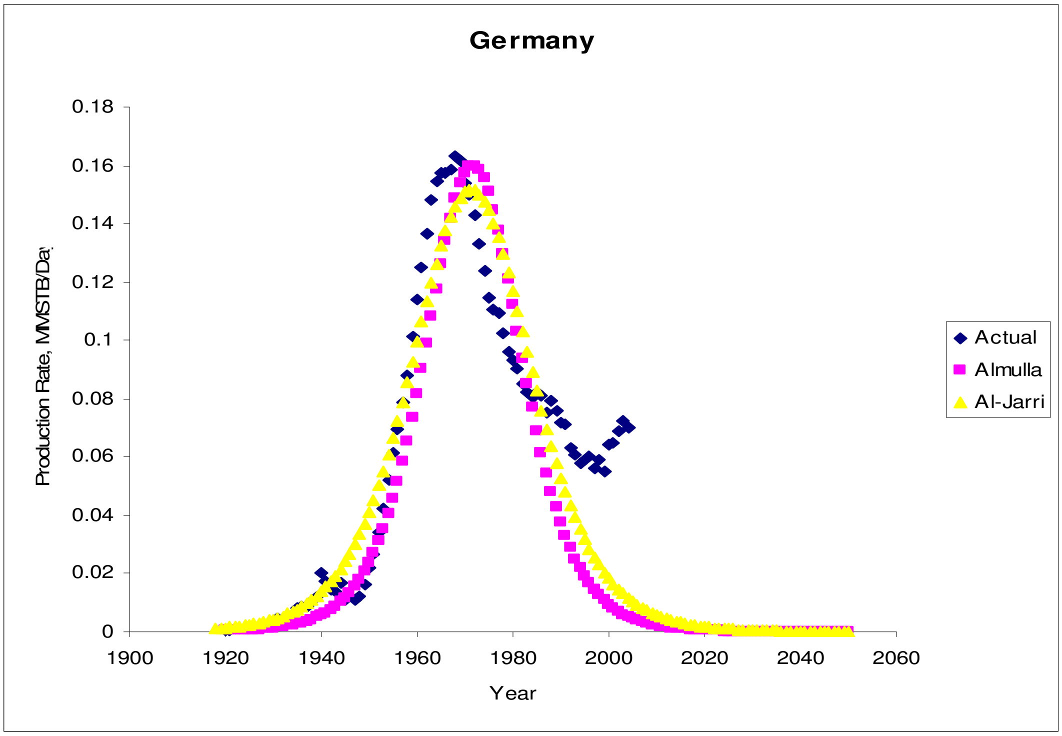

Fig A.27 Germany Production Curve

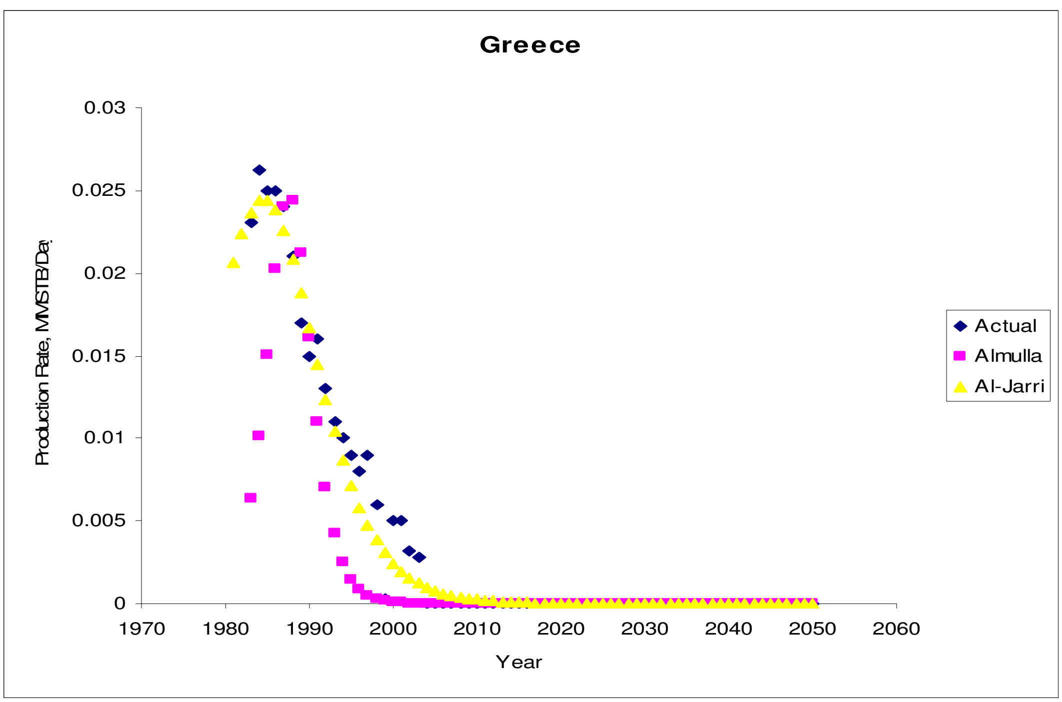

Fig A.28 Greece Production Curve

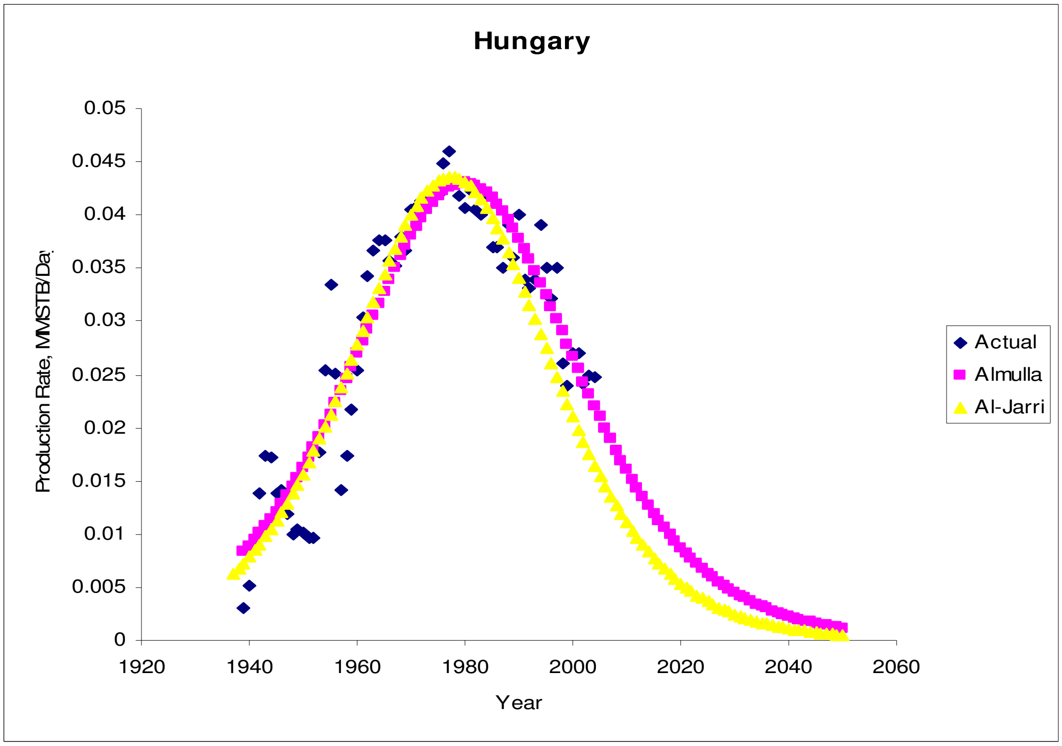

Fig A.29 Hungary Production Curve

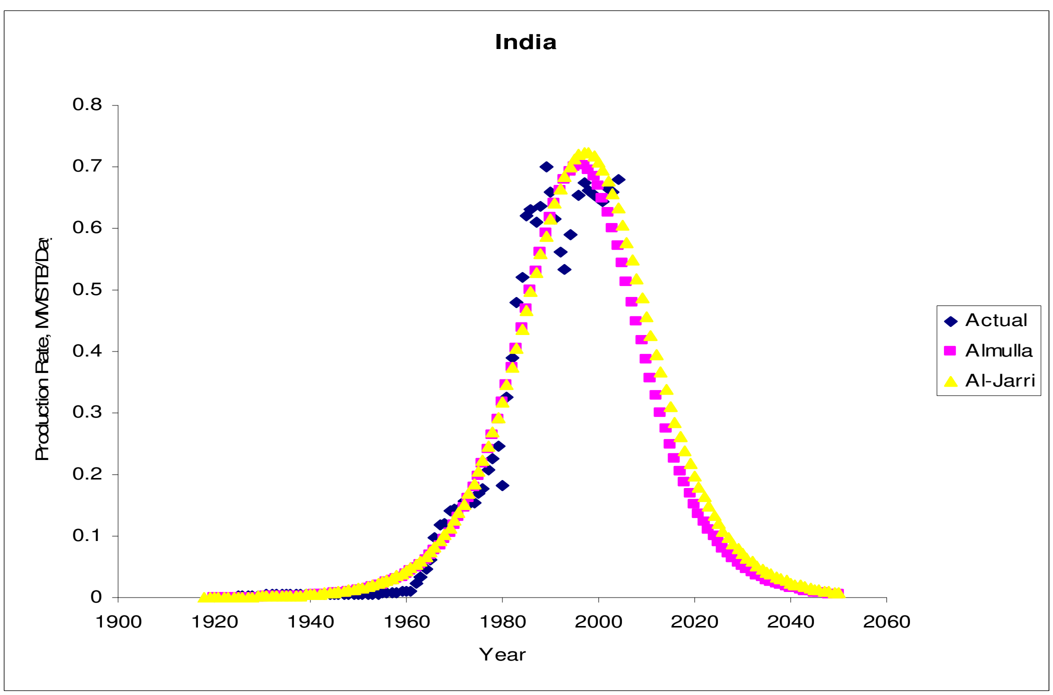

Fig A.30 India Production Curve

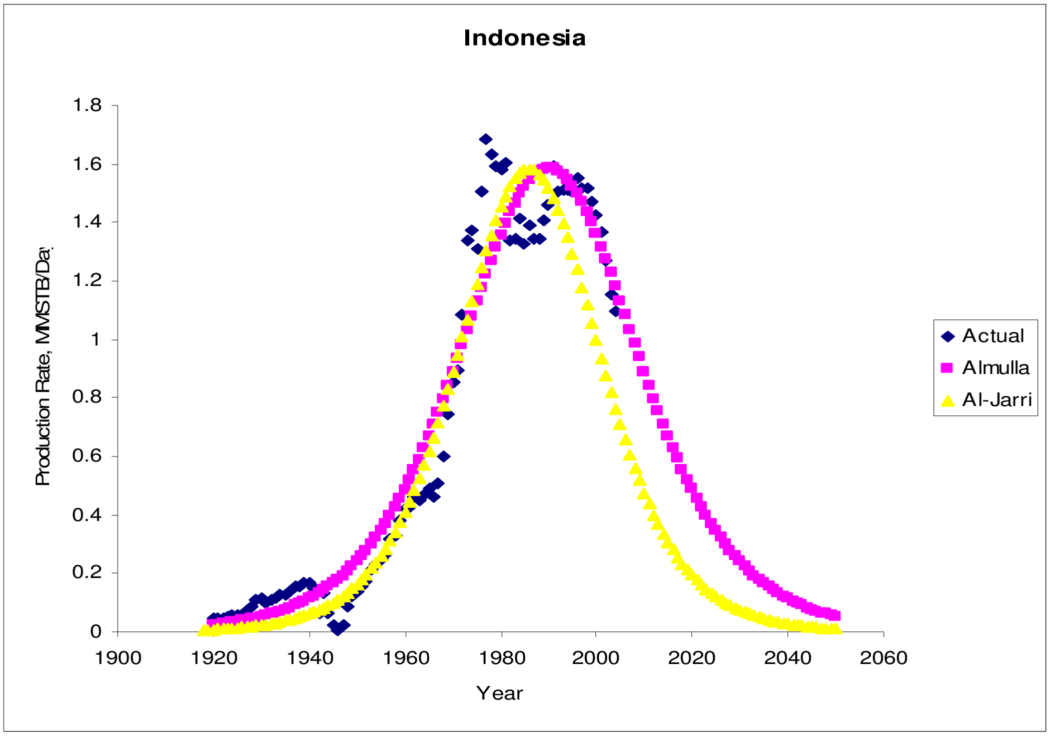

Fig A.31 Indonesia Production Curve

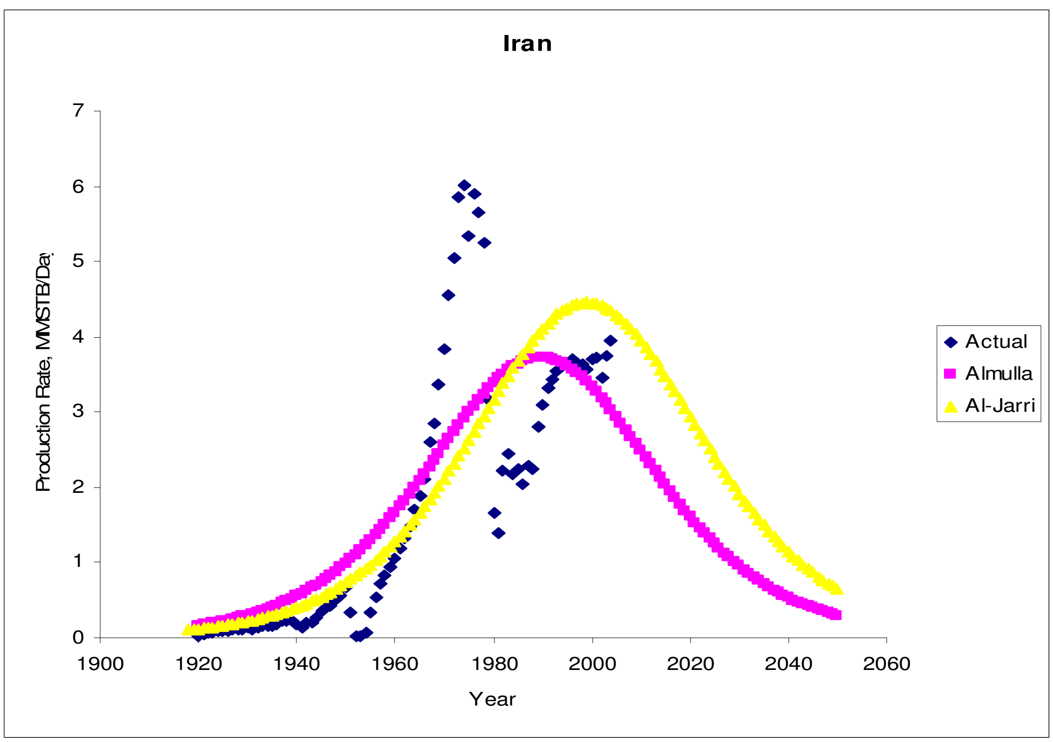

Fig A.32 Iran Production Curve

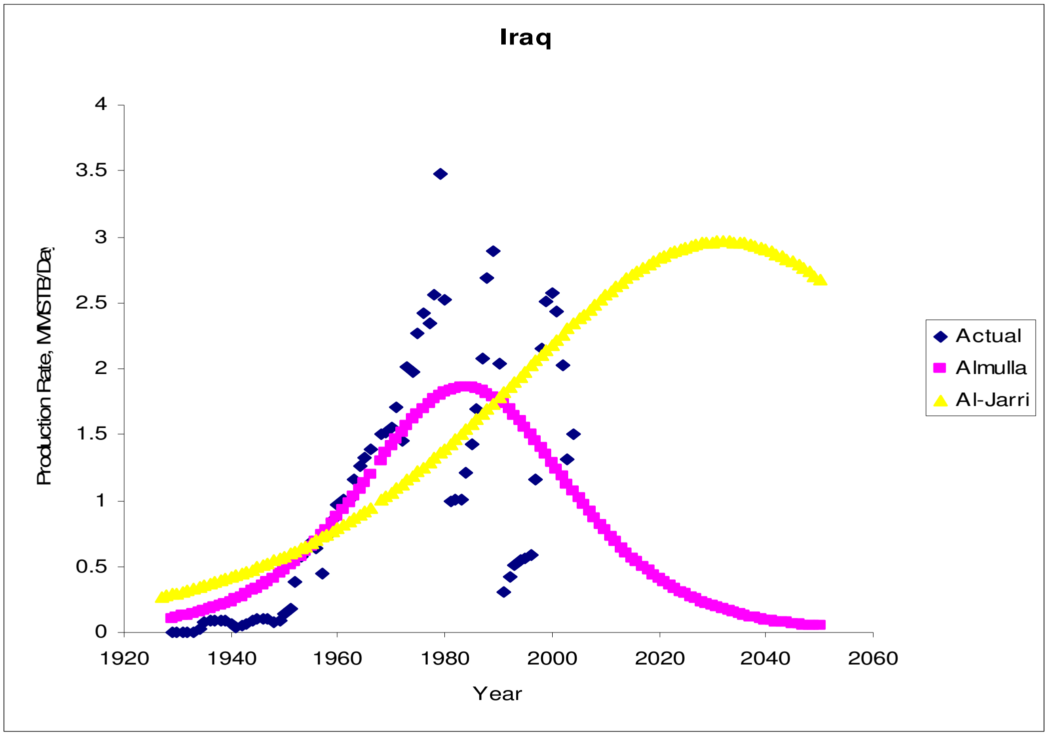

Fig A.33 Iraq Production Curve

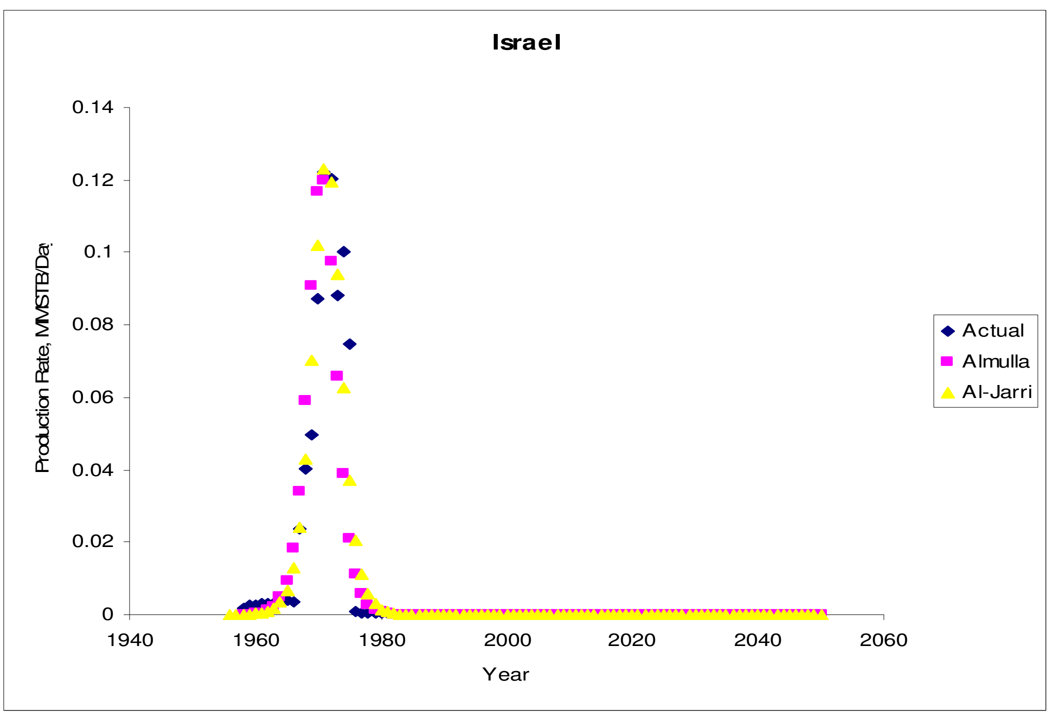

Fig A.34 Israel Production Curve

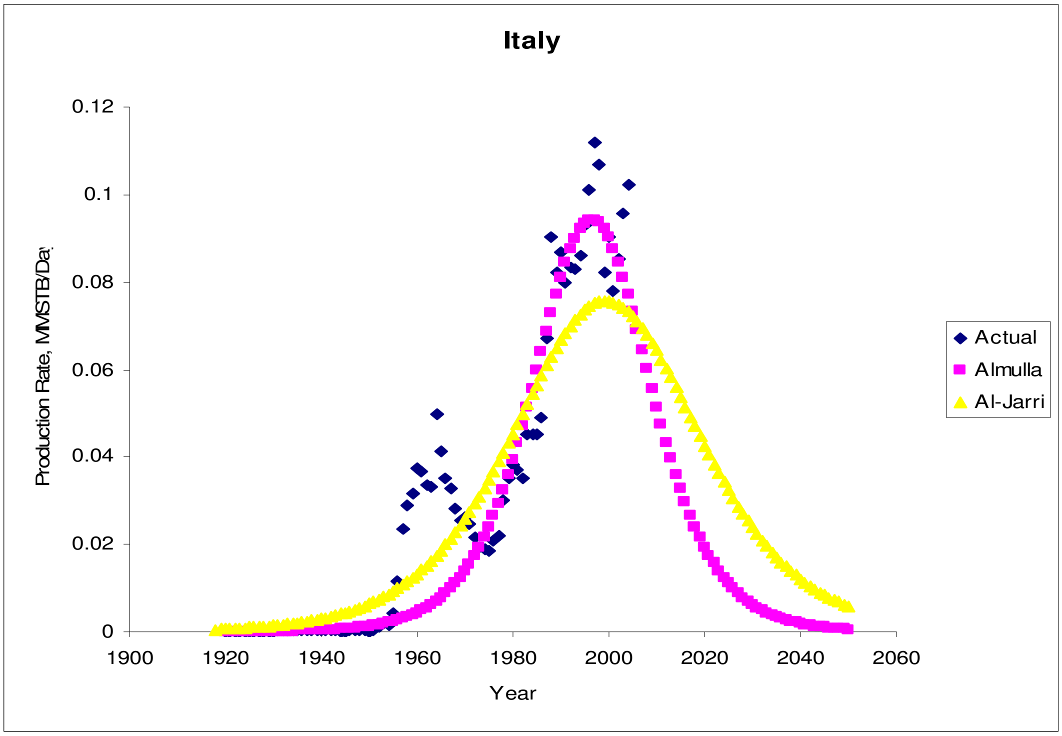

Fig A.35 Italy Production Curve

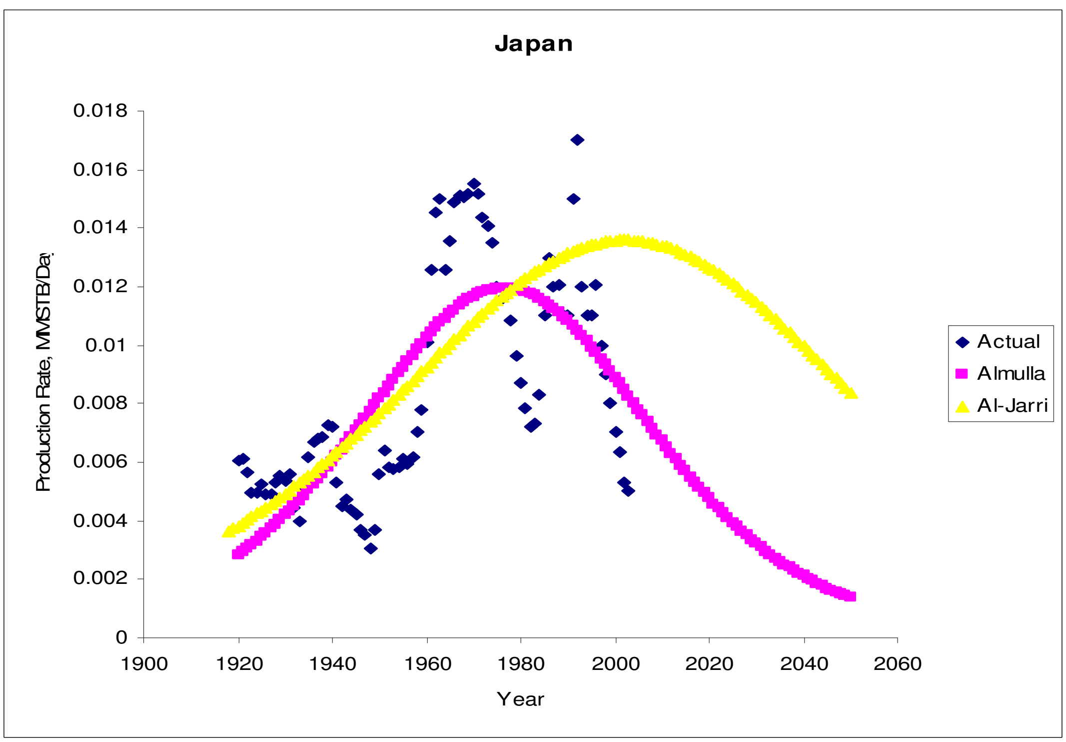

Fig A.36 Japan Production Curve

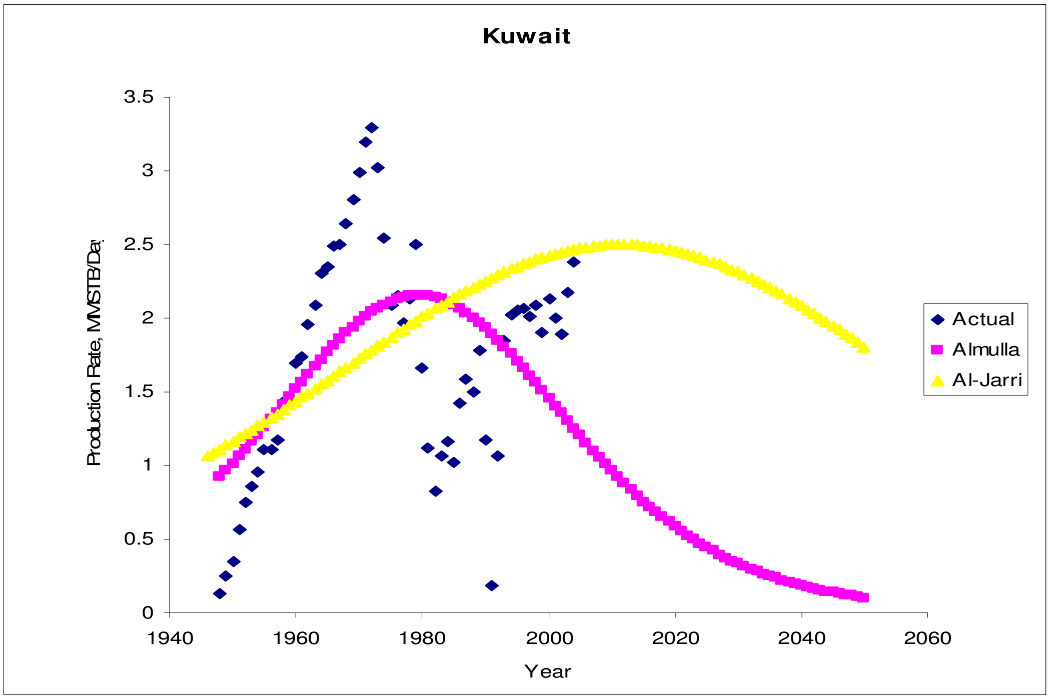

Fig A.37 Kuwait Production Curve

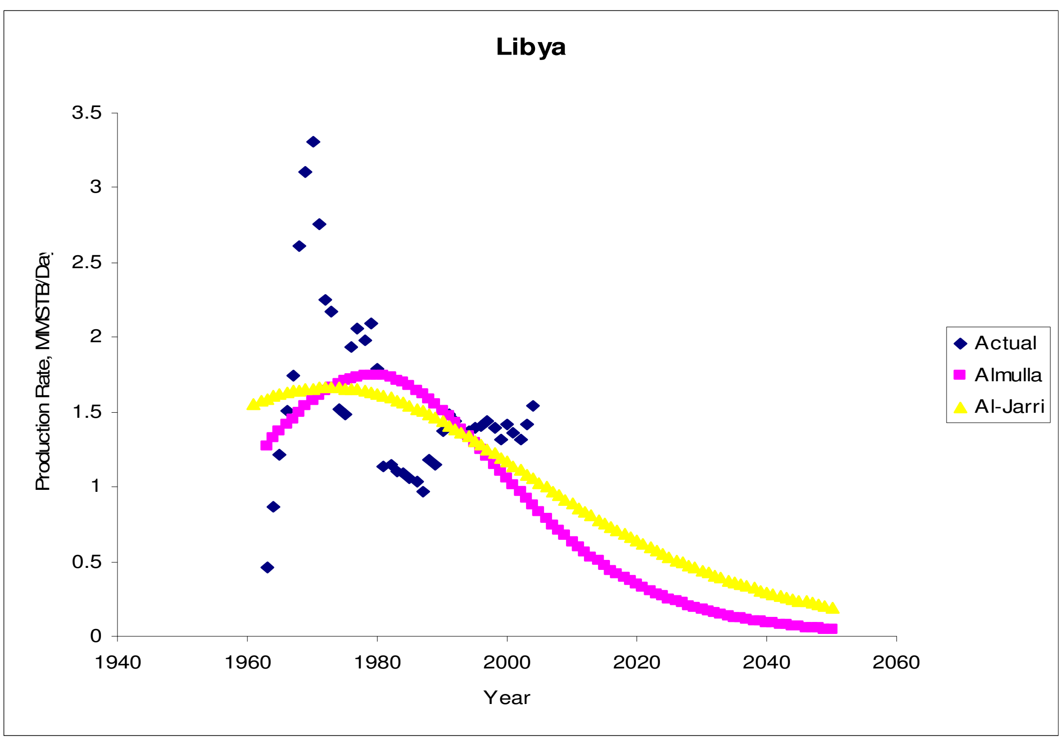

Fig A.38 Libya Production Curve

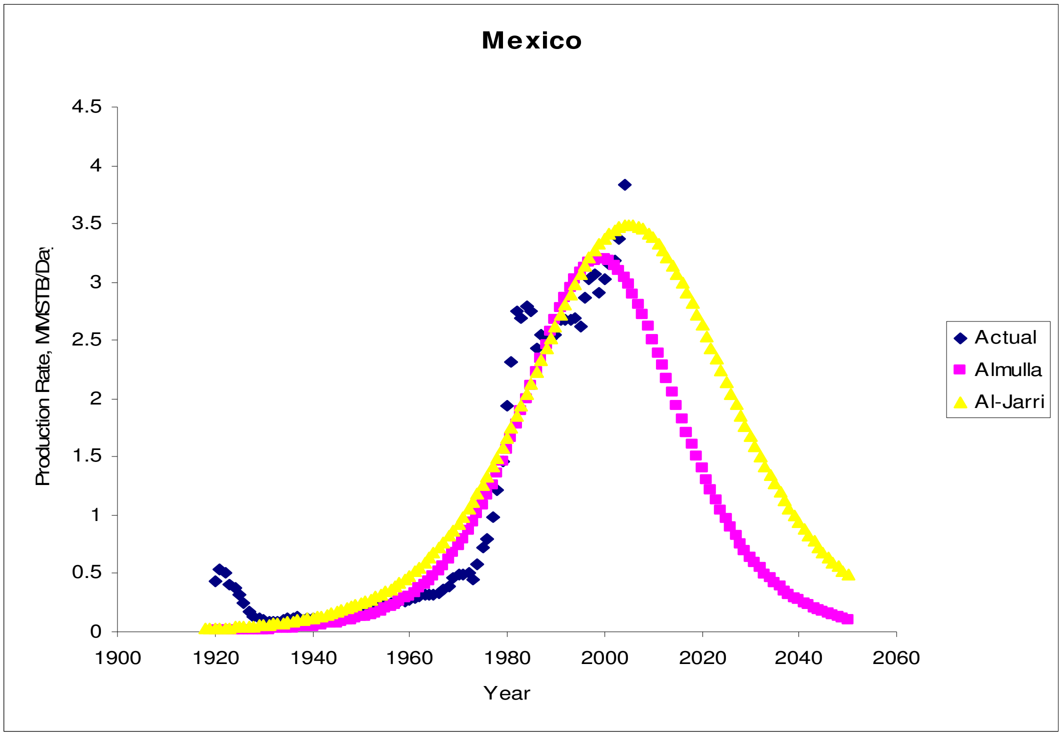

Fig A.39 Mexico Production Curve

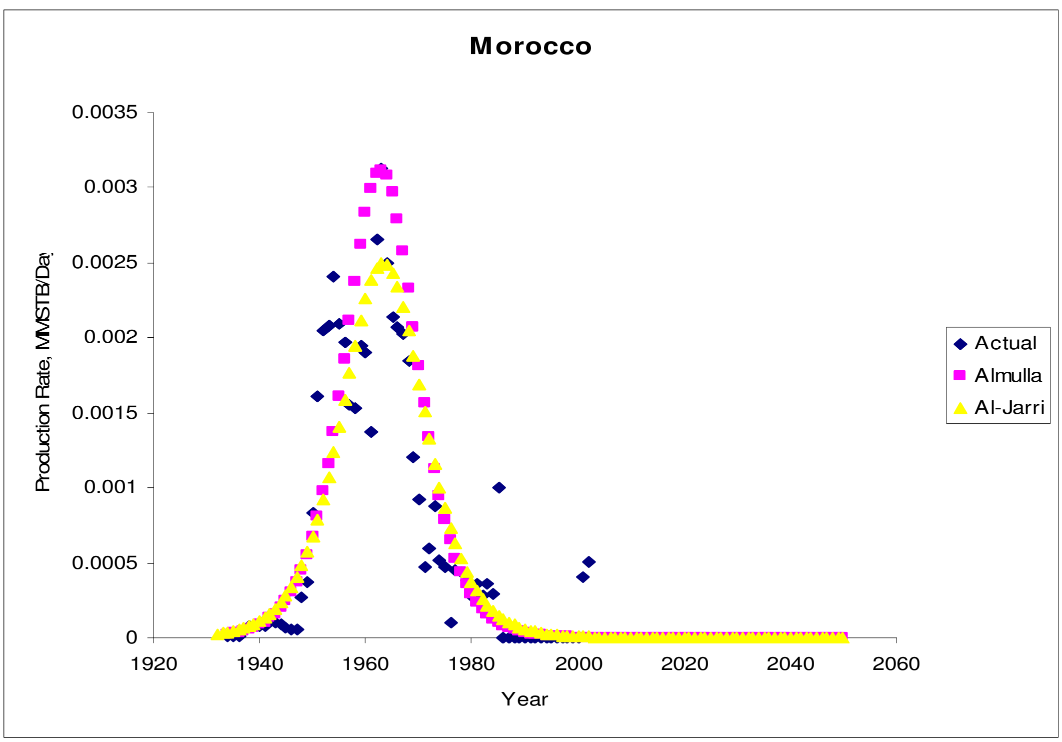

Fig A.40 Morocco Production Curve

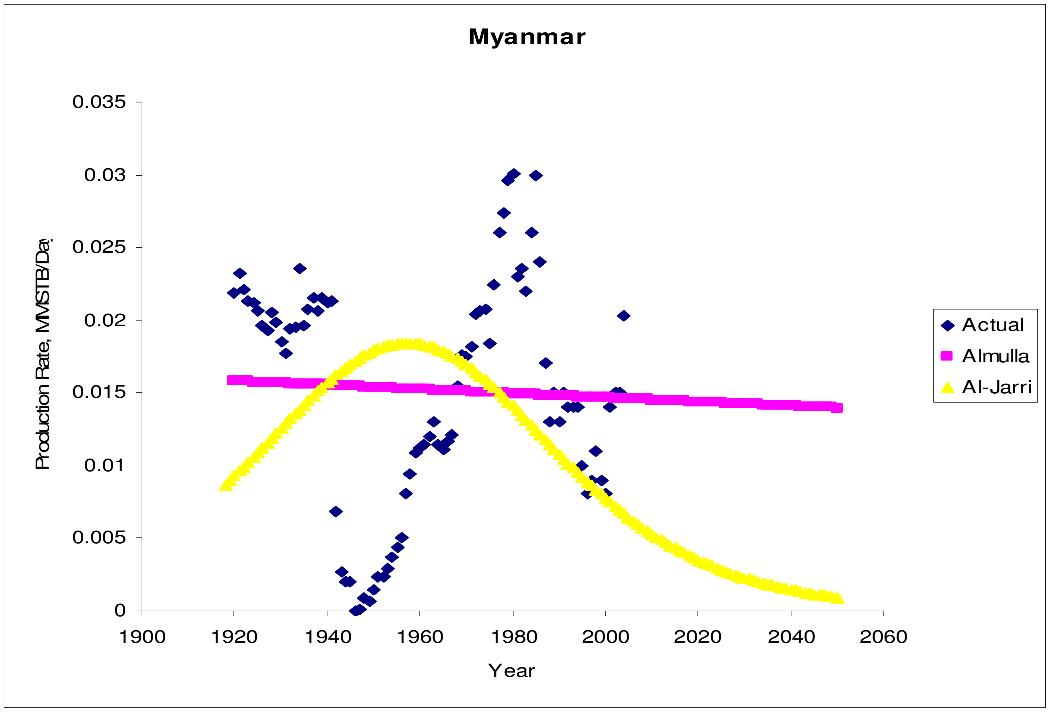

Fig A.41 Myanmar Production Curve

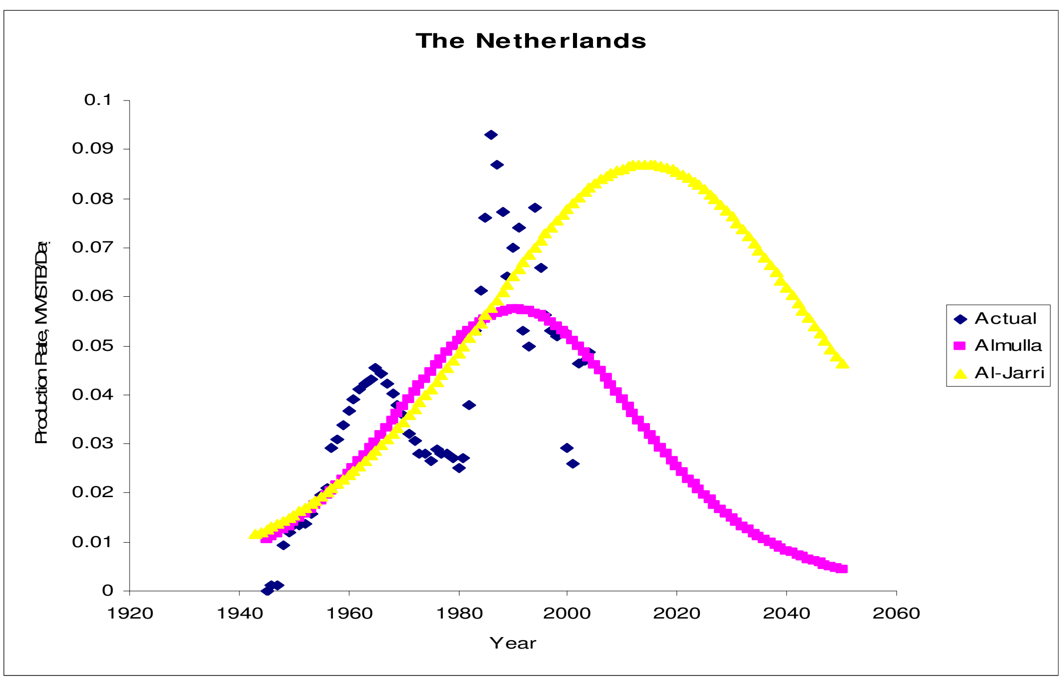

Fig A.42 The Netherlands Production Curve

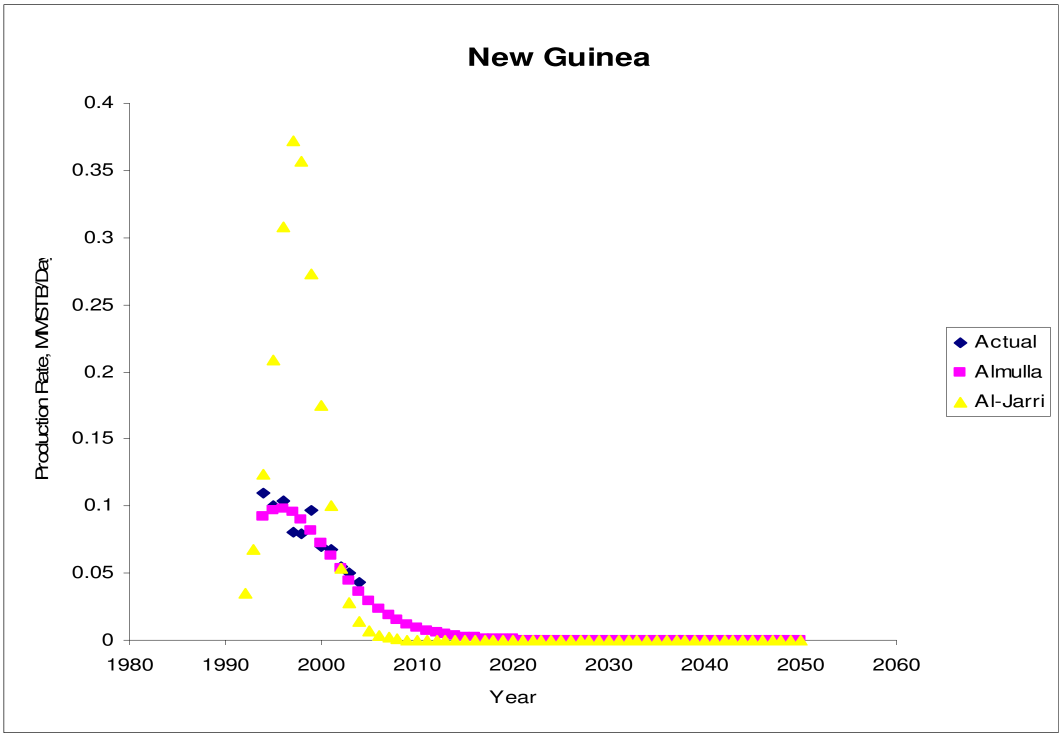

Fig A.43 New Guinea Production Curve

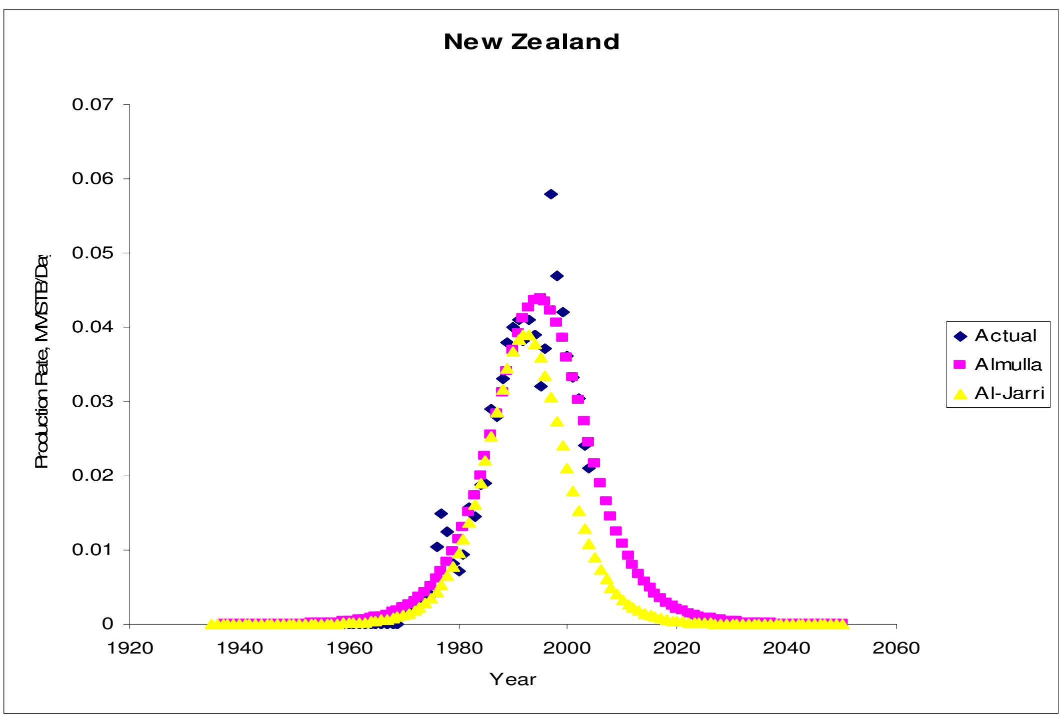

Fig A.44 New Zealand Production Curve

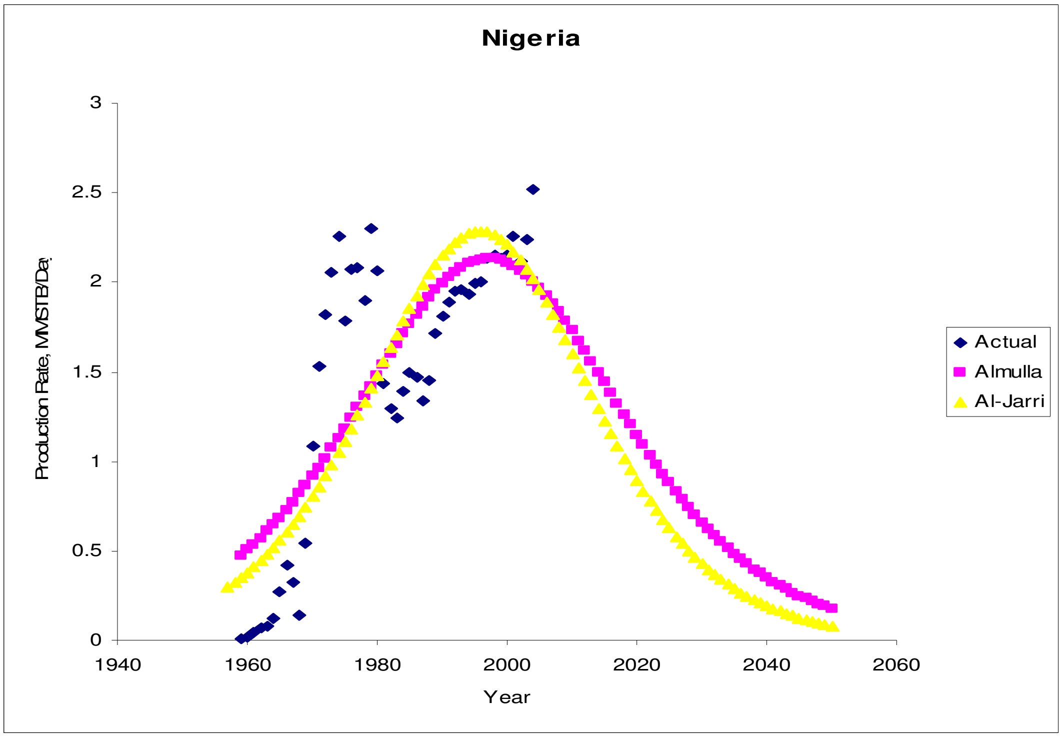

Fig A.45 Nigeria Production Curve

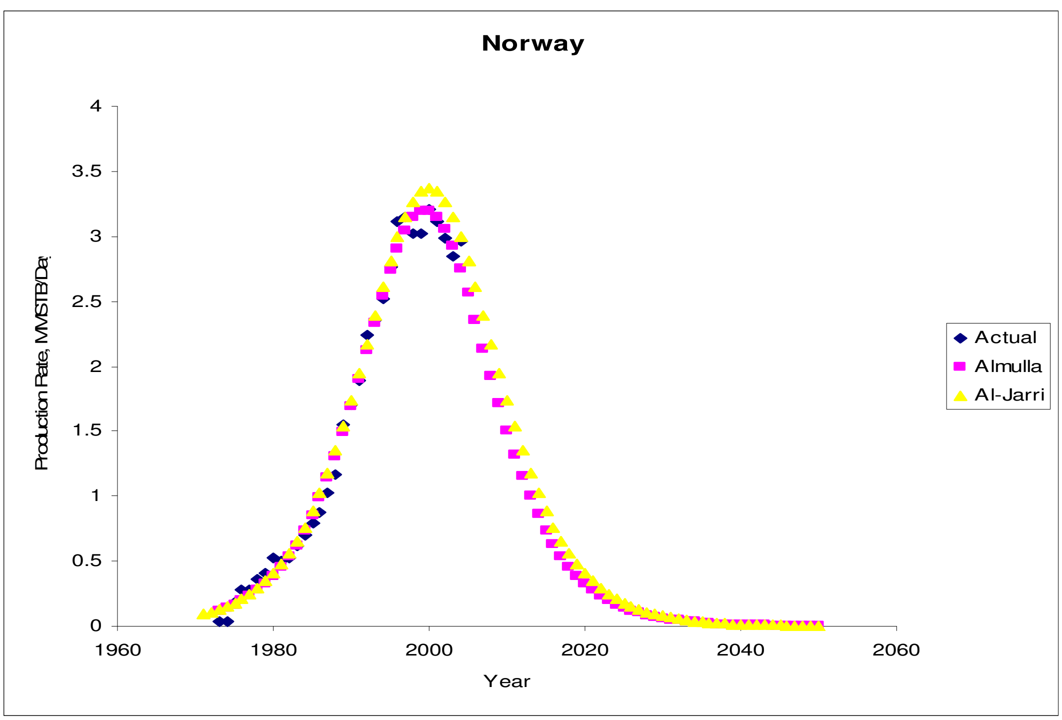

Fig A.46 Norway Production Curve

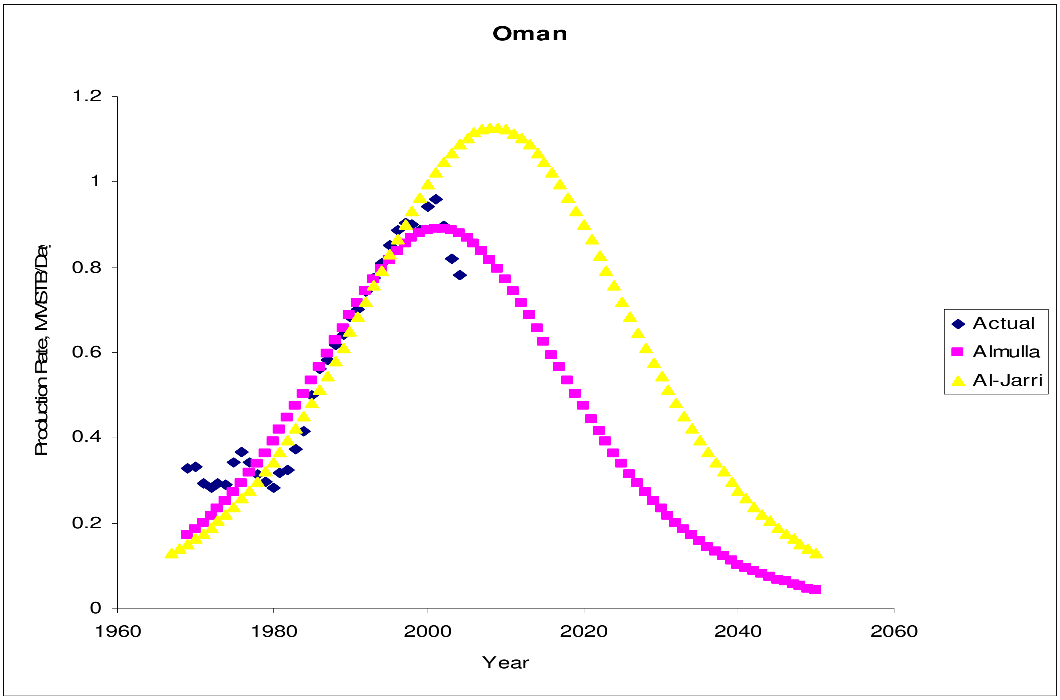

Fig A.47 Norway Production Curve

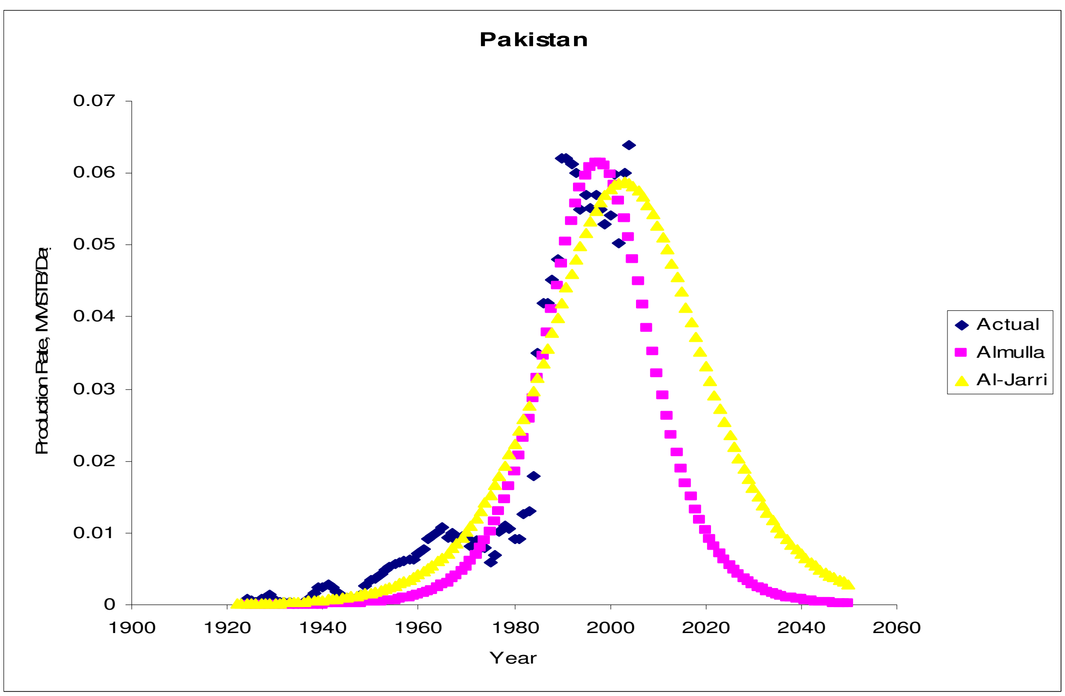

Fig A.48 Pakistan Production Curve

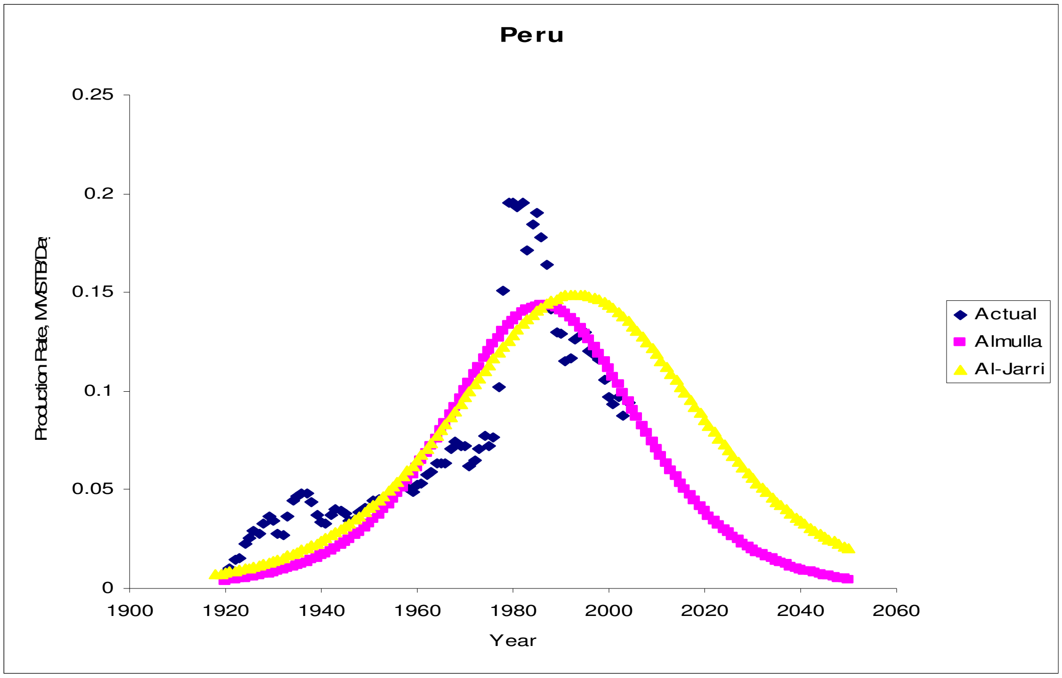

Fig A.49 Peru Production Curve

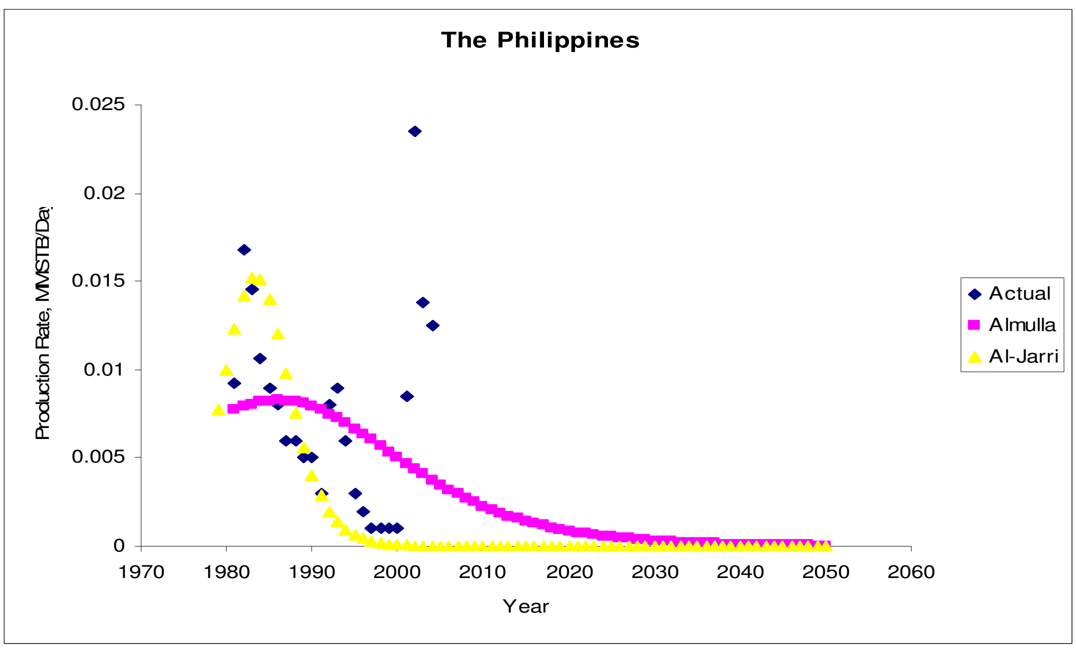

Fig A.50 The Philippines Production Curve

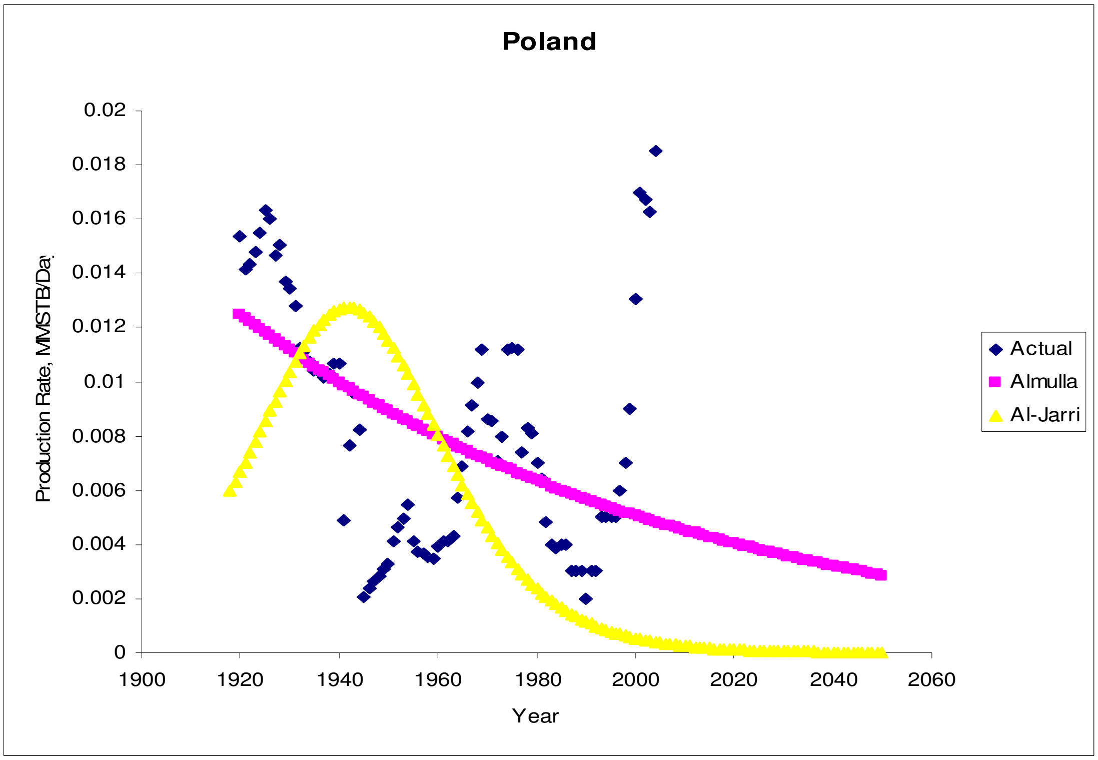

Fig A.51 Poland Production Curve

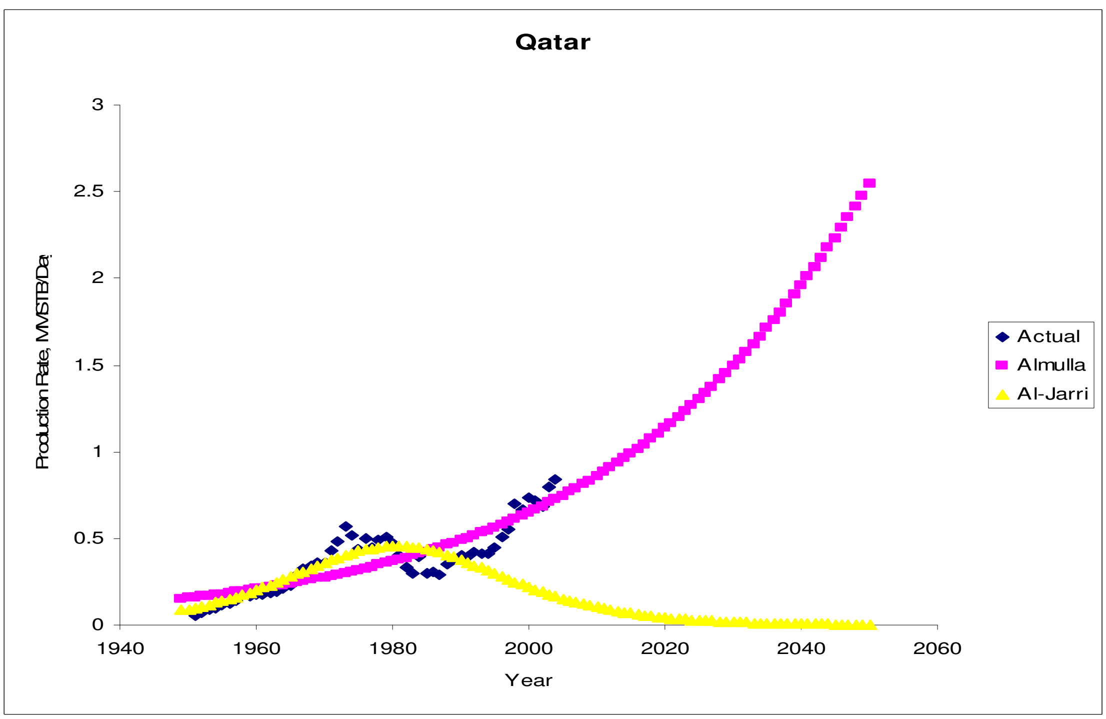

Fig A.52 Qatar Production Curve

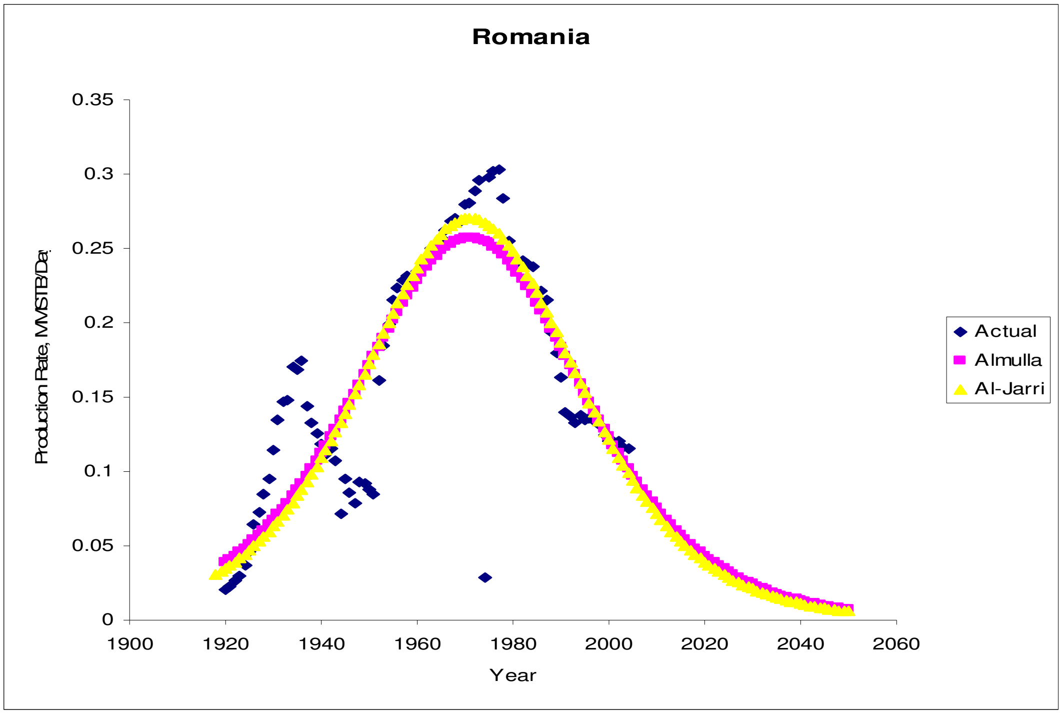

Fig A.53 Romania Production Curve

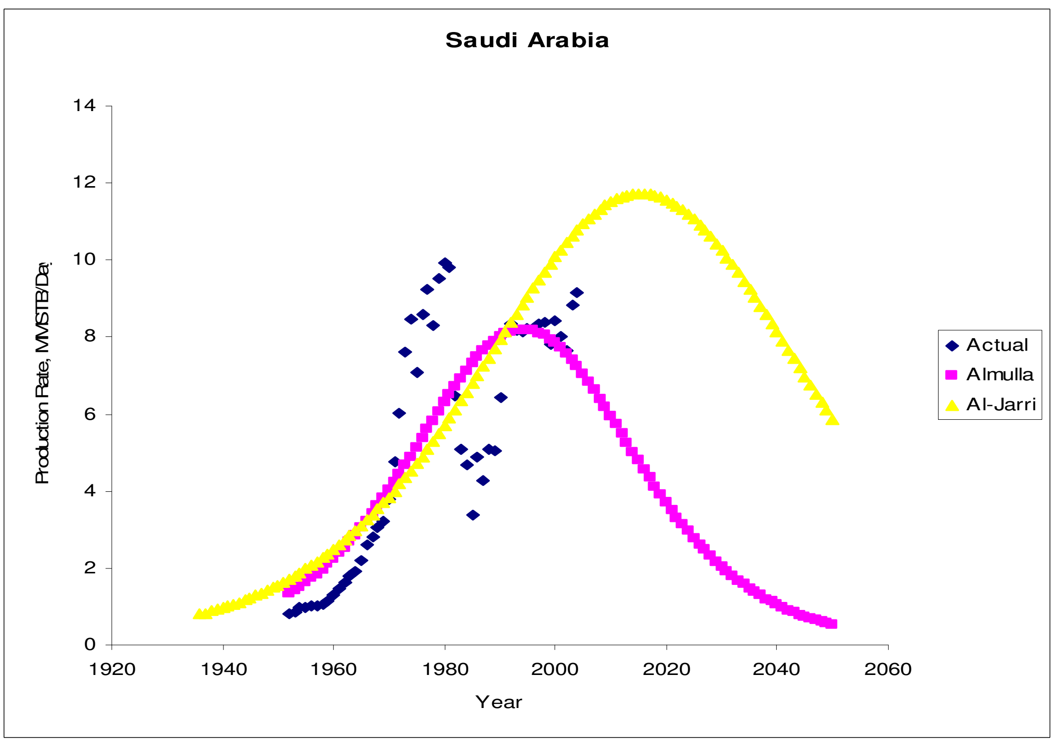

Fig A.54 Saudi Arabia Production Curve

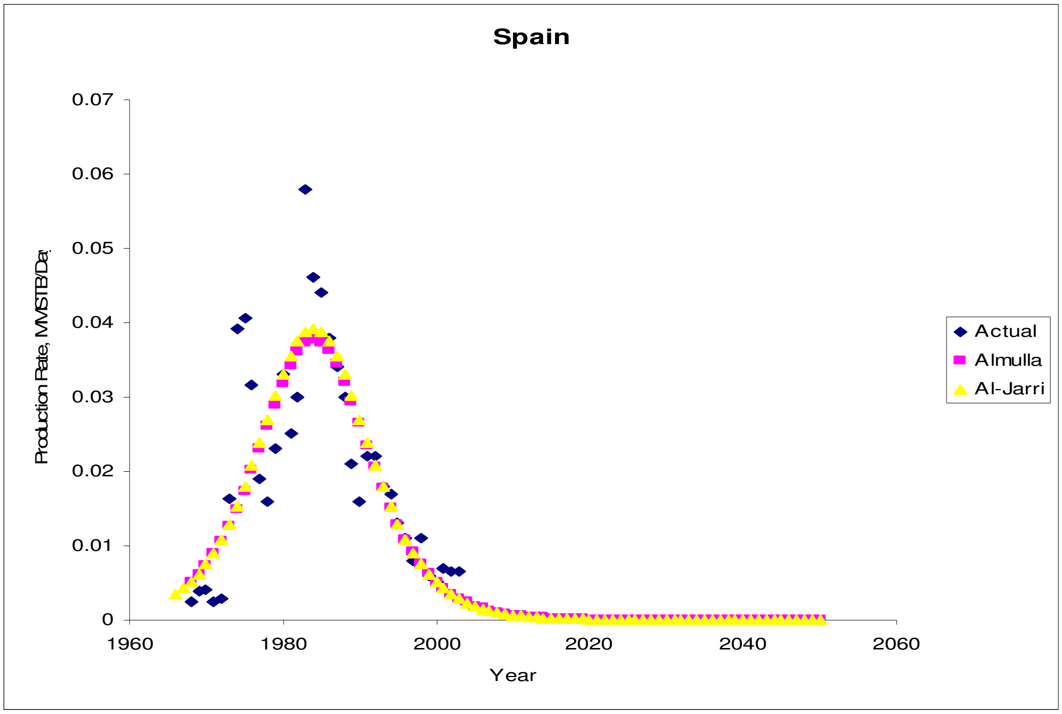

Fig A.55 Spain Production Curve

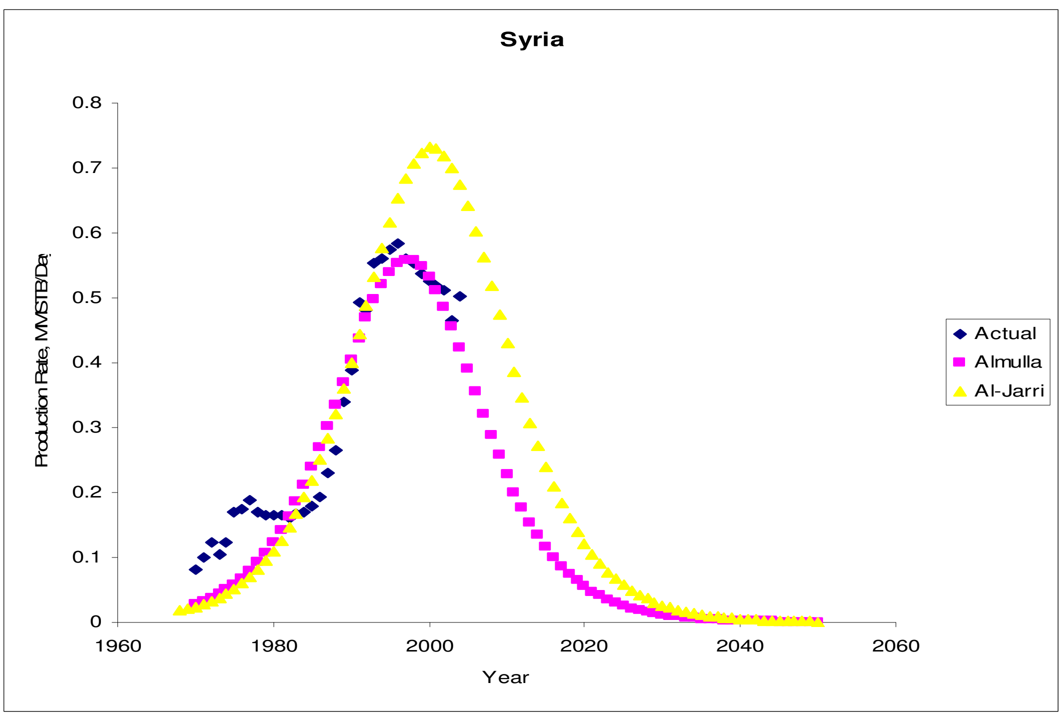

Fig A.56 Syria Production Curve

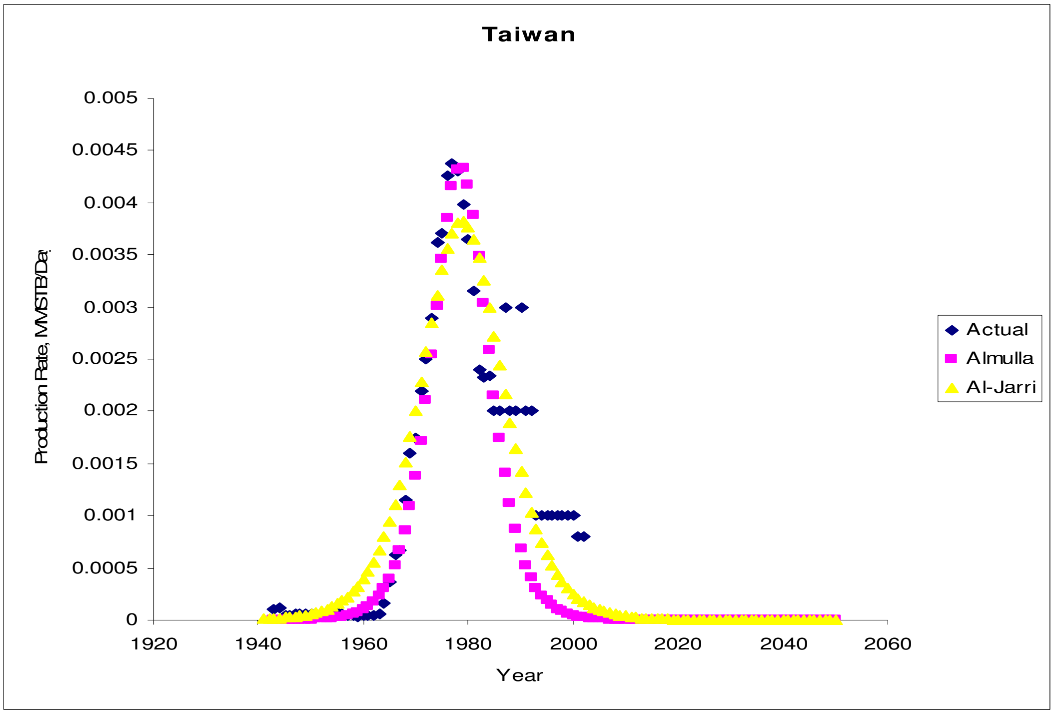

Fig A.57 Taiwan Production Curve

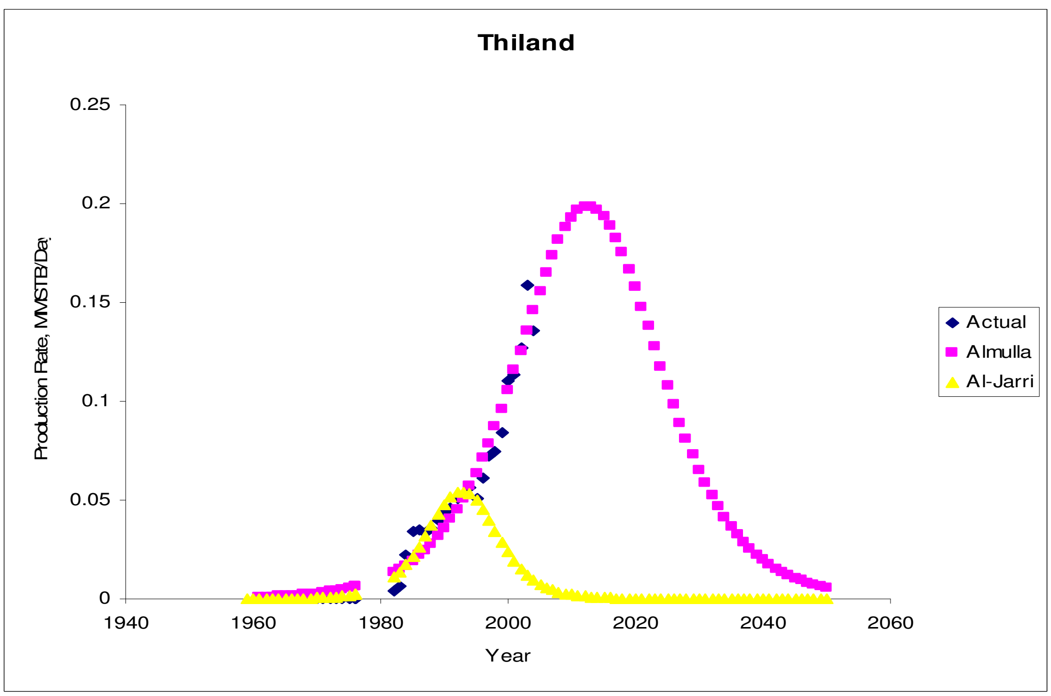

Fig A.58 Thiland Production Curve

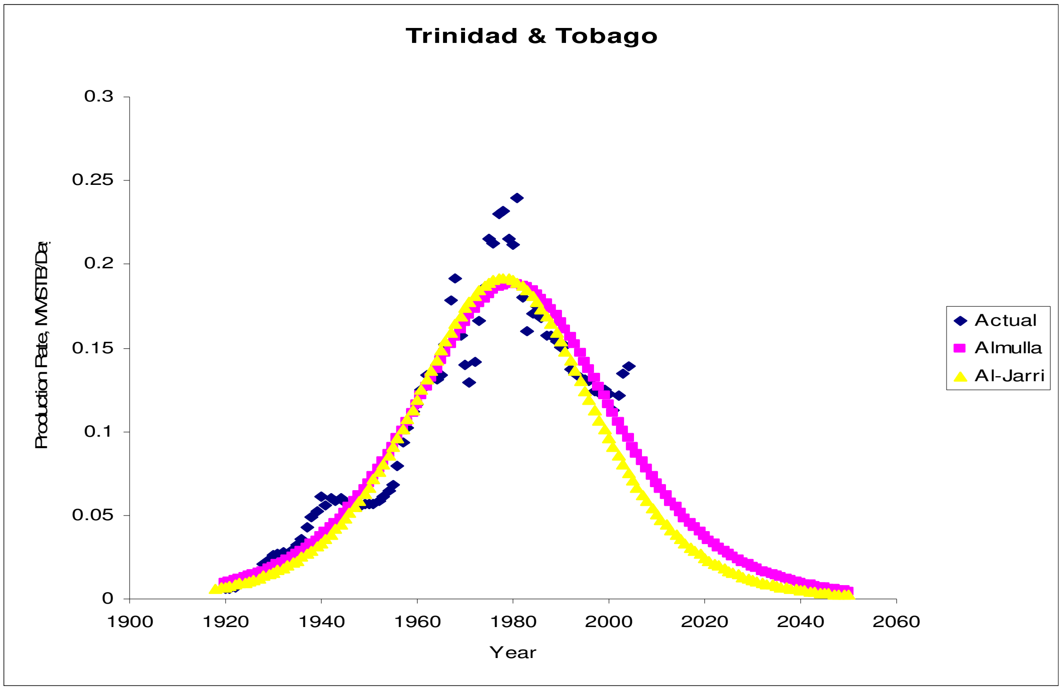

Fig A.59 Trinidad and Tobago Production Curve

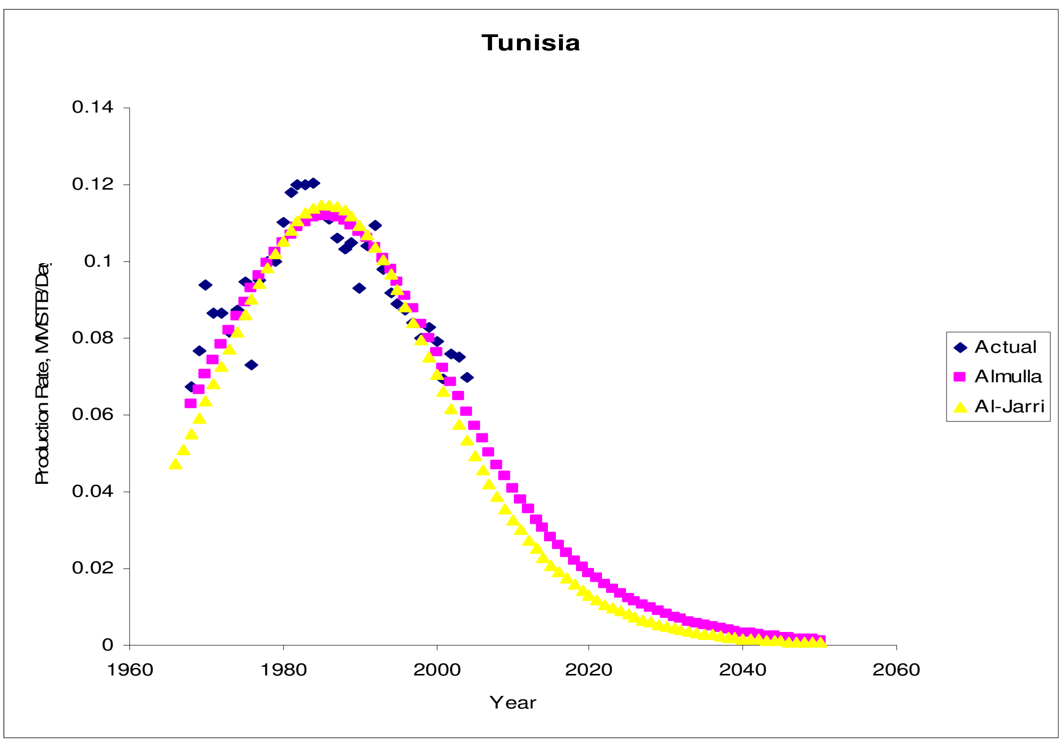

Fig A.60 Tunisia Production Curve

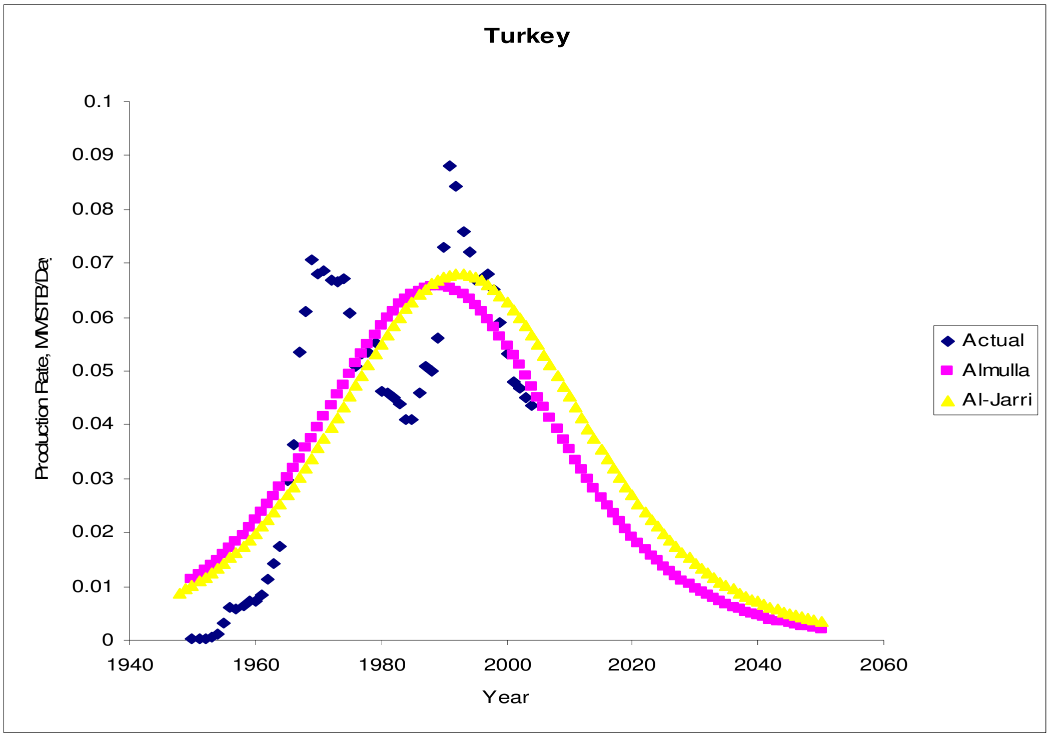

Fig A.61 Turkey Production Curve

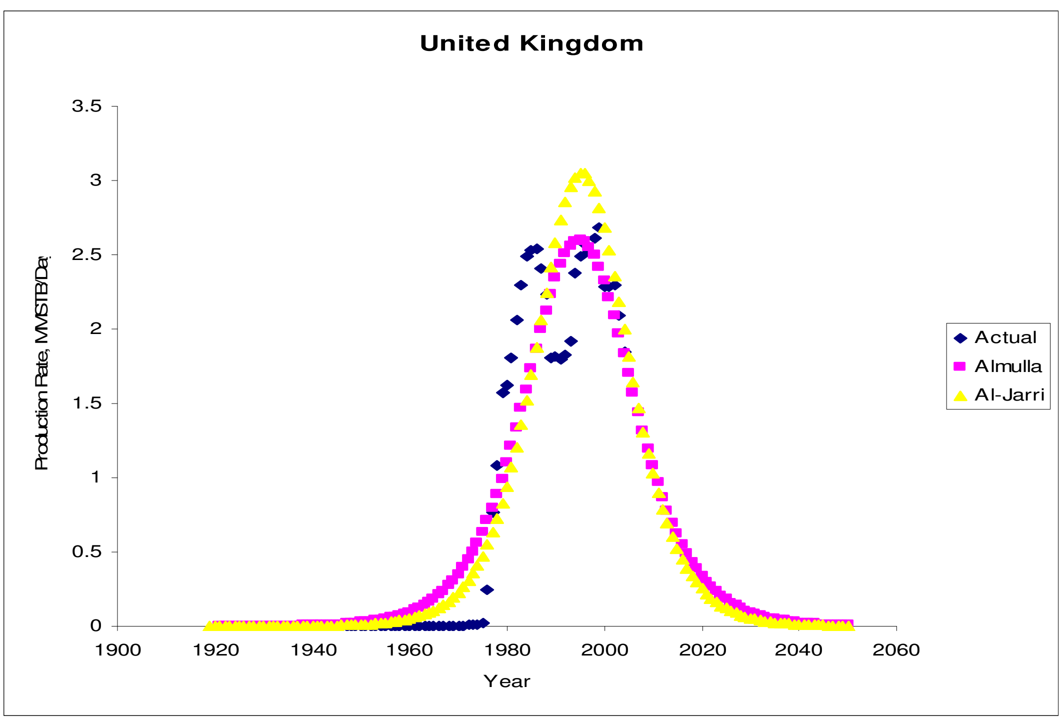

Fig A.62 The United Kingdom Production Curve

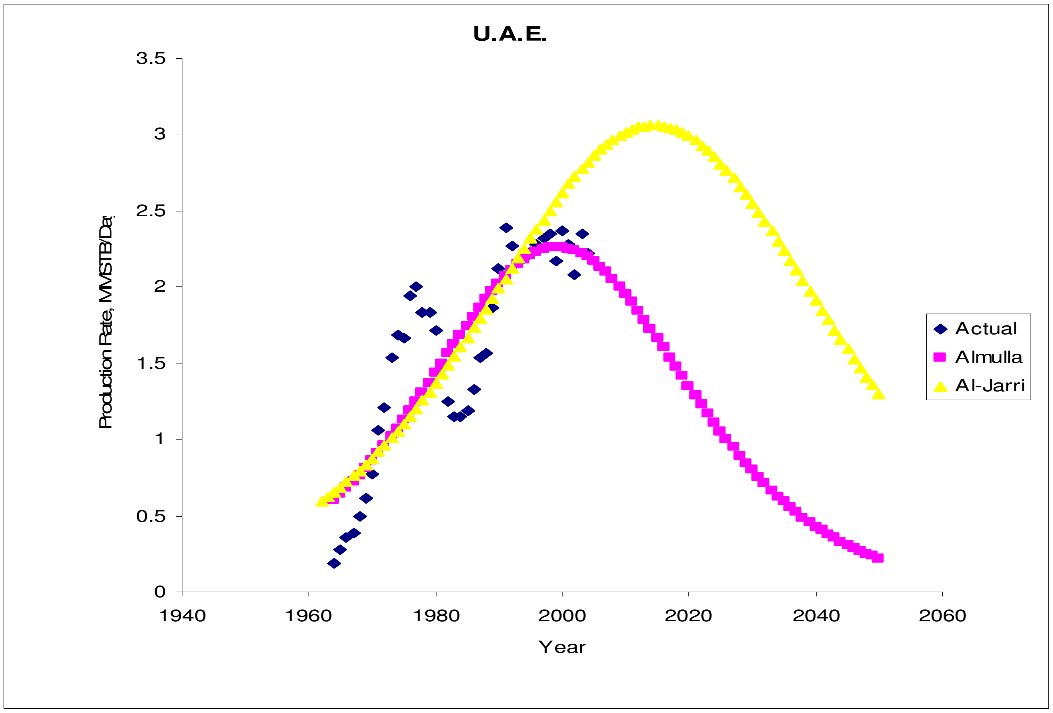

Fig A.63 The United Arab Emirates Production Curve

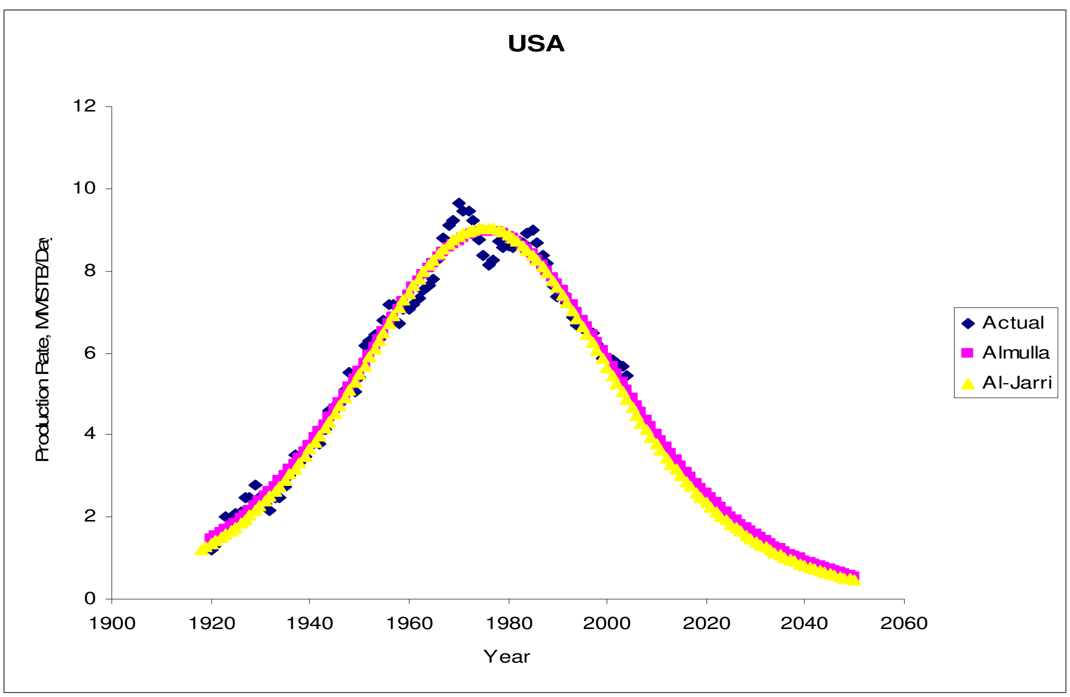

Fig A.64 The United States of America Production Curve

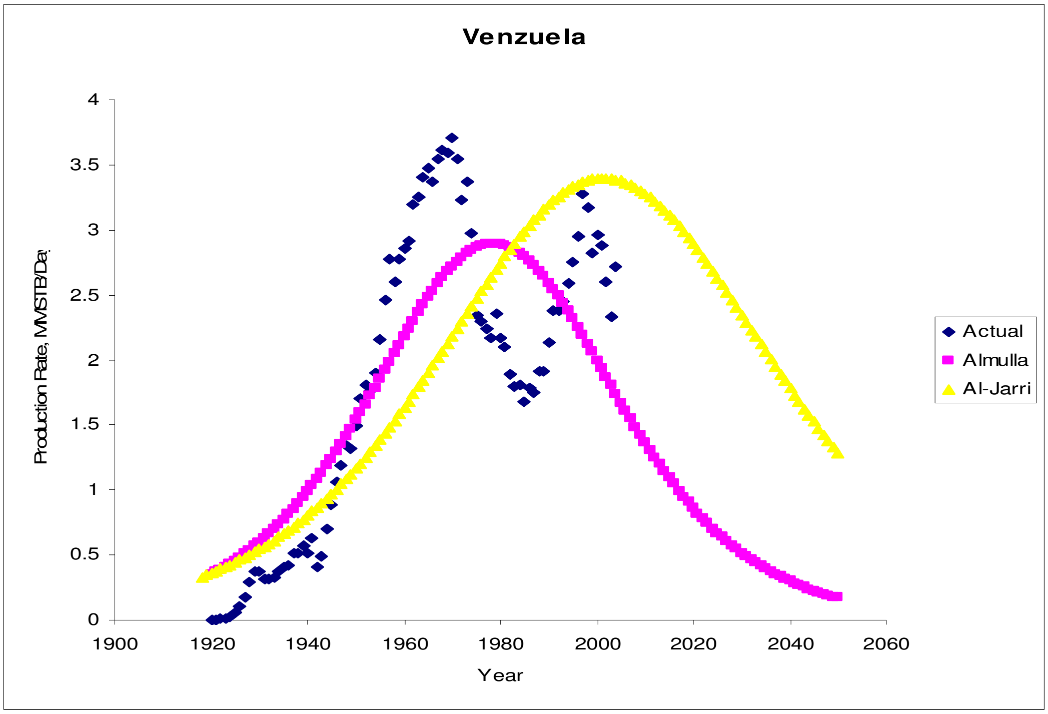

Fig A.65 Venezuela Production Curve

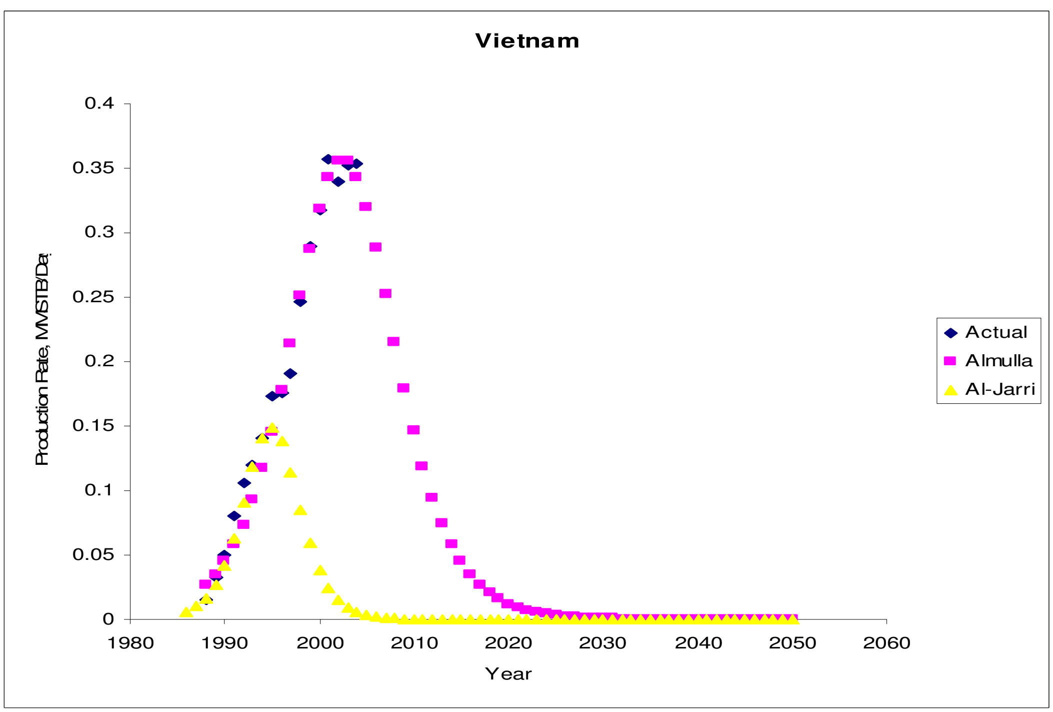

Fig A.66 Vietnam Production Curve

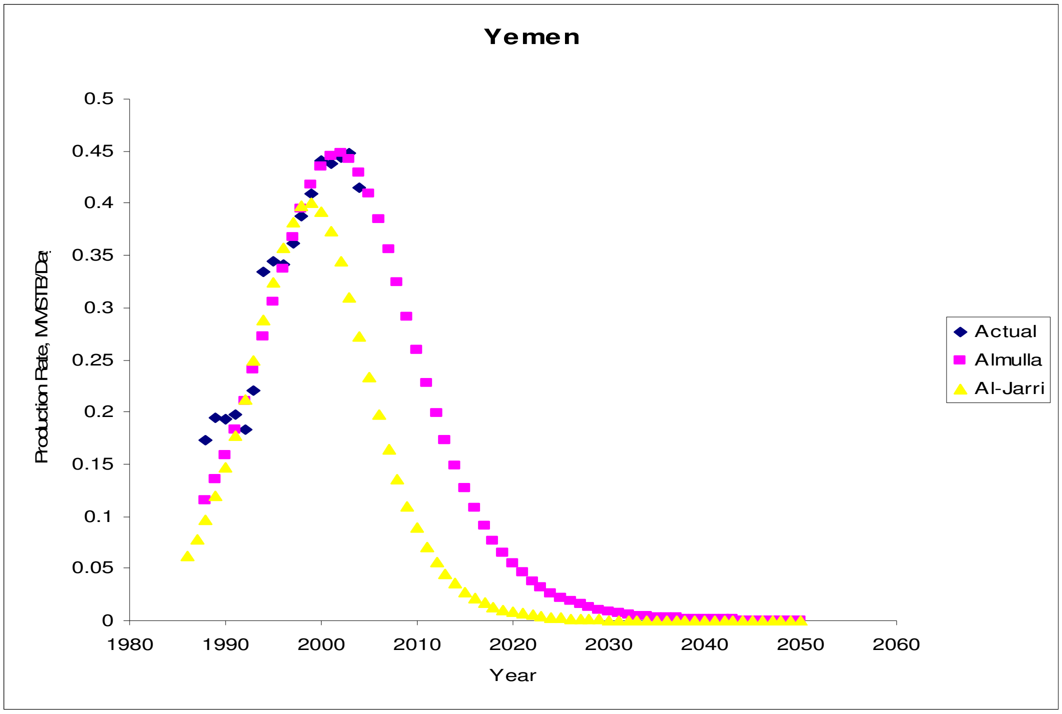

Fig A.67 Yemen Production Curve

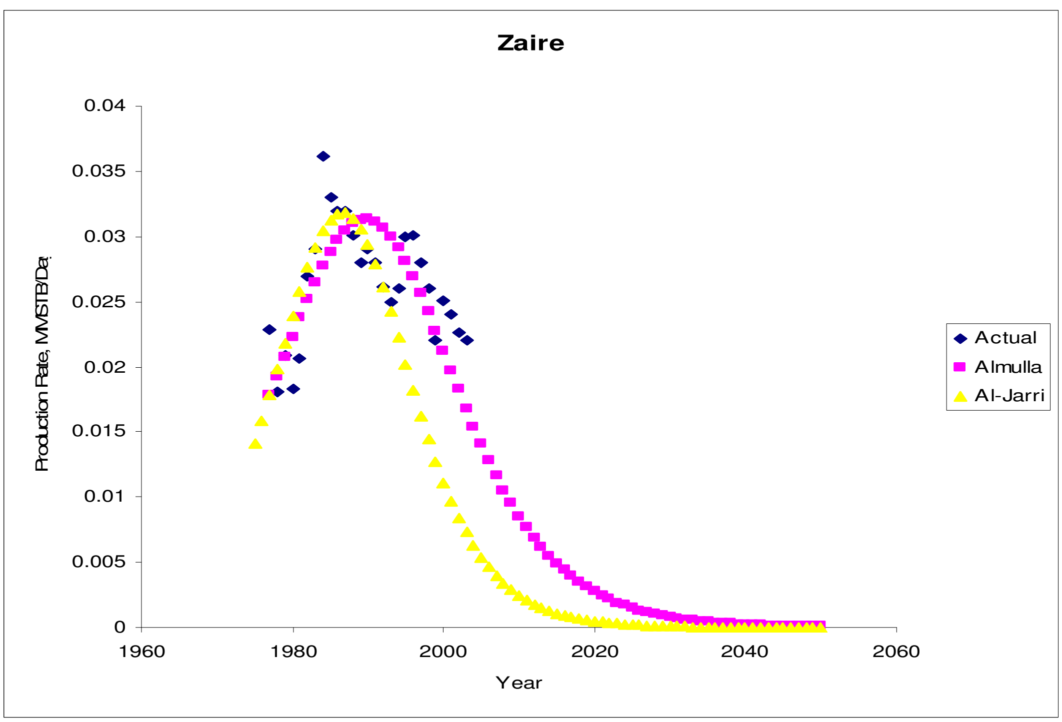

Fig A.68 Zaire Production Curve

APPENDIX B

WORLD PRODUCTION CURVES

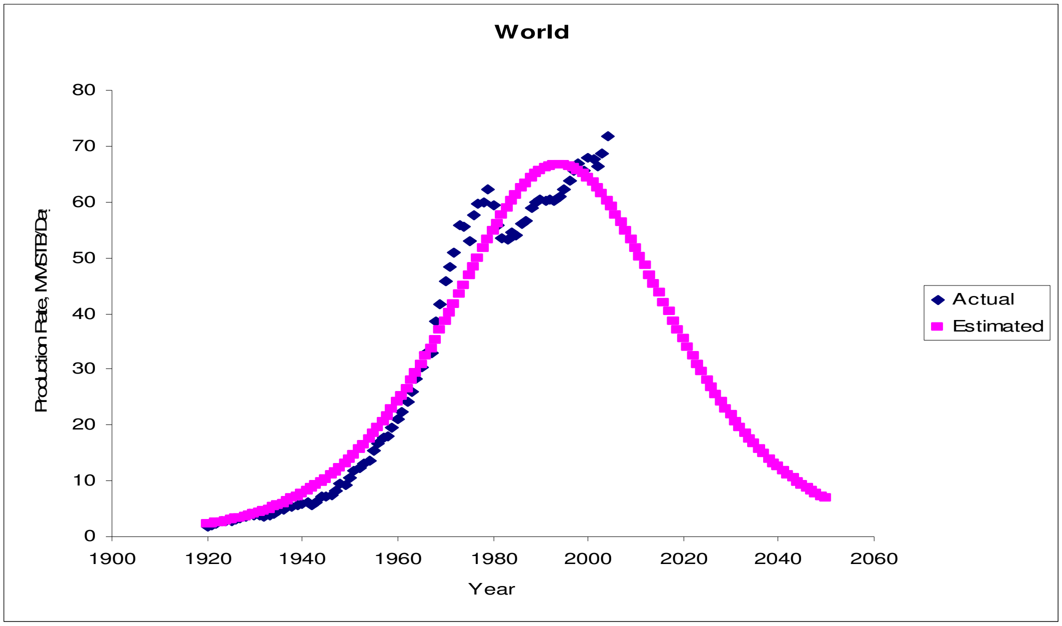

Fig B.1 World Production Curve

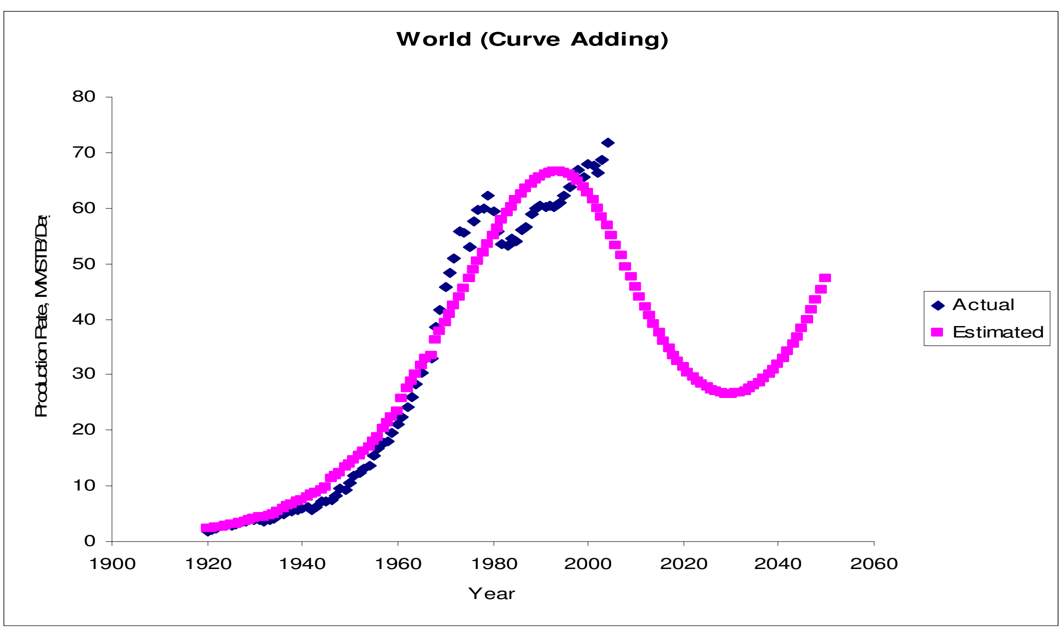

Fig B.2 World Production Curve (Curve Adding)

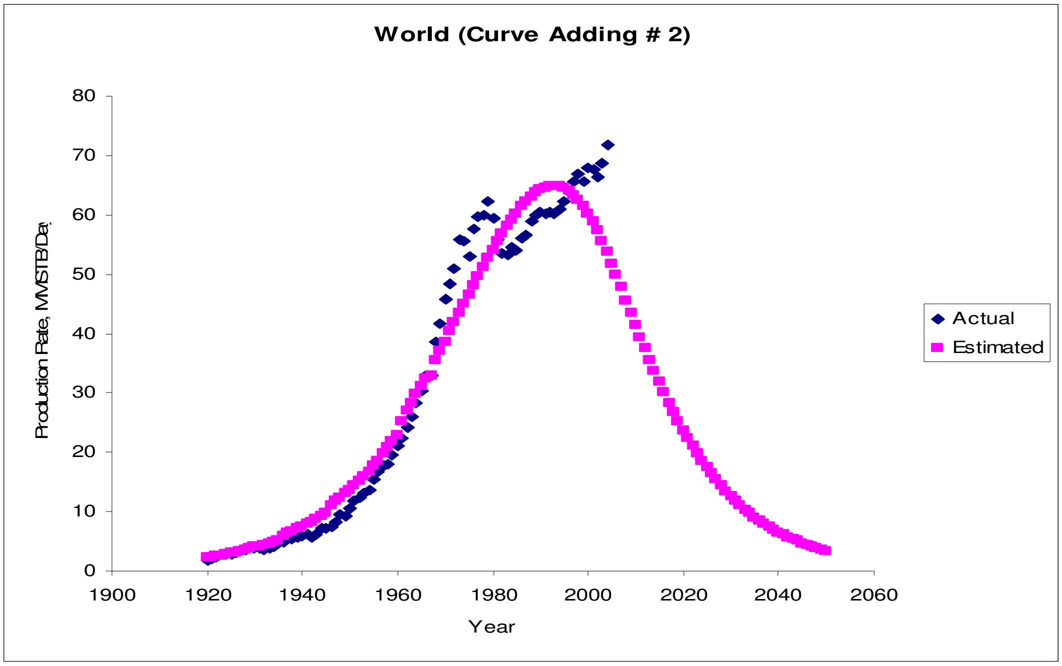

Fig B.3 World Production Curve (Curve Adding # 2)

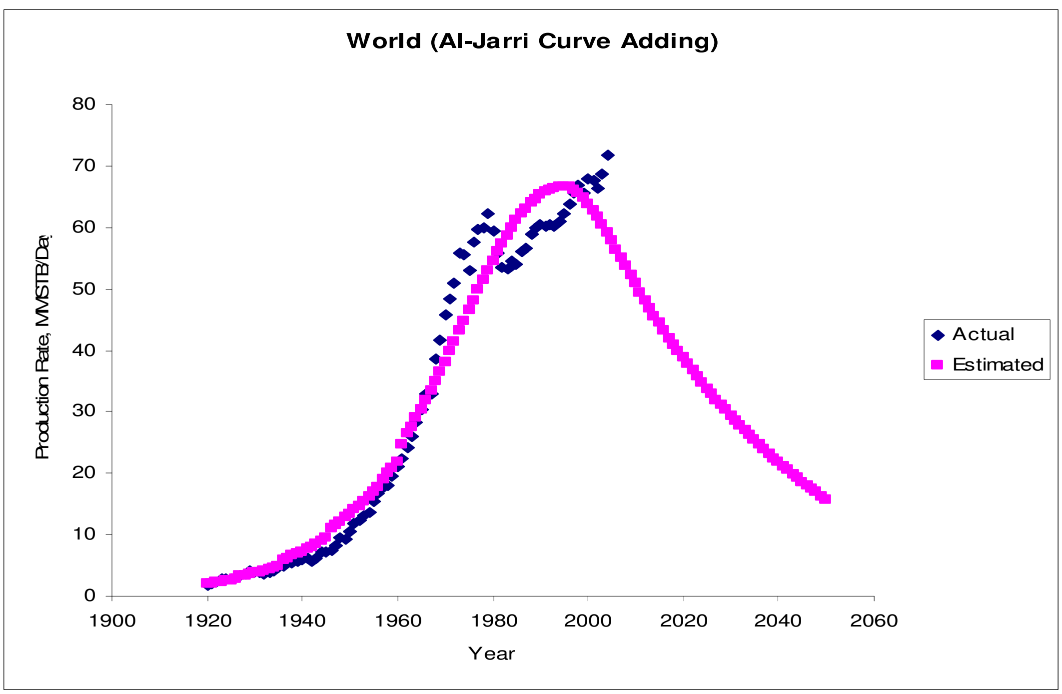

Fig B.4 World Production Curve (Al-Jarri Curve Adding)

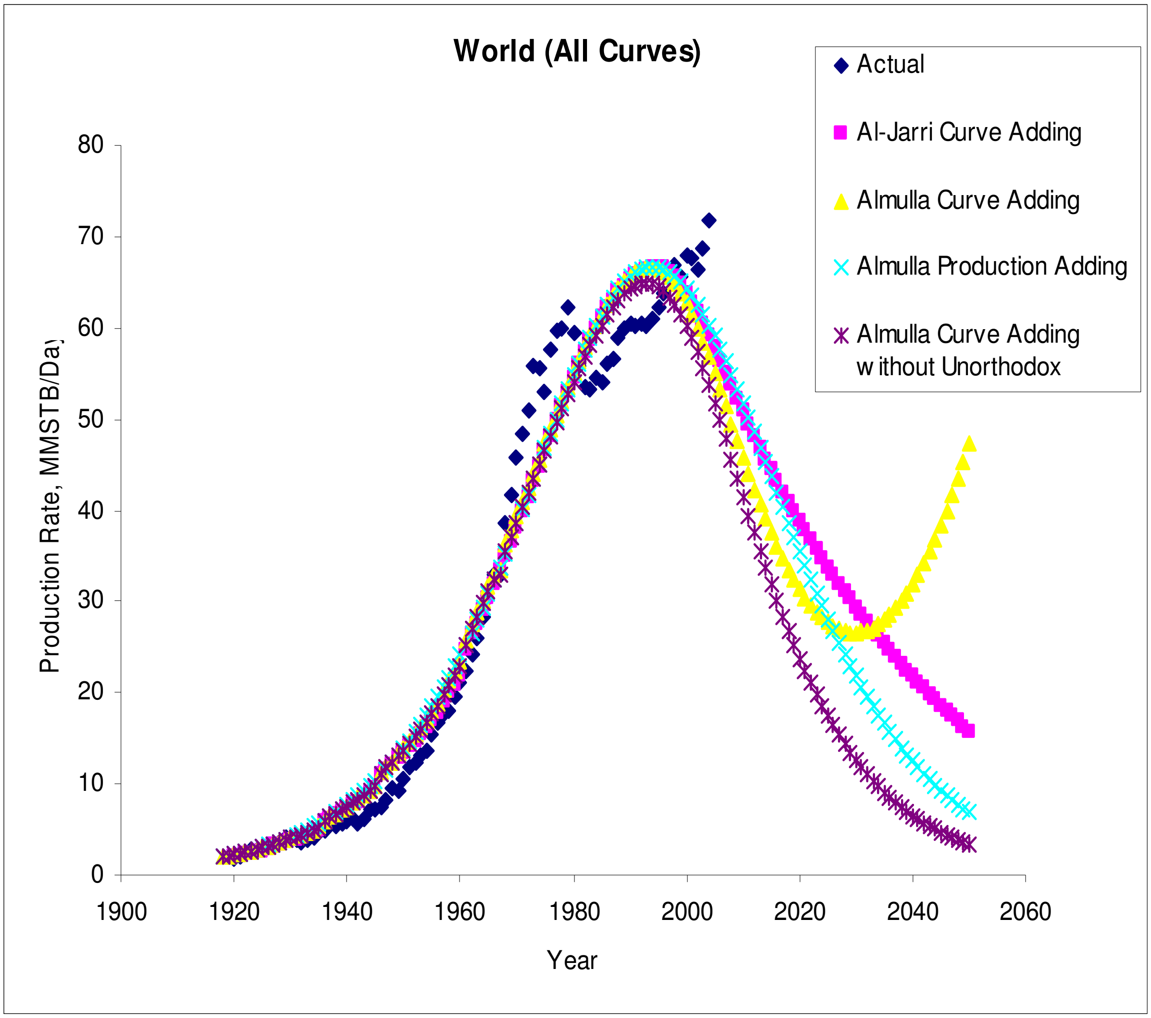

Fig B.5 All World Production Curves

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