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Viewpoint

China's oil reserve forecast and analysis based on peak oil models

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ABSTRACT

In order to forecast future oil production it is necessary to know the size of the reserves and use models. In this article, we use the typical Peak Oil models, the Hu–Chen–Zhang model usually called HCZ model and the Hubbert model, which have been used commonly for forecasting in China and the world, to forecast China's oil Ultimate Recovery (URR). The former appears to give more realistic results based on an URR for China of 15.64 billion tons. The study leads to some suggestions for new policies to meet the unfolding energy situation.

1. Introduction

Every country, including especially the so-called developing countries, has become addicted to oil. China's economy has expanded rapidly in recent years leading to soaring oil demand and growing imports. It was able to meet its needs from indigenous production up to 1993 (Fig. 1), but imports have grown rapidly since such that by 2006 as much as 47.5% (BP Statistical Review of World Energy, 2006) of its consumption had to be imported (Fig. 2). The gap between production and consumption is expected to continue to widen presenting a major challenge for the country's oil industry.

Since oil has to be found before it can be produced, it is useful to extrapolate the discovery trend to obtain an indication of the size of the endowment, termed Ultimate Recovery (URR). With this in place, it is possible to forecast this URR using the statistical Hu–Chen–Zhang (HCZ) and Hubbert models. This knowledge may be valuable to policy makers in designing future economic and political strategies.

2. China's discovery trend

China's oil history may be divided into five stages, as illustrated in Figs. 3 and 4: The first stage (1907–1949) saw the birth of the industry with discoveries in the Ordos Basin and in a few other places; The second stage (1950–1964) saw irregular growth, with important developments in the Songliao Basin; The third stage (1965–1975) was marked by the development of the Bohai Bay Basin; The fourth stage (1976–1990) was the most successful throughout the country; The fifth stage, which opened in 1991, saw the discovery of the Tarim and Junggar Basins, as well as further developments in the Ordos Basin.

3. Forecasting methodology

Two forecast methods are introduced following: one is HCZ model, the other is Hubbert model.

3.1. HCZ model

The HCZ model was established by three well-known Chinese geologists in 1995 (Hu Jianguo et al., 1995) after a thorough study of oilfield data. Eq. (1) provides the integral allowing the determination of total discovery with the following formulae (Eqs. (2) and (3)), as duly adapted under (Eqs. (4)–(7)).

Alternative assumptions of N_R yield a scatter plot, which can be studied with least-square and Microsoft Excel goal-seeking methods to obtain the highest correlation co-efficient, leading to the determination of the most likely solution. By calculation, the parameters in following equations can be all determined

$$n_D = aN_R\, e^{(-(a/b)e^{-bt}-bt)} \tag{1}$$

$$\int_0^t n_D\, dt = \int_0^t aN_R\, e^{(-(a/b)e^{-bt}-bt)}\, dt \tag{2}$$

$$N_D = N_R\, e^{-(a/b)e^{-bt}} \tag{3}$$

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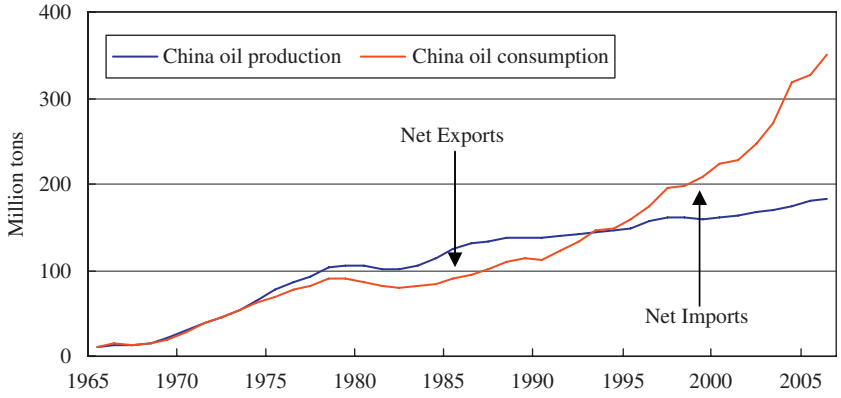

Fig. 1. China oil production and consumption history.

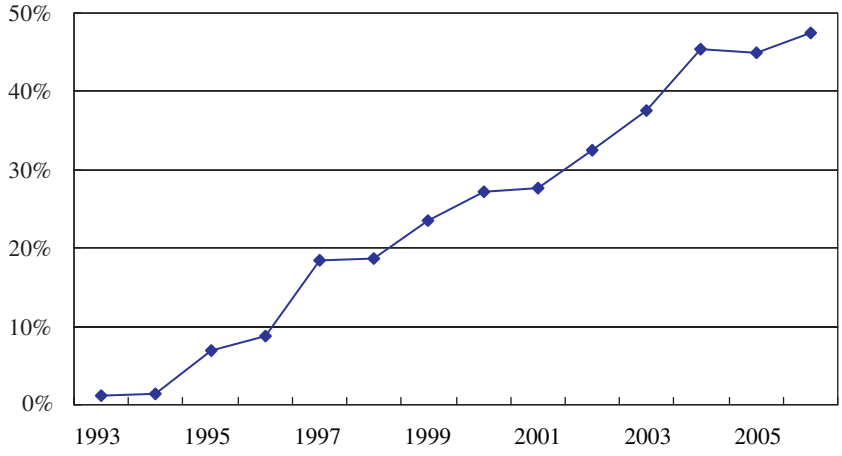

Fig. 2. China's oil-import dependence ratio.

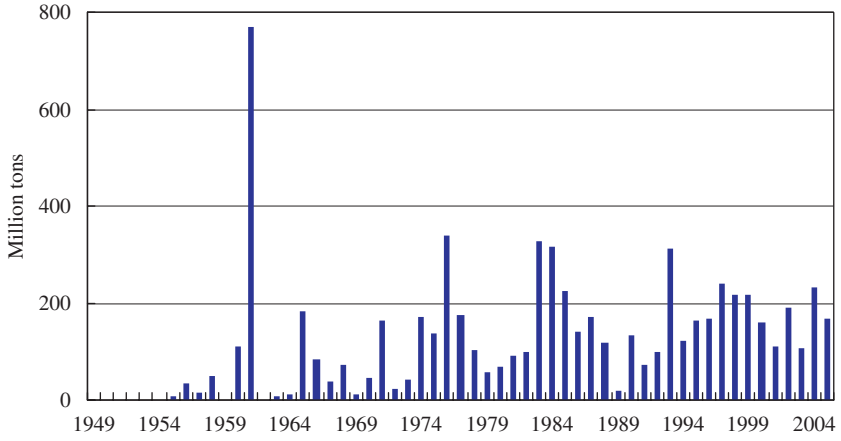

Fig. 3. China's annual discovered proved recovery increase trend.

$$\frac{N_D}{N_R} = e^{-(a/b)e^{-bt}} \tag{4}$$

$$\ln\left(\frac{N_D}{N_R}\right) = -\frac{a}{b}e^{-bt} \tag{5}$$

$$\ln\left[-\ln\left(\frac{N_D}{N_R}\right)\right] = \ln a - \ln b - bt \tag{6}$$

When $A = \ln a - \ln b$, $B = -b$, Eq. (6) can be written as

$$\ln\left[-\ln\left(\frac{N_D}{N_R}\right)\right] = A + Bt \tag{7}$$

3.2. Hubbert model

The well-known Hubbert model was developed in the 1960s by an American geologist of the same name. He found that

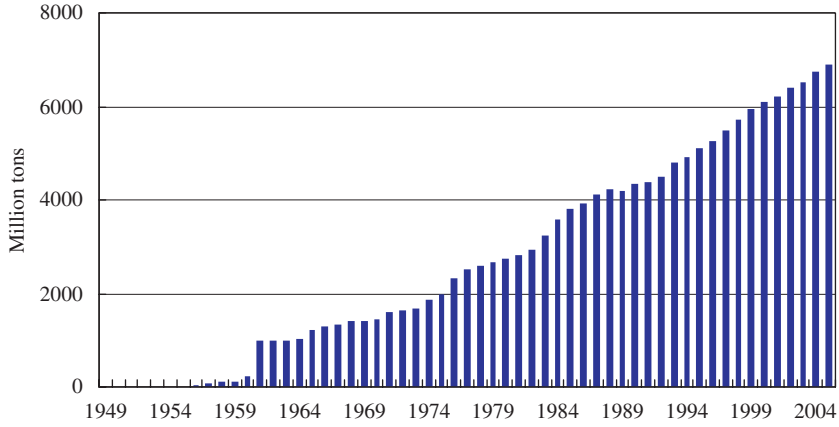

Fig. 4. China's cumulative proved recovery increase trend.

Table 1
N_R forecast

N_R (billion tons)	A	B	R
20	1.4890	−0.0252	0.9973
15.64	1.4847	−0.0295	0.9976

production over time followed a logistic bell-shaped curve, which could also be extrapolated to indicate URR. The equations are as follows:

$$n_D = \frac{abN_D\,e^{-bt}}{N_R} \tag{8}$$

$$N_D = \frac{N_R}{1 + a\,e^{-bt}} \tag{9}$$

Some changes must be taken first in order to determine the parameters in Hubbert model:

$$\ln\frac{N_R - N_D}{N_D} = \ln a - bt \tag{10}$$

When $A = \ln a$, $B = -b$, Eq. (10) is written as $\ln(N_R - N_D)/N_D = A + Bt$. Then the same method which is used like HCZ model, the suitable N_R, A, B, a, b, n_D for Hubbert model are all known.

In above equations, N_D is the cumulative proved recovery, million tons; N_R is the URR, million tons; n_D is the annual discovered proved recovery, million tons per year; t is the time, a; and a, b are the model factors.

4. N_R forecast for China

4.1. HCZ forecast

It is necessary to make two assumptions as follows: N_R is here taken to be 20 billion tons first and t is 1949, corresponding to the foundation of the People's Republic of China. After various manipulations, the highest correlation co-efficient is obtained when N_R is 15.64 billion tons, not the assumption 20 billion tons (Table 1). So the calculations suggest URR is 15.64 billion tons (Table 2).

4.2. Hubbert forecast

The procedures are similar but suggest a much lower URR of 9.31 billion tons (Table 3).

Table 2
Parameters a and b for HCZ model

N_R (billion tons)	A	B	a	b
15.64	1.4847	**−0.0295**	0.1301	0.0295

Table 3
Parameters a and b for Hubbert model

N_R (billion tons)	A	B	a	b
9.31	1.4114	0.0324	4.1020	**−0.0324**

5. Analysis

5.1. Analysis of results

The two models give very different results and it is difficult to know which to accept. But Zhai Guangming (2002) estimated an URR of 16 billion tons and a Government study in 2005 indicated 16.4 billion tons under the 95% confidence level, suggesting that the HCZ model is to be preferred. On the other hand, Colin Campbell (2005), founder and honorable chairman of Association for the Study of Peak Oil and Gas (ASPO), in his book *Oil Crisis* gives 55 billion barrels (7.5 billion tons) in 2004 subsequently revised to 65 billion barrels (8.87 billion tons), while Jean Laherrère, the well-known French analyst, gives 70 billion barrels (9.55 billion tons). Both are close to the results of the Hubbert model discussed herein, but far below the official forecast.

Recognizing the huge amount of study behind the official estimates, we conclude that Campbell and Laherrère are unduly pessimistic. Exploration in China is at a much less mature status than, for example, in the United States, so we conclude that there is plenty of scope for new discovery. Accordingly, on balance, we prefer the HCZ forecast of an URR of 15.64 billion tons.

5.2. Forecasting China's future discovery

The HCZ forecast of future discovery by year (n_D) and N_D are indicated in Figs. 5 and 6. It shows that China has passed its peak discovery and that annual discovery will decline in the years ahead at the average rate of 1.62% a year. It follows that production will also be constrained. Demand on the other hand is rising steeply.

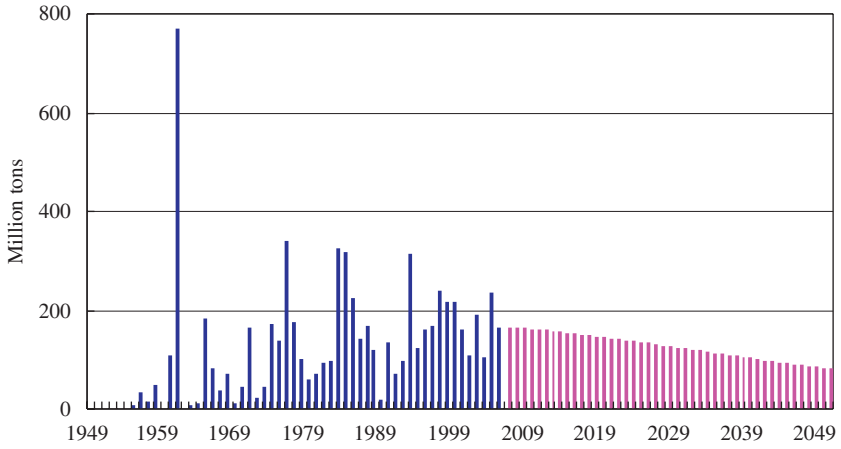

Fig. 5. n_D forecast.

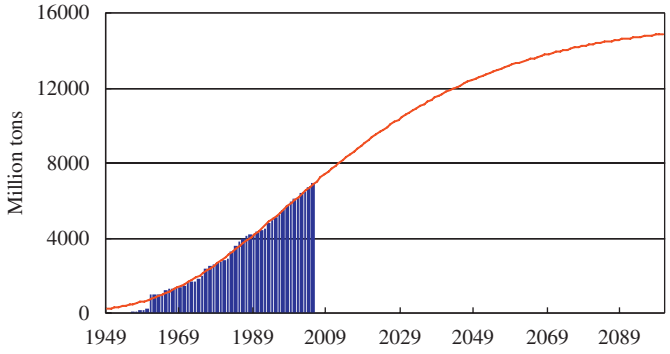

Fig. 6. N_D curve.

Fig. 6 depicts past discovery as a so-called S-curve. It is noteworthy that the Belgian mathematician Verhulst has used this approach in 1845 to predict US population to 1930, which was largely confirmed. He was followed in the 1920s by Pearl and Reed who refined the technique. Indeed, many phenomena in nature follow the S-curve model, being described in China as "birth-growth-maturity-death" process (Weng Wenbo, 1984). It is evident, as discussed above, that China's discovery record does follow an S-curve, eventually delivering an URR of 15.64 billion tons.

China's total discovery through 2005 amounted to 6.9 billion tons, as illustrated in Fig. 6. It means that, although peak has been passed, there is still plenty left to find and develop. Indeed, the forecast suggests that as much as 9 billion tons left, which will be produced and consumed gradually.

5.3. Forecasting China's future production

The rapid increase in demand has prompted many countries to undertake new research into production technology and plan accordingly. An increasingly long list of countries, including for example the United States and Japan, join China in facing the need to increase their imports as domestic production falls from natural depletion. So forecasts of oil production are significant for each country.

The HCZ production forecast equation can be written as follows (Eq. (11)), which in turn allows the production forecast to be derived (Eq. (12)) after calculation. As shown in Fig. 7, production is expected to peak in 2011 at 197.76 million tons, only 14 millions tons above the 2006 level. It is accordingly most important that the country should start to plan its response to declining indigenous production

$$Q = mN_R\, e^{[-(m/n)e^{-nt}-nt]} \tag{11}$$

where Q is the production, million tons; N_R is the URR, million tons; t is the time, a; m, n are the model factors

$$Q = 0.3183N_R\, e^{[-9.0943\, e^{-0.0350t}-0.0350t]} \tag{12}$$

5.4. Technological improvements

While forecasts must perforce be based on historical trends, it is important to also take into account the impact of advances in technology, knowledge and other factors. It remains possible therefore that more oil will be found at greater depth and in deep water than the record to-date would suggest. For example, the recent discoveries of the Nanpu Field in the Bohai Bay of China and the reported Tupi Field in deepwater off Brazil rely in part on new technology. We must not accordingly dismiss the role of technological progress, especially in regard to tapping so-called unconventional resources.

China itself may be able to increasingly turn to unconventional resources, such as oil-sand, coal bed methane and oil shale. In 2006, the world production of unconventional resources included 1.1 Mb/d from the tar sands of Canada, 600 kb/d from the Extra Heavy oils of Venezuela, and 260 kb/d of bio-ethanol (Annual Energy Outlook, 2007), and we may expect further technological breakthroughs to increase these levels in the future.

5.5. International co-operation

China's oil endowment is relatively small in international terms. The OPEC countries, such as Saudi Arabia and Iran, are the main powers in the oil market (Fig. 8), and China needs will be increasingly met by co-operation with these countries. It has already secured some important stakes in Africa, but new relationships have to be forged to secure more, not forgetting the unconventional production of Canada and Venezuela.

6. Conclusions

This article has used the HCZ and Hubbert statistical models to forecast China's future oil production. The results differed widely,

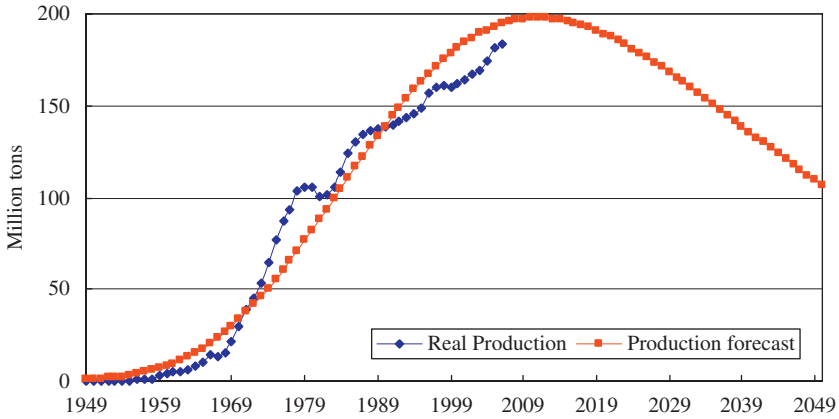

Fig. 7. China oil production forecast.

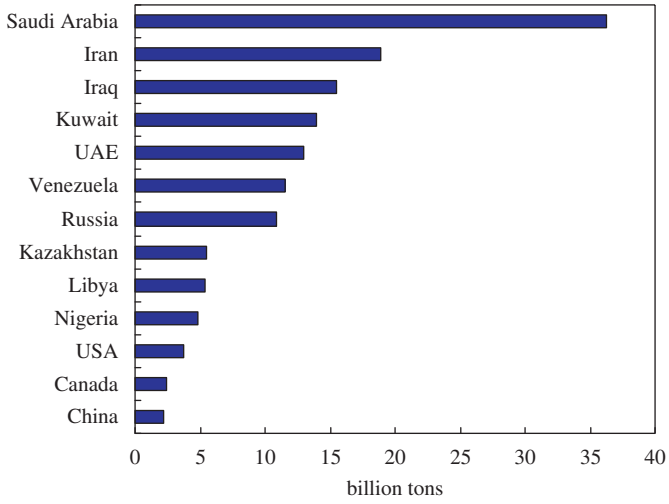

Fig. 8. Oil proved reserves for main countries.

but the preference is given to the HCZ model, giving an URR of 15.64 billion tons that better matches the official estimates. The issue of Peak Oil, which is now attracting interest around the world, has to be based on the underlying reserve data. The details naturally evolve over time, but the position is becoming clear for both China and the World as a whole. The implications are considerable and need to be addressed by policy makers. In the case of China, special attention needs to be focused on technological progress and cementing special relationships with more richly endowed exporting countries.

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