



A model based on stochastic dynamic programming for determining China's optimal strategic petroleum reserve policy

Xiao-Bing Zhang, Ying Fan*, Yi-Ming Wei

Center for Energy & Environmental Policy research, Institute of Policy and Management, Chinese Academy of Sciences, Beijing 100080, China

ARTICLE INFO

Article history:

Received 26 August 2008

Accepted 21 May 2009

Available online 17 June 2009

Keywords:

Stochastic dynamic programming

Strategic petroleum reserve

Optimization

ABSTRACT

China's Strategic Petroleum Reserve (SPR) is currently being prepared. But how large the optimal stockpile size for China should be, what the best acquisition strategies are, how to release the reserve if a disruption occurs, and other related issues still need to be studied in detail. In this paper, we develop a stochastic dynamic programming model based on a total potential cost function of establishing SPRs to evaluate the optimal SPR policy for China. Using this model, empirical results are presented for the optimal size of China's SPR and the best acquisition and drawdown strategies for a few specific cases. The results show that with comprehensive consideration, the optimal SPR size for China is around 320 million barrels. This size is equivalent to about 90 days of net oil import amount in 2006 and should be reached in the year 2017, three years earlier than the national goal, which implies that the need for China to fill the SPR is probably more pressing; the best stockpile release action in a disruption is related to the disruption levels and expected continuation probabilities. The information provided by the results will be useful for decision makers.

© 2009 Elsevier Ltd. All rights reserved.

1. Introduction

China's demand for oil has skyrocketed with the rapid development of its economy. In 2002, China's oil consumption surpassed that of Japan, and became the second largest oil consuming country in the world, just behind the US. Simultaneously, its dependency on foreign oil is rapidly increasing. In 1993, China became a net importer of oil, and in 2007 its dependency on foreign oil increased to 46.05%. Furthermore, the oil that China imports comes from highly centralized sources, with nearly 40% coming from the Middle East. This high dependency on oil from overseas and centralization of oil imports poses risks for China's oil supply. If oil supply is interrupted, it will be detrimental to China's economic security and social stability. It is thus critical to take measures to ensure the security of China's oil supply.

Strategic Petroleum Reserve (SPR) is a basic strategy for mitigating the effects of a disruption to the oil supply and it has proved to be rather effective in many developed countries. The National People's Congress of China named the development of a SPR a primary goal in 2001 and the Chinese government has been preparing for the establishment of its SPR since March 2004.

According to the remarks made by Chen Deming, the former vice minister of the National Development and Reform Commission (NDRC) in November 2007, the planned goal is to build a SPR

equivalent to 30 days of net oil import by 2010, and to store sufficient amount to cover about 90 days of net imported oil by 2020 (China News Service, November 23, 2007), which is about 320 million barrels according to China's oil import level in 2006 (State Statistical Bureau, 2007). The first SPR base of China, located in Zhenhai, was finished in August 2006. This base is one of the four stockpile bases included in China's first SPR project and has a capacity of 5.2 million cubic meters.

That China should establish a SPR is indisputable, but some questions remain regarding the cost of stockpiling plans, such as how large the SPR should be, whether the government's goal is the optimal, when the best time for China to fill the SPR capacity is, and what the optimal acquisition and drawdown strategies are. Hence, it is vital to devise an optimal SPR policy for China, including the optimal size and best buildup and drawdown rates, to minimize the cost or to maximize the benefit of establishing its SPR.

Many countries, including the US, suffered greatly from the oil crisis in the 1970s, triggering a wave of studies concerning SPR and energy security. Balas (1981) studied a short-term interaction between oil importing nations and a politically motivated cartel that takes advantage of disruptions to inflict economic losses on importing nations. In this study, Balas investigated the 'deterrence effect' of a SPR and found that a stockpile not only reduces the economic losses from a disruption, but also lessens the likelihood of a disruption. Teisberg (1981) developed a dynamic programming model for the SPR of the US, which could be used to determine optimal acquisition and drawdown strategies for two different states of the world oil market: normal and disrupted.

* Corresponding author. Tel.: +86 10 62542627; fax: +86 10 62650861.
E-mail addresses: yfan@casipm.ac.cn, ying_fan@263.net (Y. Fan).

Samouilidis and Berahas (1982) established a decision tree model to evaluate different scenarios for a SPR based on a cost function that includes procurement, maintenance, and shortage costs. Chao and Mane (1983) developed a multi-period dynamic programming model for obtaining the optimal stockpiling and petroleum usage rates based on their analysis of the oil supply policies of the US. Hogan (1983) extended Teisberg's model of US stockpiling to a Stackelberg model to examine the interactions between two consuming countries, where one follows the other's lead. Samouilidis and Magirou (1985) presented a concise analysis for the optimal selection of the size of a SPR for a small country based on the work of Samouilidis and Berahas (1982). Oren and Wan (1986) presented a non-linear programming model for conducting a steady-state analysis on the optimal size, fill-up, and drawdown rates for a SPR under variety of different supply and demand conditions. Murphy et al. (1987) presented a Nash dynamic game model of interactions between oil inventory and tariff policies for oil-importing countries to analyze their SPR policies. Zweifel and Bonomo (1995) established a model that considers multiple risks to energy supplies to illustrate that one-dimensional rules such as an "oil reserve for 90 days" turn out not only to be suboptimal but also suggest adjustments that make them even more suboptimal. All these above-mentioned studies provide valuable information for China's SPR research.

The majority of studies concerning China's SPR only contain qualitative analysis. However, more quantitative studies have appeared in recent years due to greater concerns about the oil supply security of China. Wei et al. (2008) conducted an empirical analysis of the optimal SPR size for China based on a decision tree model. Wu et al. (2008) presented an uncertain programming model for analyzing acquisition strategies for China's SPR. However, these studies considered the optimal size or acquisition strategies alone, and did not present a comprehensive SPR policy.

Referring to the above-mentioned models, we developed a stochastic dynamic programming model for China, which we termed Strategic Oil Stockpiling for China (SOSC) to determine the optimal SPR size and strategies that include both the acquisition and release strategies for several different situations for the time horizon from 2009 to 2039. We believe that the establishment of China's SPR should be principally based on the normal domestic supply and normal import. This means that in order to avoid a potential rapid increase of oil prices due to China's oil stockpiling action, China should not increase the amount of oil it imports to stock its SPR. Our model is based on this concept. In the following sections we develop our SOSC model, which is based on stochastic dynamic programming. In Section 2, we develop our SOSC model step by step. The implementation of this model is described in Section 3. Then, Section 4 presents illustrative results obtained by implementing our model. It also discusses the implications of the results. Finally, in the last section we give some conclusions and make suggestions for policy-makers based on the results of our model.

2. The SOSC model

Our SOSC model is based on the US SPR models presented by Teisberg (1981), Oren and Wan (1986), and Murphy et al. (1987). It is a multi-period stochastic dynamic programming model, which can be used to determine the best buildup or drawdown rate for each time period. Dynamic programming (DP) is a methodology for optimizing decision processes that can be divided into several stages (Denardo, 1982).

The following notations are used in this paper:

| | |
|---------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| t | time period ($t = 0$ stands for the year 2008, $t = 1$ is 2009, etc.) ¹ ; |
| i | index for the state of the oil market ((1) normal; (2) slight disruption; (3) serious disruption); |
| $s(t)$ | stockpile acquisition in period t ; if $s(t) < 0$, it indicates release; |
| $S(t)$ | SPR size at the beginning of time period t ; |
| $P(s(t), i, t)$ | equilibrium oil price of China in period t determined by the market-clearing condition. It depends on the state of the market, stock changes, and the time period. As stated above, our SPR strategy is not based on importing extra oil, and so the equilibrium oil price of China is determined by the total demand ² and supply that includes regular imports; |
| $P_b(t)$ | base oil price without SPR acquisition or drawdown in the normal market state in period t ; |
| $D(P(t), t)$ | China's oil demand without taking account of oil stockpile acquisition (or release); |
| $Q(i, t)$ | China's oil supply including normal oil import; |
| M_1 | loss of Chinese consumers' surplus due to an increase in the oil price, which can be considered as the first component of potential macroeconomic loss; |
| M_2 | the second component of China's potential macroeconomic loss, which arises because modern industrial economies do not make perfectly smooth adjustments to rapid changes in input prices (Mork, 1982). Here, we assumed that it is a linear function of the GDP in that period; |
| SC | purchase cost of stockpiles in each period; |
| HC | holding cost of an existing SPR; |
| GDP_0 | China's GDP in period 0; |
| $GDP(t) = GDP_0 * g_g(t)$ | GDP of China in time period t ; |
| ρ | ratio of potential loss to GDP if the oil price rises by 50%; |
| λ_1 | proportion of oil supply disrupted in state i ; |
| q | initial oil supply of China in period 0; |
| d | constant term in the oil demand function; |
| k | coefficient of the price term in the demand function; |
| ε | elasticity of oil demand with respect to oil price; |
| $g_d(t), g_q(t), g_g(t)$ | growth factors of China's oil demand, supply, and GDP, respectively. Different researchers may have different growth assumptions. Some of them, like Oren and Wan (1986), just assume the static case (without a growth factor) to simplify the question. Considering the substitution effect for different energy resources and the nature of economic growth, the growth rates of China's oil demand, supply and GDP should decline slowly, which is also the experience of developed countries and the projections of many institutes. In this paper, we set the growth factors are in the following forms for their well fitting of the above-mentioned properties of sustained growth and declining growth rates: |

$$g_d(t) = \prod_{tt=1}^t (1 + g_1/(tt)^a);$$

$$g_q(t) = \prod_{tt=1}^t (1 + g_2/(tt)^b);$$

$$g_g(t) = \prod_{tt=1}^t (1 + g_3/(tt)^c)$$

where $g_1 = 0.04$, $g_2 = 0.02$, $g_3 = 0.08$ are the initial growth rates and $a = 0.21$, $b = 0.04$, $c = 0.08$ are the powers of period index tt .

¹ Because the time unit is one year, the oil price in this paper is the average annual oil price.

² Total demand equals regular demand plus (minus) SPR acquisition (release).

متن کامل مقاله

دریافت فوری ←

ISIArticles

مرجع مقالات تخصصی ایران

- ✓ امکان دانلود نسخه تمام متن مقالات انگلیسی
- ✓ امکان دانلود نسخه ترجمه شده مقالات
- ✓ پذیرش سفارش ترجمه تخصصی
- ✓ امکان جستجو در آرشیو جامعی از صدها موضوع و هزاران مقاله
- ✓ امکان دانلود رایگان ۲ صفحه اول هر مقاله
- ✓ امکان پرداخت اینترنتی با کلیه کارت های عضو شتاب
- ✓ دانلود فوری مقاله پس از پرداخت آنلاین
- ✓ پشتیبانی کامل خرید با بهره مندی از سیستم هوشمند رهگیری سفارشات