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An empirical analysis of the dynamic programming model of stockpile acquisition strategies for China's strategic petroleum reserve

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Abstract

The world's future oil price is affected by many factors. The challenge, therefore, is how to select optimal stockpile acquisition strategies to minimize the cost of maintaining a reserve. This paper provides a new method for analyzing this problem using an uncertain dynamic programming model to analyze stockpile acquisition strategies for strategic petroleum reserve. Using this model, we quantify the impact of uncertain world oil price on optimal stockpile acquisition strategies of China's strategic petroleum reserve for the period 2007–2010 and 2011–2020. Our results show that the future stockpile acquisition is related to oil prices and their probability and, if not considering the occurrence of oil supply shortage, China should at least purchase 25 million barrels when world oil price is at an optimal level. The optimal price of stockpile acquisition of every year has a stronger relationship with the probability of high price; and the optimal expected price and size of stockpile acquisition is different in each year.

Keywords: Strategic petroleum reserve; Uncertain dynamic programming model; Stockpile acquisition strategies

1. Introduction

Energy is one of the most significant factors driving China's economic growth. With continuous development of China's economy, there is a need for increasing quantities of oil to meet increasing demand. However, international oil price has fluctuated at the higher levels since 2004. China's oil import dependence has increased rapidly since 1996 when it became a net oil importer. China's crude oil import is 145 million tons and import dependence is 43.9 per cent (General Administration of Customs of China, 2007). Most of the oil import came from the unstable Middle East; 80 per cent of the imported oil has to get across the perilous Malacca Strait.

Consequently, security of China's oil supply becomes one of the most serious challenges for economic development. In reality, strategic petroleum reserve (SPR) is one of the most effective measures to ensure national oil supply security. It was anticipated that the creation of a significant operational reserve of crude oil would discourage the use of oil as a 'weapon'. In the event of any interruption, introduction into the market of oil from the reserve was expected to help calm markets, mitigate sharp price spikes, and reduce the economic dislocation. After the OPEC oil embargo, the US established SPR in 1975. The SPR was originally intended to hold at least 750 million barrels of crude oil as an insurance policy against future supply cutoffs. In United States, the US government can fill the SPR by either purchasing oil on the open market, or by collecting royalties from oil producers in the form of 'in kind' payments (i.e., oil). Most of the oil added to the reserve in the late 1970s and early 1980s was purchased on the open market when prices were relatively high. This is the main reason why the average price of oil in the SPR is greater than $27 per barrel. Recently, the SPR has been filled by collecting royalty oil from companies who operate leases on the federally owned Outer Continental Shelf. By law, these companies must pay royalties on these leases in

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the range of 12.5–16.7 per cent of the oil produced. This percentage can be paid in oil dollars equivalent or by actually delivering the oil 'in kind'.

In order to enhance oil supply security, China's government established its own SPR in 2004. The Zhenhai base was finished in August, 2006. Subsequently, the most important question for China's decision-makers is how to fill the reserve.

The establishment of SPR requires spending large amount of capital, including the cost to buy oil and the cost of maintenance. Hence, the challenge is to determine how much oil to purchase to fill the reserve in an uncertain world oil market. Since the 1980s, several researchers have established models to quantify the optimal SPR, stockpile acquisition, and release strategies. Wei et al. (2008) quantifies China's optimal SPR for the period 2005–2020, using a decision tree model based on a cost function. Murphy et al. (1989) presented and analyzed a Nash dynamic game model for investigating public and private sector oil inventory policies in unstable world oil markets. Samouilidis and Berahas (1982) established a cost function which includes the inventory procurement and maintenance cost and the shortage cost inflicted by a petroleum shortfall, and evaluated each scenario based on the cost function and decision tree model. Samouilidis and Magirou (1985) presented a simple analysis for the optimal selection of the level of petroleum reserve for a small country, based on the study of Samouilidis and Berahas (1982). Zweifel and Bonomo (1995) developed an optimal reserve model that takes into account multiple risks for oil and gas, and identified that one-dimensional rules such as 'oil reserve for 90 days', result in not only suboptimally, but also require adjustments that exacerbate suboptimality. Teisberg (1981) developed a stochastic dynamic programming model that allows explicit consideration of such uncertainty. The model has been used to determine the size of the US SPR and the optimal fill-up and draw-down rate contingent upon the supply conditions, time, and available inventory. Hogan (1983) extends the Teisberg's model of US stockpiling to a Stackelberg model, examining the interactions between two consuming countries, where one follows the other's lead. Oren and Wan (1986) explored a simple model to determine the optimal size, stockpile acquisition, and draw-down rates for an SPR under a variety of supply and demand conditions. Murphy et al. (1987) present a Nash dynamic game model of interactions among oil inventory and tariff policies for oil importing countries. They presented empirical results of the size of the stockpiles as a function of disruption probabilities, tariff policies, and cooperation versus non-cooperation between nations. Chao and Manne (1983) developed a multi-period dynamic programming model for determining optimal stockpiles and petroleum usage rates, based on their analysis of US petroleum supply policies. Similar interactions between public and private stocks in the US are considered by Wright and Williams (1982), though their focus is primarily on the implications of oil price controls and on game-theoretic 'dynamic consistency' questions that arise in comparing Nash and Stackelberg outcomes. Balas (1981) studied a short-run game between importing nations and a politically motivated cartel that takes advantage of disruptions to inflict economic losses on importing nations. In this context, he examines the 'deterrence effect' of strategic stocks where the deterrence effect is the value of a strategic reserve when the stockpile not only reduces the economic losses from a disruption, but also reduces the likelihood of a disruption. Greene et al. (1998) demonstrated the potential for future price shocks and economic losses based on a simulation model of the world market and price impacts on the US economy. His results indicated that the use of strategic reserve is relatively ineffective in reducing the damage to the US economy from such a prolonged price shock.

There are relatively few studies on China's stockpile acquisition strategies. Chen and Zheng (2006) analyzed qualitatively the imminence and necessity of SPR for China. They consider that China should not purchase oil to fill the reserve when world oil price is high, in addition to consideration of the experience of SPR in US. For decision-makers, this kind of descriptive analysis may not provide scientific information for the optimal decisions, due to uncertain world oil prices and economic risks of stockpile acquisition for SPR. Moreover, it is difficult to make scientific decisions using only judgments based on intuition. Therefore, it is necessary to quantify the optimal stockpile acquisition strategies for SPR in different years, based on an uncertain dynamic programming model.

This article is organized as follows. Section 2 describes the methods and assumption of uncertain dynamic programming modeling. Section 3 presents and discusses the empirical results of optimal stockpile acquisition strategies. The final section presents conclusions and policy implications.

2. An uncertain dynamic programming model of China's SPR

Based on the US SPR models developed by Teisberg (1981), Samouilidis and Berahas (1982), Samouilidis and Magirou (1985), Oren and Wan (1986), and Murphy et al. (1987), we also develop an uncertain dynamic programming model of the china's SPR.

The establishment of SPR means that China must purchase sufficient oil to fill the reserve. Yet, it is impossible to buy this from the open market in a single purchase. In order to reduce the reserve cost, China needs to make varying decisions at different times because of the uncertainty of international oil prices. Moreover, such decisions will directly influence future decisions for filling the reserve. When decisions at different times are made, it will form the decisions series. Therefore, the optimal stockpile acquisition is a problem of multi-period decisions. Hence, this paper presents an uncertain dynamic programming model of China's SPR. We also explore the