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A dynamic programming model of China's strategic petroleum reserve: General strategy and the effect of emergencies

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ABSTRACT

To protect the security of energy supply, China is building national strategic petroleum reserve (SPR). We present a dynamic programming model to determine the optimal stockpiling and drawdown strategies for China's SPR under various scenarios, focusing on minimizing the total cost of reserves. In contrast to previous research, the oil price given in our model is exogenous on a monthly instead of annual basis, with a view to more realistic simulation of optimal strategies each year. Our model results show that in the case where stockpiling affects oil prices, a given SPR size will be achieved earlier than when stockpiling does not affect oil prices. In different emergency conditions, the optimal stockpiling and drawdown strategies of China's SPR are very different. When an emergency occurs, the shock of stockpiling on the oil price per barrel could range $0.49–$6.35, while the impact of drawdown on the oil price per barrel could range −$6.22 to −$0.48.

1. Introduction

Oil crises prompt the development of national Strategic Petroleum Reserves (SPR), which effectively reduce the impact of such crises. During the first world oil crisis in 1973–74, oil prices quadrupled, causing enormous economic losses to the major industrialized countries. The rates of GDP growth of the United States and Japan, for example, decreased from 5.6% and 8.4% respectively in 1972 to −0.47% and −1.2% in 1974 (World Bank, 2010). To reduce oil supply shortages and their impacts on national and global economies, the Organization for Economic Cooperation and Development (OECD) established the International Energy Agency (IEA) in 1974, which required all member states to establish the SPR equivalent of 60 days of net import volume (later increased to 90 days). During the second world oil crisis in 1979–80, oil prices soared from US$13 to US$41 per barrel. The strategic petroleum reserves of major industrialized countries at that time had already begun to take shape and played an active role in stabilizing markets and guaranteeing supply such that the resulting economic losses were relatively confined. The growth rates of GDP in the United States and Japan, decreased from 5.6% and 5.3% in 1978 to −0.24% and 2.8% respectively in 1980 (World Bank, 2010). This paper investigates how to stockpile and draw down China's SPR to minimize the impacts of different potential future crises on society and the economy, including the costs of stockpiling when future emergencies such as oil supply shortages cause fluctuation of oil prices.

When China again became a net importer of petroleum products in 1993, researchers began recommending a national SPR in order to protect energy security. After a decade of debate, the Chinese government officially approved the establishment of the national SPR in 2003 with a planned total reserve capacity of 500 million barrels (about 68 million tons) and an estimated total investment of about 100 billion Yuan RMB (NDRC, 2010). Establishing the SPR will take about 15 years to complete and is being undertaken in three phases, incrementally adding reserve capacities of 88, 205, and 205 million barrels, respectively. Phase I began in March 2004, with four reserve bases concentrated in coastal areas: Zhenhai of Ningbo, Daishan of Zhoushan, Huangdao of Qingdao, and Xingang of Dalian (the later names of each being municipal jurisdictions). Among these, Zhenhai is the largest, established in August 2006 to stockpile crude oil with an inventory of 33 million barrels. The other three bases were completed by the end of 2008, with a total inventory of 103 million barrels for Phase I.

Unlike the U.S. SPR, which is stored in caverns in subsurface salt domes, Phase I of China's SPR was mainly constructed in above-surface tanks. Although such tanks have several advantages, notably fast construction, flexible site selection, and ease of use, their disadvantages

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include relatively high costs and low safety compared to underground caverns (Davis, 1981). Therefore, Phase II of China's SPR includes not only above-surface tanks but also subsurface caverns. The site selection is shifting also in part to inland areas, including Lanzhou of Gansu province and Shanshan of Xinjiang autonomous region, as shown in Fig. 1 By 2009, Shanshan of Xinjiang and Binhai of Tianjin municipality had commenced construction under Phase II: the total inventory of Phase II is 168 million barrels.

2. Review of literature on SPR strategies

After the first world oil crisis in 1974, the major oil importing nations began to establish their national strategic petroleum reserves to ensure the security of oil supply. Both the oil embargo of 1973 and shutdown of the Iranian oil supply during the Iranian revolution in 1979 triggered a wave of studies on SPR strategies, from which a variety of national oil stockpiling strategies have been developed. This was followed by studies using more advanced models that can be categorized into the following types.

2.1. Studies of SPR strategies based on dynamic programming models

Early analyses focused on determining the optimal SPR size using simple static two-period models for which stockpiling and drawdown policies are predetermined. Since the 1980s, researchers have established a few dynamic programming models to quantify optimal SPR stockpiling and drawdown strategies. Teisberg (1981) developed a stochastic dynamic programming model that allows explicit consideration of uncertainty. The model was used to determine the size of the U.S. SPR and optimal stockpiling and drawdown rates contingent on supply conditions, time, and available inventory. Hogan (1983) extended Teisberg's model of the U.S. stockpiling to a Stackelberg model, examining the interactions between two consuming countries, where one follows the other's lead. Chao and Manne (1983) developed a multi-period dynamic programming model to determine optimal stockpiles and petroleum usage rates based on analysis of U.S. petroleum supply policies. These models have been used to determine both SPR size and optimal stockpiling or drawdown rates, again contingent on supply conditions, time, and available inventory. They also allow for additional emergency policy instruments such as quotas and tariffs. Wu et al. (2008) presented a dynamic programming model under uncertainty to analyze SPR stockpiling strategies in China. Zhang et al. (2009) developed a stochastic dynamic programming model to evaluate the optimal SPR policy for China based on a total potential cost function for establishing the SPR. They indicate that the optimal SPR size for China is around 320 million barrels. In all of these studies, optimal decisions are determined on an annual rather than monthly basis.

2.2. Studies of SPR strategies based on decision and simulation models

As the cost of an SPR is quite high, some researchers have developed cost functions focusing on the optimal SPR size and stockpiling or drawdown rates. Samouilidis and Berahas (1982) established a cost function that includes inventory procurement, maintenance costs, and shortage costs inflicted by a petroleum shortfall, and then evaluated different scenarios based on this cost function and a decision tree model. 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 U.S. economy. Their results indicate that use of the SPR is relatively ineffective in reducing damage to the U.S. economy from a prolonged price shock. Wei et al. (2008) quantified the optimal Chinese SPR for the period 2005–2020 using a decision tree model based on a cost function. Zweifel and Bonomo (1995) developed an optimal reserve model that takes into account multiple risks for oil and gas. They found that one-dimensional rules such as maintaining an oil reserve equal to 90 days of net imports are not only suboptimal but also require adjustments that exacerbate the inefficiencies. Kuenne et al. (1979) developed an optimization model to describe drawdown trajectories

Fig. 1. The spatial distribution of China's strategic petroleum reserves.