ISSN 1749-3889 (print), 1749-3897 (online)
International Journal of Nonlinear Science
Vol.22(2016) No.2, pp.100-108

Potential Benefit of U.S. Strategic Petroleum Reserve: A Dynamic Estimation

Yang Bai, Fanyi Meng *
[a] School of Business, Nanjing Normal University, Nanjing, Jiangsu, 210023, China
[b] College of Economics and Management, Nanjing University of Aeronautics and Astronautics, Nanjing, Jiangsu, 210016, China

(Received 11 January 2016, accepted 10 August 2016)

Abstract: Strategic Petroleum Reserve has been implemented as a powerful weapon against oil supply interruptions. However, it also needs huge investment to build and maintain such an emergency preparedness. Previous studies have tried to evaluate the costs and benefits for SPR policy of oil consuming countries, i.e. the U.S., and answer the question whether the SPR is worthy of taxpayers money. However, empirical results seem have difficult to come to unanimous conclusion. Previous surveys limited in assessing the potential benefit of SPR and operation efficiency of decision makers. This study proposed a dynamic decision model to examine the desirable U.S. SPR policy and potential SPR benefit. The government is considered as a perfect decision maker who is able to take out optimal SPR stockpiling, releasing and refilling actions to maximize SPR benefit. It is found that, from 1977 to 2012, the potential net benefit could be as high as 193.1-476.0 billion dollars by optimal operation of SPR. The specific number is affect by uncertain factors, i.e. interest rate, demand elasticities and GDP-price elasticity. The sensitivity analysis shows that the optimal SPR policy is sensitive to real interest rate, but less sensitive to other uncertain factors.

Keywords: strategic petroleum reserve (SPR); optimal decision making; cost and benefit analysis; oil supply disruption

1 Introduction

The Strategic Petroleum Reserve (SPR) has been known as the world's largest government-owned emergency oil supply. It aims to provide oil consuming countries with insurance against the threat of a severe supply interruption. The SPR provides two potential economic benefits. First, releasing the reserves in a disruption can moderate the increase of oil prices, thereby mitigates the negative effect on the economy. Second, releasing of SPR reduces excess import cost caused by the increase of oil price [1]. The SPR program also costs taxpayer hundreds of millions of dollars to establish such a program in normal state. Bai and Dahl [2] took out a survey on the real cost and benefit of U.S. SPR based on actual data of SPR investment and revenue from 1976 to 2012. The estimation found that the real SPR cost could be as high as 110 billion dollars.

Comparing with the huge investment and cost, the benefit of SPR is inapparently at most time. There have been arguments on the necessity of SPR program in long term. Most of the oil import countries and organizations have shown great support to the SPR policy. Nordhaus [3] suggests the government enhance import tariff and establish SPR in response to oil embargoes. Hogan [4] pointed out that oil stockpiling is as the most visible and substantial measure of government activity in energy policy where other institutions and resources had been deployed. Tolley and Wilman [5] believes stockpiling could limit embargo price rise to unit cost of storage divided by embargo frequency. However, with low embargo frequency, the effect of stockpiling is unwarranted. Balas [6] believes that SPR acts as a deterrent which is able to decrease the oil embargo frequency and reduce the nations vulnerability to similar supply interruptions.

Opponents of SPR have suspicion that the SPR is not worthy of its expenditures. According to a conservative estimation, Taylor and Doren [7] finds that the SPR has cost taxpayers at least $ 41.2-$ 50.8 billion (in 2004 dollars), or $

* **Corresponding author**. *E-mail address*: tsyz-mengfanyi@163.com

IJNS.2016.10.15/929

64.64-$ 79.58 per barrel of oil deposited therein. However, the SPR has been used only three times. In each case, the releases were too modest to produce significant benefits. Considine [8] estimates the effect of stock sale on market price using a monthly econometric model. It finds that sale from SPR had minor impacts on market price and could be easily trumped by actions of other players. Bai and Dahl [2] finds the real cost of U.S. SPR could be as high as $ 110 billion concerning inflation and capital cost, whereas the benefit of SPR sale is only $ 67.2 billion.

The public concerns mainly focus on two main issues. First, whether is the SPR worth of its investment? Second, whether does the government operate the SPR efficiently? Earlier studies have tried to estimate the cost and benefit of SPR program. The empirical results have difficult to come to a conclusion. Previous studies also limited in evaluating the efficiency of SPR activities. This paper evaluated the potential benefit of SPR policy under the assumption of perfect decision maker. We try to answer the question whether the SPR worth of its investment and all costs related if been well implemented. For doing so, we proposed a dynamic analysis framework. The government is concerned as a perfect decision maker who decides SPR actions, i.e. stockpiling, sale and refilling. The objective is to find out minimal SPR cost or maximal net benefits given actual market information in whole period from 1976 to 2012.

2 Methodology

2.1 Notation

t: Time stage (month)
s_t: State variable
λ_t: Disruption magnitude
a_t: SPR acquisition (or drawdown) rate (million barrels per month)
$\overline{a}$: Maximum SPR acquisition rate (million barrels per month)
$\underline{a}$: Minimum SPR acquisition rate (million barrels per month)
v_t: SPR capacity (million barrels)
$\overline{v}$: SPR capacity limit (million barrels)
p_t: Oil price at stage t (dollars per barrel)
g: GDP value (million dollars)
e: Oil-price elasticity of GDP
δ: Ratio of SPR construction cost to purchase cost
γ: Discount rate
σ: Demand elasticity
ψ: Supply elasticity
d_t: Regular demand quantity (million barrels per month)
q_t: Regular supply quantity (million barrels per month)
c^s: SPR acquisition (release) cost (revenue) (million dollars)
c^f: Consumer welfare loss (million dollars)
c^c: SPR facilities and management & operation (million dollars)
c^g: Macroeconomic adjustment loss (million dollars)
c^e: Excess wealth transfer (million dollars)

Parameters λ_t is disruption magnitude. Concerning constraints on SPR facilities, we use $\overline{a}$ and $\underline{a}$ to indicate the maximum SPR acquisition and drawdown capacity of each stage. Oil-price elasticity of GDP (e) denotes percentage change in GDP in response to percentage change in oil price [1]. Similarly, Demand elasticity of oil price indicates percentage change in demand in response to percentage change in oil price.

2.2 SPR costs and disruption loss

There are both cost and benefit for the strategic petroleum reserve. The costs of the reserve itself include the investment on the storage facilities, oil expenditure and the operation and maintenance costs. The benefits come from oil sale on one side and the avoided losses due to the release of SPR in the case of a supply disruption [1].

(1) Cost (or revenue) for oil acquisition (or release)

The SPR stockpiling (or release) cost (or revenue) depends only upon the fill rate (a_t) and oil price (p_t) as shown in equation (1)

$$c_t^s(a_t, s_t) = a_t(s_t)p_t(a_t, s_t). \tag{1}$$

The oil price (p_t) depends on market state s_t and SPR action a_t. When the government release SPR, a_t is negative and c_s means the income from oil sale.

(2) Costs for facilities and management & operation (M&O)
The facility and management & operation expenditure is correlative to stockpiling cost to a certain proportion as shown in equation (2).

$$c_t^f(a_t, s_t) = \delta c_t^p(a_t, s_t) \tag{2}$$

where δ is the ratio of facilities cost to oil acquisition cost.

(3) The welfare loss

The fluctuation of oil price may lead to consumer welfare loss and improved the welfare of domestic producers as mentioned by Teisberg [9] and Bai et al. [10]. As the biggest importer of international market, the variation of U.S. oil stock inevitable has an effect on the oil price. We assume the activity of oil acquisition for SPR works on oil price by affecting balance of supply and demand. The net welfare loss can be presented by equation (3).

$$c_t^c(a_t, s_t) = \int_{p_t^0}^{p_t(a_t,s_t)} D(p) - Q(p)\, dp \tag{3}$$

where p_t^0 is the oil price at the beginning of each stage *t*. D(p) and Q(p) are demand and supply function respectively. We assume the oil price keep steady if there is no supply disruption at each stage. Therefore, there is net welfare loss in normal state.

(4) Economic loss and excess import cost

The macroeconomic loss arises because the rigidity of the macroeconomy prevents a smooth adjustment to a price shock. As one of the important economic input, the price hike can cause temporary resource dislocation and underutilization which further reduces the output level of economy. On the other hand, the raising oil price also increases U.S. oil imports costs [1]. Following [2], the economic adjustment loss is indicated by equation (4).

$$c_t^g(a_t, s_t) = g_t((p_t(a_t, s_t)/p_t^0)^{-e} - 1) \tag{4}$$

where p_t^0 is the oil price at the beginning of each stage *t*, *e* is GDP-Price elasticity which indicates the GDP sensitivity to oil price. It also costs consumers more than usual to import oil. The excess import cost caused by price soaring can be indicated as equation (5).

$$c_t^g(a_t, s_t) = (1 - \lambda_t) D_t(p_t(a_t, s_t) - p_t^0). \tag{5}$$

To sum up, the costs of SPR policy include crude acquisition (c^s), facilities and management & operation (c^f) and net welfare loss (c^c). The potential benefit of SPR comes from avoided welfare loss (c^c), excess import cost (c^e) and economic adjustment loss (c^g). Concerning economic effectiveness, the desirable SPR policy should minimize the sum over of the total expenditure on SPR policy and economic loss of disruption.

2.3 Dynamic SPR model

The SPR project could be concerned as a multi-period sequential decision problem. The government decides to fill or sale the inventory at the beginning of each stage based on the information of market $s_t \in S$. We assume the market information is a three-dimension state variable (s) which includes oil supply $q_t \in Q$, price $p_t \in P$, and inventory $v_t \in V$. The decision variable is SPR fill rate (a^+) or sale rate (a^-) where $a \in A_s$. Given perfect information, the government is capable to optimize its SPR activities and minimize the total SPR cost and disruption loss for the whole period. Given the structure of SPR cost and disruption loss, the total cost ct in a single period t can be expressed by equation (6).

$$c_t(a_t, s_t) = c_t^s(a_t, s_t) + c_t^f(a_t, s_t) + c_t^c(a_t, s_t) + c_t^e(a_t, s_t) + c_t^g(a_t, s_t). \tag{6}$$

Concerning the whole period, the total SPR cost and disruption loss are indicated by equation (7)

$$V_t^\pi(a_t, s_t) = \sum_{t=1}^{N} \gamma_t c_t^\pi(a_t, s_t), \tag{7}$$

where $\pi = u_1, u_2, \ldots, u_t$ is one of the feasible SPR action sets, r_t is the discount factor of year t. The objective is to find out the desirable SPR policy π^* which minimize the total SPR cost and disruption loss in given period as shown by equation (8).

$$V_t^{\pi^*}(a_t, s_t) = \min_{\pi \in \Pi} \sum_{t=1}^{N} \gamma_t c_t^{\pi}(a_t, s_t). \tag{8}$$

For each stage, the model finds optimal SPR acquisition rate a_t^*. To solve the problem, we further convert equation (8) into Bellman equation form (9).

$$\Big\{ f_t(s_t) =_t, s_t) = \min_{\pi \in \Pi} \{V_t^{\pi}(a_t, s_t) + \gamma_t f_{t+1}(s_{t+1})\}, t = 1, \ldots, T f_{T+1}(s_{t+1}) = 0, \tag{9}$$

where s_t is the state variable of period t. Then the objective function $f_t(s_t)$ indicates the minimal SPR cost and disruption loss of the whole period. SPR acquisition stops at stage T. We assign zero to $f_{T+1}(s_{T+1})$. Then the sequential decision problem can be solved by dynamic programming method.

3 Model initialization

3.1 Market information

In this section, we specify the time interval, market state, parameter values and all actual data required for numerical analysis. We take monthly time interval. The estimation period is from Jan. 1976 to Dec. 2012. The market information comes at the beginning of each month. Decision maker chooses to either buy oil or sale SPR from the inventory. Market state (s) includes the information of supply $q_t \in Q$, price $p_t \in P$, and inventory $v_t \in V$. The initial supply quantity (q_t) and demand quantity (d_t) for each stage are cited from the Oil Market Report Tables of International Energy Agency (IEA) . For the Oil Market Report Tables has only quarterly data, we assume that the initial demand and supply quantity keep steady in each quarter. The initial monthly price is offered by the Database of Petroleum & Other Liquids, U.S. Energy Information Administration (EIA) . All prices used here have been adjusted to 2012 value by using consumer price index (CPI). The inventory vt depends on the decision action at at the stage and inventory size of last stage v_{t-1}.

A lot of empirical studies have tried to identify its possible value range [11-14]. The results seem to cluster to a range of [-0.05 0.2]. Here we selected a reference value of -0.1 for demand elasticity. The sensitivity analysis is proposed within a wider range of [-0.05 0.2]. The supply elasticity of world market and domestic are set to be 0.2 and 0.05 respectively.

3.2 Market information

(1) Disruption size

In history, emergency releases of SPR have only occurred three times. Table 1 summarizes the details of the three releases.

Table 1: The information of three supply emergencies and SPR release since 1990.

Supply emergency	Initial price	Peak price	Peak loss	SPR release
1991 Operation Desert Storm	$\$30.5/bbl$	$\$36/bbl$	$4.3mbd$	$33.75mb/45d$
2005 Hurricane Katrina	$\$65/bbl$	$\$70/bbl$	$1.5mbd$	$20.8mb/30d$
2011 Middle East Turbulent	$\$92/bbl$	$\$113/bbl$	$1.6mbd$	$60mb/30d$

(2) Disruption loss

As mentioned in section 2, the appreciable Macroeconomic adjustment loss only exists in a severe energy supply interruption. Such losses are usually accounted by its quantitative relation to oil shocks. Former empirical surveys have found significant causal correlations between oil price shocks and macroeconomic performance (Brown and Ycel [6], Mork [21], Gisser and Goodwin [12], Bruno and Sachs [7], and Hamilton [13]). The economy adjustment loss depends on the size of the price hike as well as the vulnerability of the macroeconomy to a price shock of given size. The effect of oil price shock on gross economic output has been widely represented by a parameter oil-price elasticity of GDP. The vulnerability to adjustment loss mainly depends on oil consumption level rather than imports. Jones and Leiby (1996) took out a comprehensive survey on studies of the macroeconomic impacts of oil price shocks and concluded that the U.S. GDP-Price elasticity ranges between -0.02 and -0.06. The DOE Interagency 1990 study assumed a GNP elasticity range of -0.02 to -0.04, with a preferred value of -0.025. Although commonly differing across countries and regions, empirical estimated values of the GDP-price elasticity for the U.S. has ranged between -0.02 and -0.06. In the study, we pick the reference GDP-price elasticity of -0.025 along with some sensitivity analyses in the range of [-0.01, 0.1]. There are three emergency SPR releases. Therefore we concern only the three economic adjustment losses during the three disruptions. The nominal GDP values are offered by database of the Word Bank . We adjust the nominal values into fixed-price GDP value of 2012. More values of the parameters necessarily for numerical analysis have been listed in Table 2.

Table 2: The information of three supply emergencies and SPR release since 1990.

Variable	Value	Units	Description
GDP_2	[5996,12716,15070]	$\$billion$	Real GDP[a]
d_0^{us}	[7.5, 5.5, 5.6]	million barrels per day	Domestic demand[c]
d_0	[65, 84.3, 87.5]	million barrels per day	World demand[b]
s_0	[65, 84.3, 87.5]	million barrels per day	Regular world supply[b]
e	[-0.01, -0.1]	–	Real GDP[1]
σ	0.2	–	World demand price elasticity
ε	0.2	–	Supply elasticity of world market
φ	[-0.2, -0.05]	–	Domestic demand elasticity
ψ	0.05	–	Domestic supply elasticity
λ	[1.5, 4.5]	million barrels per day	Range of supply disruption size[d]
ρ	0.3	–	Utilization rate of commercial storage
η	0.3	–	Utilization rate of spare capacity

[a] The Word Bank, open database, available at http://data.worldbank.org.
[b] International Energy Agency (IEA), Oil Market Report Tables.
[c] U.S. Energy Information Administration (EIA), database of Petroleum & Other Liquids.
[d] International Energy Agency (IEA), 2012. Oil Supply Security: Emergency Response of IEA Countries 2012.

4 Results and discussions

4.1 Result of base case

In this section, we try to find the best decisions for the government to optimize its SPR activities and maximize the potential benefit of SPR filling and releasing given perfect information. A dynamic model is built based on the components of SPR cost and benefit proposed in section 2. Then we take out an empirical study by specifying the issue with actual historical data.

The U.S. SPR program started from 1976. Therefore, we consider the time span of 1976 2012 with monthly decision intervals. The influential factors concern oil price, interest rate, demand and supply, SPR cost, economy response to oil price and so on. Oil price used here is actual monthly data. The interest rate is converted from real annual data to real monthly data. The price and GDP have been recalculated by the fixed price of the year of 2012. The results show optimal SPR actions and the maximized net benefit along with those actions. The maximal benefit of SPR policy could be as high as $\$295.4$ billion which is much higher than the estimation of Bai and Dahl [2]. However, considering that the government is unable to perform as perfect decision maker, the potential value could be lower than the estimation.

We consider the uncertain factors of real interest rate, world demand elasticity, domestic demand elasticity and GDP-price elasticity. The real interest rate used in base case is actual monthly interest rate. Other parameters' value set for base case are -0.1 of world demand elasticity, -0.1 of domestic demand elasticity and -0.025 of GDP-price elasticity. As shown in figure 1, the blue solid line shows the optimal SPR stockpiling and releasing size. The dotted green line shows the monthly real price (by the fixed price of the year of 2012). Generally speaking, the desirable SPR action shows a basic rule of ”buy low and sell high”. The stockpiling and drawdown activities seem more concentrated when the price fluctuates significantly. The net benefit of SPR could be as high as $\$295.4$ billion by well operation.

As shown in figure 2, the blue solid line indicates actual history oil price (by the fixed price of the year of 2012). The

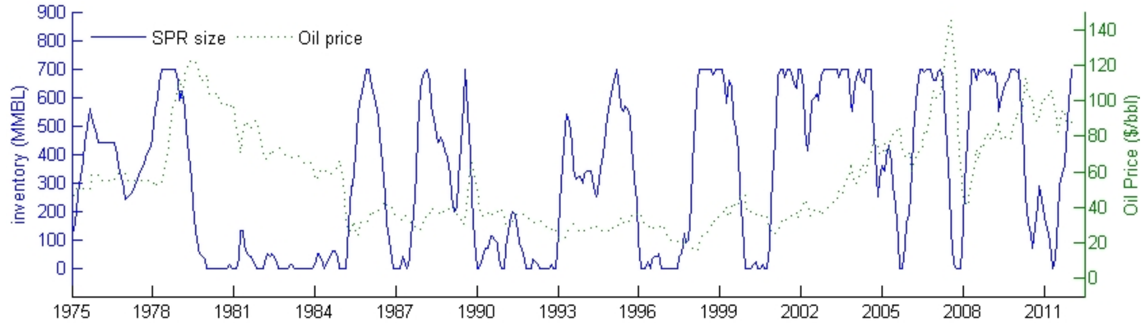

Figure 1: The optimal SPR stockpiling and drawdown policy 1976-2012.

dot-dash red line is estimated price trajectory taking account of SPR activities. Generally speaking, the estimated price is smoother especially when oil price fluctuates wildly. The operation of SPR dampens oil price shocks.

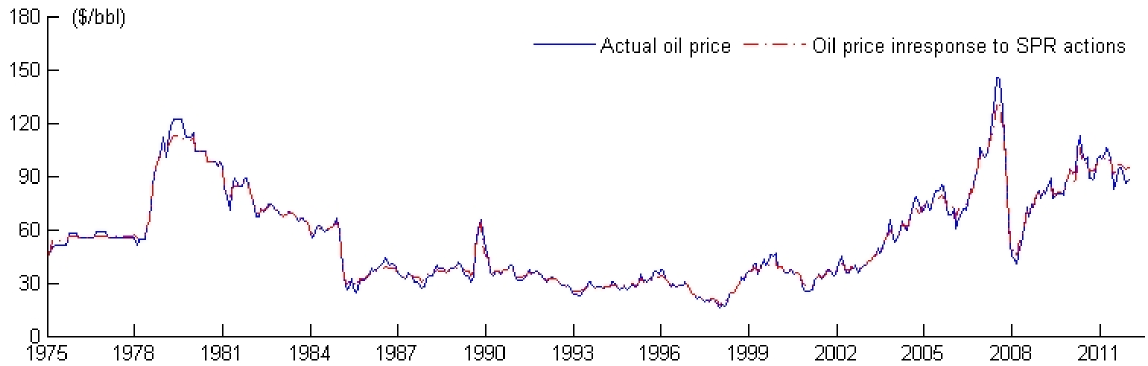

Figure 2: Actual oil price and the price responses to SPR policy.

4.2 Sensitivity analysis

(1) Interest rate

We use monthly real interest rate and the optimal SPR policy is shown by the blue solid line in figure 3. The dash-dot red line and dash green line indicate high interest rate and low interest rate respectively. The desirable SPR stockpiling and drawdown policy is quite sensitivity to real interest rate. As shown in figure 3, when the interest rate is higher, the SPR policy appears more active. The interest rate also has an effect on net benefit of optimal SPR policy. If the interest rate is high, there is supposed to be more capital cost which reduces the net benefit. By our estimation, it is found the net benefit is $193.1 billion in the case of high interest rate. In the case of low interest rate, the net benefit is $459.1 billion.

(2) World demand elasticity

We proposed three scenarios to examine the sensitivity of SPR policy to the elasticity of international market. The elasticity of -0.05 and -0.2 indicate the market states of inelastic and elastic respectively. If the market were inelastic, then the SPR activity should have less effect on oil price. Therefore, the SPR activity is supposed to be more active to dampen oil price shock and stabilize market fluctuations. Figure 4 shows that the SPR policy is insensitive to elasticity. The net benefit of SPR policy is $297.2 billion in the case of inelastic. In the other case, the net benefit is $294.2 billion. The result implies that SPR policy could be more effective when the market is inelastic.

(3) Domestic demand elasticity

The domestic demand elasticity mainly affects the social welfare loss and excess import cost when oil price changes.

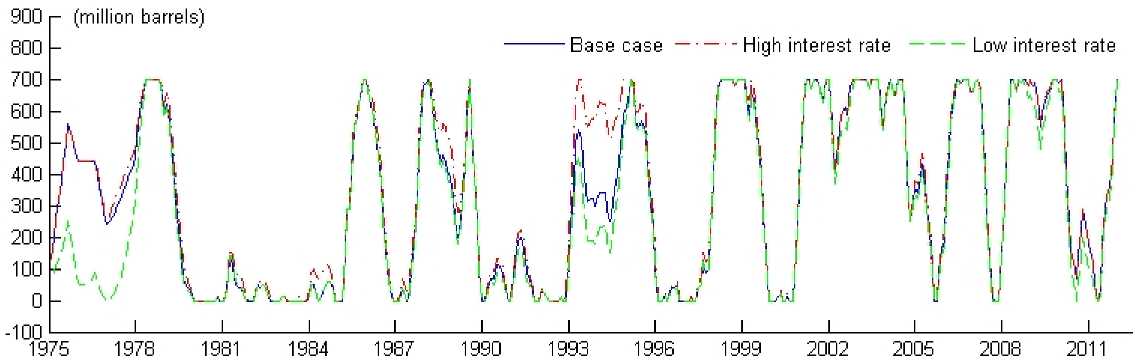

Figure 3: Sensitivity analysis of optimal SPR policy to real interest rate.

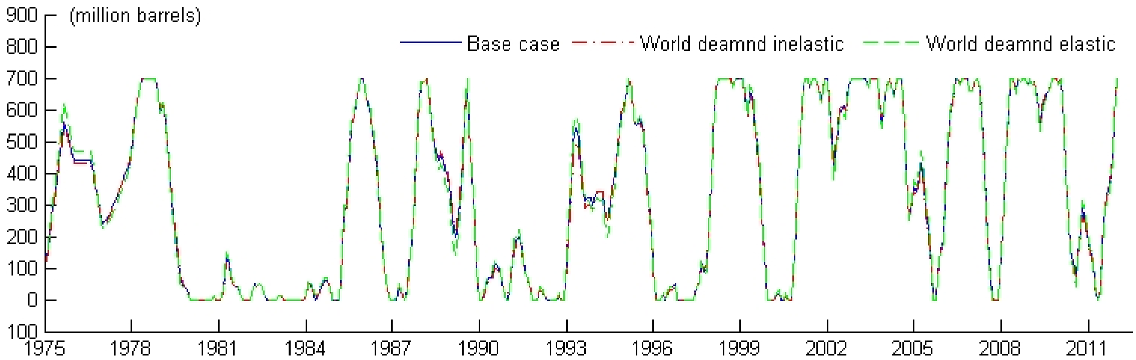

Figure 4: Sensitivity analysis of optimal SPR policy to world demand elasticity.

The more inelastic, the more welfare loss and import cost there is when price shocks. Similarly as international market, we set -0.05 and -0.2 to indicate the inelastic and elastic scenarios of domestic market. As shown in the figure 5, the SPR policy is also insensitive to domestic elasticity. The net benefits of two cases are $298.4 billion and $294.0 billion respectively. Therefore, the SPR policy benefits more when the demand is inelastic.

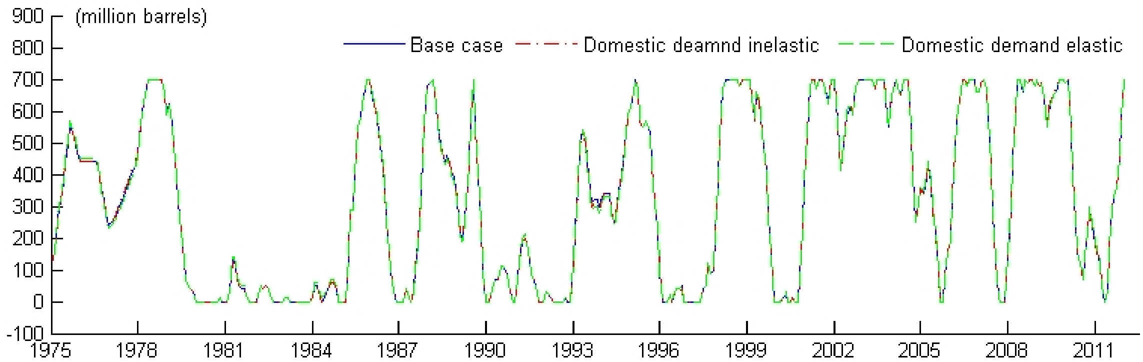

Figure 5: Sensitivity analysis of optimal SPR policy to domestic demand elasticity.

(4) GDP-price elasticity

We find the GDP-price elasticity does not affect the optimal SPR stockpiling and drawdown policies significantly (Fig. 6). It may be because the GDP-price elasticity has no effect on oil price. However, the net benefits are quite sensitive to the GDP-price elasticity. By our estimation, in the case of high GDP-price elasticity, the net benefit is as high as $476.0 billion. In the case of low GDP-price elasticity, the net benefit is only $259.2 billion.

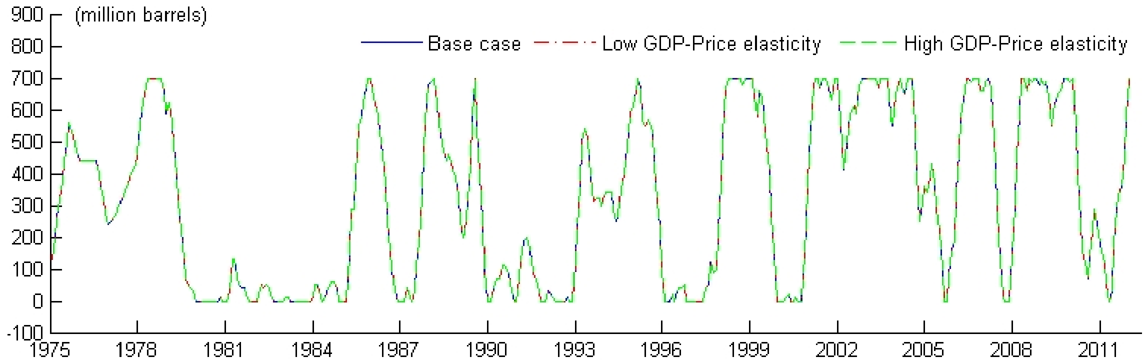

Figure 6: Sensitivity analysis of optimal SPR policy to GDP-price elasticity.

5 Conclusions

This study developed a dynamic model to estimate the maximum benefit of the SPR policy since its establishing of 1976. The government is assumed to be a perfect decision maker who is able to make precise decisions to make the best use of oil stocks. The cost accounted includes oil account, facilities and management & operation and consumer welfare loss. The benefit includes avoided economic loss and excess import cost. The actual data of oil price, interest rate and GDP values have been used as numerical input. For uncertain factors, i.e. demand elasticity, capital cost and GDP-price elasticity, we have examined the sensitivities of their impact on the result.

It is found that the optimal operation SPR could gain a net benefit of $\$295.4$ billion which is much higher than previous estimations i.e. Taylor and Doren [7] and Bai and Dahl [2]. However, the specific number could be affect by many uncertain factors, i.e. interest rate, world and domestic demand elasticities and GDP-price elasticity. The sensitivity analysis shows that the optimal SPR policy is sensitive to real interest rate, but less sensitive to other uncertain factors.

It is widely agreed that the economy has such vulnerability to oil shocks as long as the oil is still key driving force of the society. The empirical studies on SPR cost and benefit shows that the net benefit of optimal SPR policy could achieve as high as $\$193.1$ 476.0 billion. It is worth noting that the net benefit given here is base on the extreme strict assumption that policy maker has full sight of perfect market information, i.e. oil price. Though the policy maker is impossible to implement the SPR perfectly, the SPR policy may still a strong weapon in response to market shocks by well market prediction and scientific SPR operation.

6 Acknowledgements

The authors gratefully acknowledge the financial support provided by the National Natural Science Foundation of China (71403131).

References

[1] P. N. Leiby et al. Oil imports: An assessment of benefits and costs. *ORNL-6851, Oak Ridge National Laboratory.* 1997.
[2] Y. Bai and C. D. Dahl. White Knight or White Elephant: Evaluating the U.S. Strategic Petroleum Reserve. 18th IAEE *International Conference Proceedings.* (1995).
[3] W. D. Nordhaus. The 1974 report of the President's Council of Economic Advisers: Energy in the economic report. *American Economic Review.* 64(1974)(4): 556-565.
[4] W. W. Hogan, Oil stockpiling: help thy neighbor. *The Energy Journal.* 4(1983)(3): 49-72.
[5] G. G. Tolley and J. D. Wilman. The foreign dependence question. *Journal of Political Economy.* 85(1977)(2): 323-347.
[6] E. Balas. The strategic petroleum reserve: How large should it be? In: B.A. Bayraktar (ed.). *Energy Policy Planning. Plenum Press, New York.* (1981).

[7] J. Taylor and P. V. Doren. The strategic petroleum reserve: Who needs it? *Pipeline & Gas Journal* 233(2006)(2): 46-46.
[8] T. J. Considine. Is the strategic petroleum reserve our ace in the hole? *The Energy Journal.* 27(2006): 91-112.
[9] T. J. Teisberg. A dynamic programming model of the US strategic petroleum reserve. *The Bell Journal of Economics.* 12(1981)(2): 526-546.
[10] Y. Bai et al. Optimal path for China's strategic petroleum reserve: A dynamic programming analysis. *Energy Economics*. 34(2012): 1058-1063.
[11] H. B. Badi and M. G. James. Gasoline demand in the OECD: an application of pooling and testing procedures. *European Economic Review*. 122(1983): 117-137.
[12] R. Bhatia et al. Energy demand analysis in developing countries: a review. *The Energy Journal*. 8(1987): 1-32.
[13] C. A. Dahl and T. Sterner. Analyzing gasoline demand elasticities: a survey. *Energy Economics*. 13(1991): 203-210.
[14] J. L. Smith. World Oil: Market or Mayhem? *Journal of Economic Perspectives* 23(2009): 145-164.