A Policy of Strategic Petroleum Market Reserves

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Abstract. Unexpected price spikes in petroleum can lead to instability in markets and have a negative economic effect on sectors which rely on petroleum consumption. Sudden rises in the price of petroleum do not have to be long-term to cause negative, cascading impacts across the economy. Firms which make futures purchases or hedge against a higher price during a price spike can become insolvent when the price spike deflates. A policy is needed to buffer short-term perturbations in the petroleum market to avoid short-term price spikes. This study looks at the effects of implementing a Strategic Petroleum Market Reserve within a multi-agent Nation-State model which would utilize trading bands to determine when to buy and sell petroleum reserves. Our analysis indicates that the result of implementing this policy is a more stable petroleum market during conditions of resource scarcity.

Keywords: Complex Adaptive Systems, Multi-Agent-Based Modeling, Buffer Stocks, Price Stabilization, Strategic Resource Reserves, Resource Scarcity.

1 Introduction

We conducted a study to determine the effectiveness of a Nation-State having a policy of maintaining a strategic market reserve for a resource whose price can be volatile. The goal of the reserve is to buffer sudden price-spikes by reducing constraints on the availability of a resource in a domestic market. We chose petroleum due to its economic importance to many sectors of the economy and petroleum's history of volatile prices. The study utilized the Nation-State configuration of the Exchange Model developed at Sandia National Laboratories to investigate complex adaptive systems (CAS) [Beyeler et. al. 2011]. This model provides a framework to abstractly represent a system in which interacting specialists (entities) produce and consume resources that flow among entities via continuous markets.

Many countries already have national Strategic Petroleum Reserves (SPR) which are used as a deterrent to organized disruptions in the availability of petroleum in markets. In 1975, the United States (U.S.) Congress passed a bill authorizing the creation of a SPR as an emergency reserve of petroleum for both civilian and military

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needs in the event of an embargo [Carter 1975]. In the U.S., salt domes are used to store petroleum for the SPR, providing ideal containers because they are large, accessible, self-sealing, and have the virtue of previous excavation by chemical companies. Today the U.S. has roughly 750 million barrels of petroleum stored in salt domes in five different facilities along the Gulf Coast [Blumstein 1996]. The storage facilities are operated by the Department of Energy; disbursement from the SPR has to be authorized by the President of the U.S. The effectiveness of the SPR against embargos and other short-term disruptions to the domestic petroleum supply is not being questioned in this paper. The study presented here addresses the potential efficacy of a new Strategic Petroleum Market Reserve which utilizes trading bands to determine when to buy and sell petroleum with the intention of buffering price volatility resulting from an exogenous event.

The Strategic Petroleum Market Reserve (SPMR) is modeled after the Strategic Petroleum Reserve (SPR) but serves a different function. The SPR was designed and built to deter bad actors trying to disrupt imports to the U.S. Contrariwise, the SPMR is proposed to support a policy of market-based intervention designed to buffer short-term market disruptions by being an active player in the market. Like the SPR, the SPMR would need to acquire petroleum from the market, store the petroleum, and determine when and how much petroleum to release when intervention is required. We use Bollinger-Bands to define the dynamic trading bands used to make systematic buying and selling decisions. The use of Bollinger-Bands gives us a powerful tool to identify the relative highs and lows for the trading price of petroleum and the point at which intervention would be most effective.

In contrast to relying on a governing entity to decide when to buy and sell reserves, the use of a market-driven policy for petroleum reserve maintenance allows trading to be predictable, adaptable, and effective in mitigating short-term price spikes. Predictability results from markets being able to count on a consistent response by the SPMR to price perturbations. Adaptability derives from dynamic trading bands' ability to adjust the SPMR's acquisition and release of petroleum based on short-term and long-term price trends. Effectiveness stems from the SPMR's ability to ease price spikes by alleviating short-term scarcity in the petroleum market. The result of having a Strategic Petroleum Market Reserve is the reduction of short-term price spikes by easing resource contention and providing stability to domestic markets.

2 Model Description

The Exchange Model (ExM) is a hybrid combining system dynamics and agent-based modeling to represent production and consumption sectors, resource flows and market exchanges among interacting specialists (entities) in a system. All entities have a homeostatic process which maintains 'health' via the consumption of resources. The production of resources is a consequence of the consumption of resources. Entities store both the resources needed for consumption and the resources needed for production and control those resource levels through interactions with markets. Markets facilitate the exchange of resources by using a double auction algorithm to match bids and offers. Each market manages the exchanges of a single resource. The price of a proposal (bid or offer) is reflexive and represents the relative scarcity/abundance experienced by the entity creating the proposal.

2.1 Nation-State Configuration

For the purposes of this study, the ExM is configured as a hierarchical system of compound entities (Nation-States) which embed sectors (entities) for the purpose of investigating patterns of system-level exchange of resources necessary for survival. We call this type of the configuration the Nation-State configuration. All resources are exchanged in domestic markets and some resources are also exchanged in an international market. Resources are exchanged via proposals to buy or sell in markets. Figure 1 illustrates a single Nation-State configured with two entities (each producing and consuming two resources), two domestic markets and one international market.

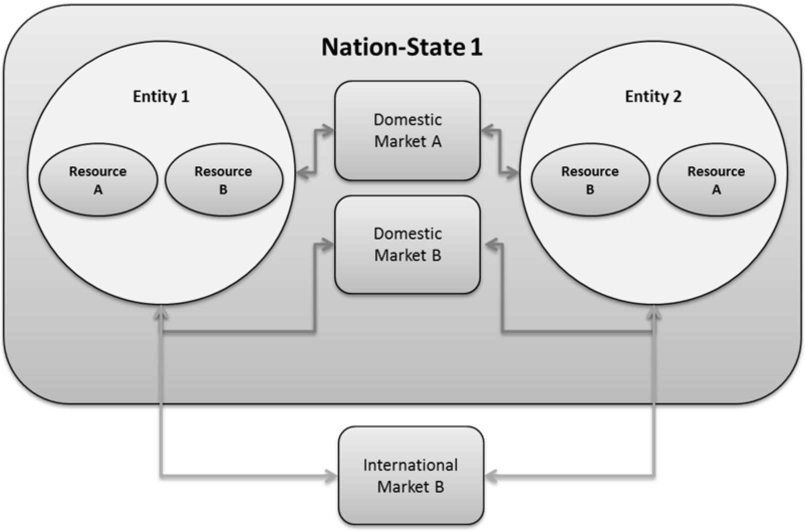

Fig. 1. Diagram of a single Nation-State depicting relationships among producing/consuming entities and markets

2.2 Trading Bands

In this model, trading bands provide a metric to determine when an observed price diverges significantly from normal price trends. Upper and lower trading bands are used to determine the significance of a price divergence. We define the upper and lower trading bands as Bollinger Bands (BB) configured with a Simple Moving Average (SMA) rule. Bollinger Bands were chosen for their ability to capture abrupt deviations from normal price movements and their prevalent use as a technical training tool [Leung, et. al. 2003]. Bollinger Bands are created from three curves drawn in relation to a series of observed prices. The middle curve is a Simple Moving Average (SMA) which serves as a base for the upper and lower bands: band spacing is wide when prices are volatile, narrowing as price becomes less volatile. The typical configuration of the bands is the use of an SMA with 20 observations and two standard deviations from the SMA to create the upper and lower bands. This configuration captures 95% of price movements.

The SMA function is defined as follows:

$$SMA_N(\mathrm{t}) = \frac{\sum_{i=t-N+1}^{t} P(i)}{N} \tag{1}$$

where $SMA_N(\mathrm{t})$ is defined as the mean of the prices in the past N observations at time t, and P(i) is the price for a given observation i.

The Bollinger Band function to determine upper and lower bands is described as follows:

$$BB_N^k(t) = SMA_N(t) \pm k \times \sqrt{\frac{\sum_{i=t-N+1}^{t} [P(i) - SMA_N(i)]^2}{N}} \tag{2}$$

where k controls the width of the Bollinger Bands due to price fluctuations around the mean in terms of the standard deviation at time t for N prior observations.

Figure 2 illustrates three Bollinger Bands (BB) calculated using historical crude oil spot price data.

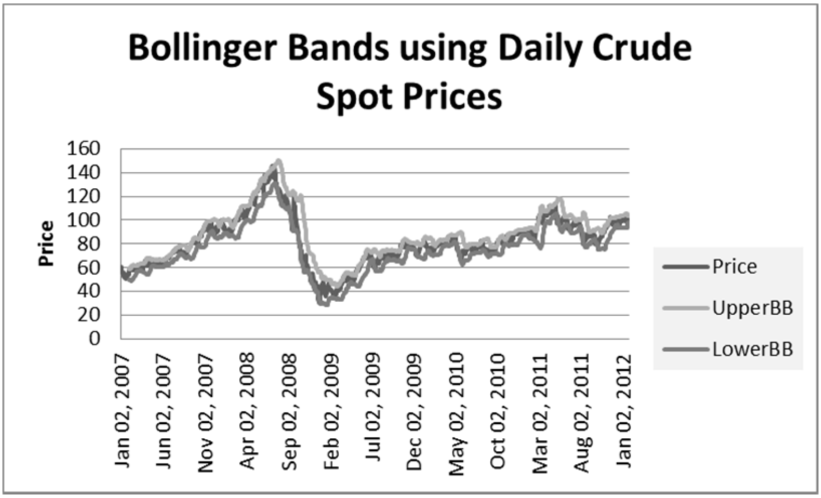

Fig. 2. Bollinger Band using daily crude oil spot prices from 01/ 2007 – 01/ 2012

Determining when to buy and sell using Bollinger Bands requires the calculation of the observed price in relation to the price bands. The following equation calculates the observed price *P(t)* in relation to the upper $BB_N^{upper}(t)$ and lower $BB_N^{lower}(t)$ trading bands. The result of the calculation is used by the SPMR to determine whether to buy, sell, or do nothing.

$$percentB = \frac{P(t) - BB_N^{lower}(t)}{BB_N^{upper}(t) - BB_N^{lower}(t)} \tag{3}$$

Figure 3 illustrates the percentB calculation on the daily crude oil spot prices for a three year period.

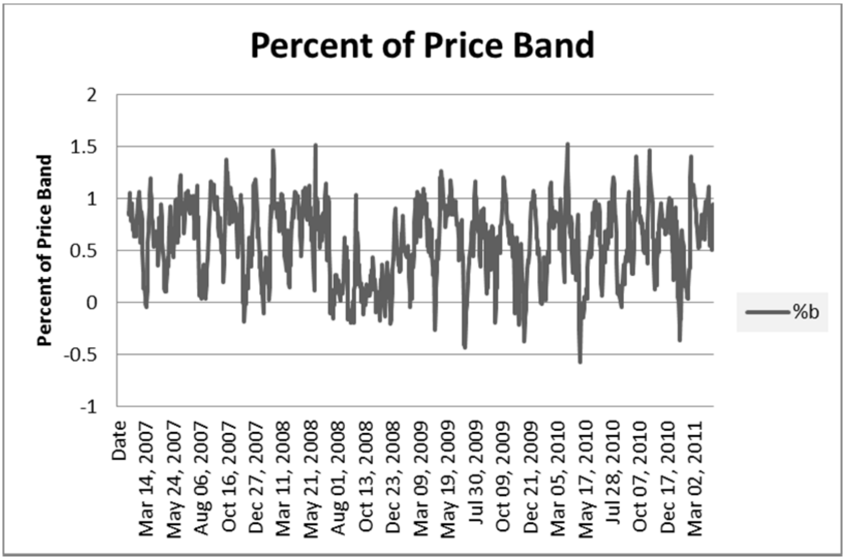

Fig. 3. Percent of price band for daily crude oil price data

3 Model Configuration

The ExM's construction of entities to produce and consume resources and exchange (trade) those resources in domestic and international markets makes the Nation-State configuration suitable for studying commodities markets and allows us to study the effect on price of short-term disruptions in the supply of petroleum. For simplicity, we configured two Nation-States: one representing the United States and the other representing the rest of the world. Table 1 lists the resources, production, and consumption rates used to configure the U.S. Nation-State; Table 2 lists the resources, production, and consumption rates used to configure the World Nation-State. The only stoichiometry imbalanced in the model, meaning that the nation-state cannot wholly obtain that resource, is Oil. The U.S. Nation-State its domestic oil consumption requirements through domestic markets and trade with international markets. All resources have domestic markets: Oil, Food, Goods, Energy, and Labor. In addition to domestic markets, there are international markets for three resources: Oil, Food, and Goods.

Table 1. U.S. Nation-State Configuration

United States	**Consumed Resources**					**Produced Resources**				
Sectors	Oil	Food	Goods	Energy	Labor	Oil	Food	Goods	Energy	Labor
Household	0	2	2	2	0	0	0	0	0	3.6
Manufacturing	0	0	0	2	1	0	0	1.8	0	0
Farming	0	0	0	1	1	0	1.8	0	0	0
Oil Production	0	0	0	0	1	1.8	0	0	0	0
Energy from Oil	4	0	0	0	1	0	0	0	4.5	0

Table 2. World Nation-State Configuration

World	**Consumed Resources**					**Produced Resources**				
Sectors	Oil	Food	Goods	Energy	Labor	Oil	Food	Goods	Energy	Labor
Household	0	8	8	8	0	0	0	0	0	14.4
Manufacturing	0	0	0	8	4	0	0	7.2	0	0
Farming	0	0	0	4	4	0	7.2	0	0	0
Oil Production	0	0	0	0	4	16.2	0	0	0	0
Energy from Oil	16	0	0	0	4	0	0	0	18	0

We ran each simulation for a total time of 7.E+4. A disruption was scripted at time 5.E+4 to reduce the international availability of petroleum causing a short-term resource constraint and resulting in a sharp increase in the spot trading price for petroleum. We configured ten different environments of petroleum scarcity. For each environment, we ran two simulations: one with a SPMR and one without an SPMR to compare the impacts to price. Table 3 describes the environments configured for this study.

Table 3. Levels of disruption to international oil production analyzed in this study

Environment	International Oil Production Disruption
1	5%
2	10%
3	15%
4	20%
5	25%
6	30%
7	35%
8	40%
9	45%
10	50%

3.1 Strategic Petroleum Market Reserve

An SPMR was added to the model to mediate short-term disruptions in the supply of petroleum to the U.S. domestic market. The SPMR was endowed with an initial level of petroleum and was configured with the trading band rules needed to govern when it buys and sells petroleum from the U.S. domestic petroleum market. Table 1 lists the parameters used to configure the SPMR.

Table 4. Strategic Petroleum Market Reserve Parameters

Parameter	Value	Description
monitorPeriod	10	A time constant used to determine when to sample prices from the market and make a decision to buy, sell, or do nothing.
tAveragePrice	2000	A time constant for how long, in terms of time, is the simple moving average window
reserveLevel	1000	Initial amount of resource endowed to the reserve.
proposalAmount	50	The amount of resources to propose when buying or selling from the SPMR.

4 Analysis

We are modeling the SPMR with an initial reserve capacity which can increase or decrease depending on whether or not the SPMR is buying or selling petroleum. There is not limit on the total amount of petroleum which can be bought or sold only the quantity proposed. All of our simulations configure the SPMR to have 1000 units of petroleum in the reserve. This initial amount is somewhat arbitrary and represents a large buffer for U.S. consumption requirements.

Output results from the Nation-State ExM are stated in terms of the percent deviation in price during the period of resource supply disruption. The magnitude of the resource disruption is stated as a fraction of the SPMR petroleum reserve capacity. For each environment configured, a simulation was run with and without a U.S. SPMR. The SPMR was designed to automatically buy and sell petroleum from the market when the trading bands indicated intervention was warranted.

Figure 4 illustrates the percent change in price for the various environments of international petroleum supply disruption (see Table 3). The y-axis lists the percent change in price from the pre-disruption average spot price to the maximum price during the price spike. The x-axis lists the magnitude of the resource disruption stated as a fraction of the SPMR resource level. For example, the first data points are for a simulation where the total international resource loss was 50% of the SPMR capacity and the resulting price was driven up 2.5%.

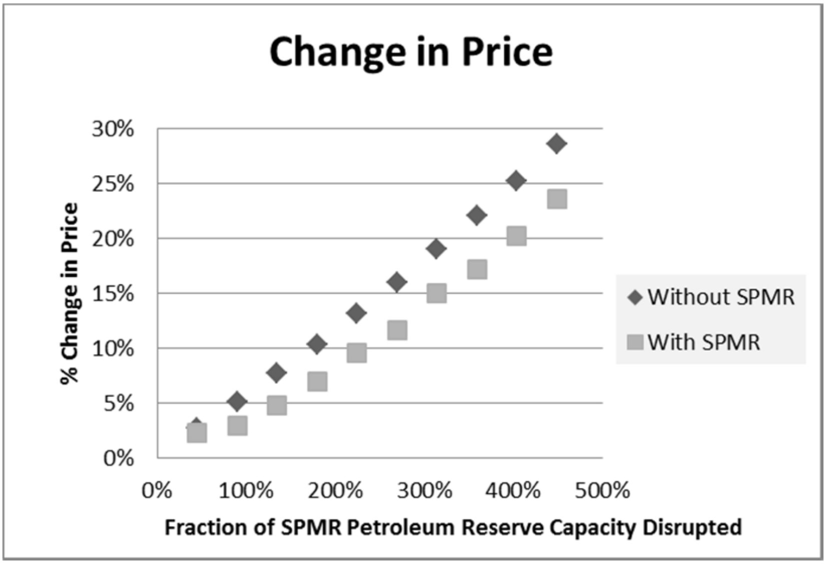

Fig. 4. Comparison of the change in price due to disruption of petroleum for simulations with and without a SPMR

Modeling results show a linear relationship between the price spike and the level of disruption to petroleum supply and indicate that having a SPMR reduces a price spike but did not eliminate it. At the smallest modeled disruption, the impact of the SPMR on the price spike is minimal; as the magnitude of disruption increases, the SPMR buffers the spike more effectively. The implementation of buying and selling rules in accordance with trading bands explains this behavior. Small changes in the average spot trading price are not that far outside of normal price fluctuations and thus require little or no intervention from the SPMR. As disruptions become larger, more dramatic changes in price signal a larger response from the SPMR. In our study, the response of the SPMR is limited by its resource level, which is why we stated the disruption as a fraction of the SPMR reserve capacity.

Figure 5 depicts the effectiveness of the SPMR at buffering price spike. The y-axis shows how much of the price spike was buffered by the SPMR. The x-axis lists the magnitude of the resource disruption stated as a fraction of the SPMR resource level.

The results shown in Figure 5 demonstrate that the SPMR is most effective when mitigating a disruption in supply which is relative in size to the SPMR capacity. The disruption scenarios we implemented affected the international production of petroleum, so at first glance these results were puzzling. Because the U.S. market purchases only a fraction of the international production of petroleum (see Table 1), we anticipated that the SPRM would be able to mitigate disruptions much larger than

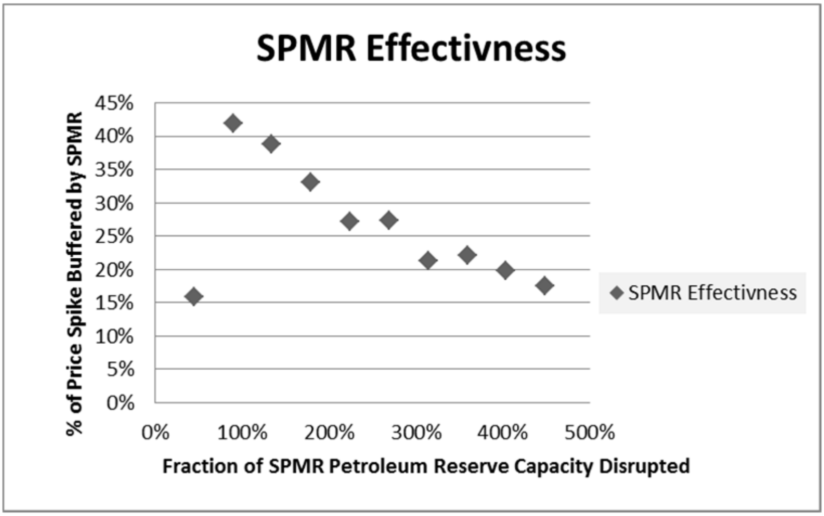

Fig. 5. Effectiveness of the SPMR in buffering price shock due to disruption

the resources it has available to sell. Additionally, the SPRM sells only to the U.S. domestic market and the impact of a disruption to international petroleum production would only fractionally affect the U.S. On further investigation we found that the open access of U.S. petroleum producers and consumers to both domestic and international markets causes prices to equalize in both markets. The effect of the SPMR selling petroleum on the U.S. domestic market is a reduction in the spot trading price for the domestic market. U.S. producers selling petroleum do not have an incentive to sell in the domestic market if they can get higher prices in the international market. Therefore both the U.S. domestic market and the international market will always have the same spot trading price for petroleum.

5 Conclusion

The results of this study indicate that implementation of a national policy for maintenance of a Strategic Petroleum Market Reserve would effectively buffer short-term disruptions to petroleum resource availability and provide some level of price stability that could not be achieved without it. Utilizing trading bands to determine when to buy and sell from such a reserve allows the petroleum market to function without intervention unless spot prices deviate from normal trends. By configuring the trading bands to use a Simple Moving Average to determine normal price trends and setting the upper and lower bands two standard deviations from the SMA, 95% of the price movement will fall within those bands. The SPMR would only interact with the market when prices rise or fall outside of the trading bands. When domestic and international markets are frictionless, the amount of resource needed to respond to a disruption in supply is not limited to the relative disruption to the domestic consumers, but is relative to the absolute amount of resources disrupted.

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