Simulating the impacts of a strategic fuels reserve in California

Andrew Ford*

Program in Environmental Science and Regional Planning, Washington State University, Troy Hall, Pullman, WA 99164-4430, USA

Abstract

This paper describes a simulation analysis of the impacts of a strategic fuels reserve (SFR) designed to limit the increase in gasoline prices in the days following a refinery disruption. The analysis is based on a computer simulation model developed for the California Energy Commission. The model simulates the supply of gasoline as the sum of refinery production, cargoes arriving from outside California, withdrawals from private storage and the release of gasoline from the SFR. The demand for gasoline is the sum of the retail demand and the wholesale demand to rebuild inventory. The paper presents simulations to illustrate the impact on California consumers of refinery disruptions of different size and duration. The simulations are repeated with a strategic reserve operated with the time-swap mechanism proposed for California. The simulations demonstrate large intended benefits of a SFR in the event of a major refinery disruption. The simulations are then repeated with an unintended impact. The new simulations show that the SFR could lead to negative impacts on California consumers in the event of small disruptions. The paper concludes that the overall impact of the SFR is likely to be dominated by the frequency of large disruptions.

Keywords: Gasoline; Reserves; Simulation

1. Background

Gasoline prices in California are more volatile than in the rest of the country due to a variety of factors including the insular nature of the California market and the unique fuel specifications to improve air quality (Stillwater, 2002, p. 5). According to Finizza (2002, p. 1), volatility in gas prices has increased since the introduction of CARB Phase II gasoline and has remained at high levels since 1999. (CARB—California Air Resources Board, one of several acronyms listed in Table 1.) In 1999, following a series of refinery outages and price spikes, the California Attorney General created a task force to investigate price volatility. The efforts of the task force led to a report on gasoline pricing (AG, 2000) and to Assembly Bill 2076.

AB 2076 called on the California Energy Commission (CEC) to examine the feasibility of operating a strategic fuels reserve (SFR). The CEC was directed to study the costs and benefits of a SFR designed to insulate California consumers and businesses from short-term price increases arising from refinery outages and other similar supply interruptions. AB 2076 also directed the CEC to examine an appropriate level of reserves, adding “in no event may the reserve be less than the amount of refined fuel that the commission estimates could be produced by the largest California refinery over a two-week period” (Stillwater, 2002, p. xv). The CEC issued two reports on the SFR in July 2002 (Stillwater, 2002; Finizza, 2002).

The Stillwater report concludes that “the California gasoline market suffers from insularity caused by its unique specifications, a subsequent lack of liquidity, inability to lock in pricing for forward trades, and impediments to market entry by outside sources.” These factors are listed along side of the “supply disruptions identified as a cause of price spikes” that led to the Stillwater study. The Stillwater report found “overwhelming evidence” of the consumer benefits associated with the creation of an SFR. It called for the state of California to “issue a tender for the creation of a 5 million barrel of versatile petroleum product storage under long-term lease agreements.” A central principle is a SFR that operates free of government interference with market forces: “unlike European, Asian and US federal reserve systems, California SFR inventories will not be sold at all. Its gasoline will be ‘time-traded’…contractual volumes will be loaned out.

*Tel.: +1-509-335-7846; fax: +1-509-335-7636.
E-mail address: forda@mail.wsu.edu (A. Ford).
on the next pipeline cycle for replenishment within ‘x’ number of weeks.” (Stillwater, 2002, p. B-4)

In the second report, Finizza describes a mathematical model of the price impacts of refinery disruptions in California. The model allows for refinery disruptions of different size and duration, and it calculates the price impact on California consumers. The SFR is represented by a limit on the price impact based on an estimate of the “time swap auction premium,” the portion of the price spike that an SFR could eliminate. The model calculates expected impacts across a wide range of disruptions with the help of “Crystal Ball,” a Monte Carlo estimator add-in to Excel. Finizza found “the net benefit of the SFR to the California consumer of avoiding prices spikes” at around “$400 million per year against an annualized cost of $20 million.” He estimated that the benefits can “rise to $700 million or fall to below $200 million” and noted “even at the low value, the benefits are an order of magnitude above the projected costs.”

The reports from July of 2002 focus on the intended impacts of the SFR. Both reports conclude that the intended impacts are an order of magnitude above annualized cost of running the SFR. These studies mentioned the possibility of unintended impacts such as the displacement of private storage by the creation of storage in the SFR. According to the Attorney General’s report (AG, 2000, p. 10), the subcommittee assigned to study reserves “expressed concern that a state reserve would lead refiners to reduce their own inventory levels.” On the other hand, the Stillwater report concludes that “it is very unlikely that the presence of a reserve…will have any significant impact on inventories currently held by the industry” (Stillwater, 2002, p. 70).

In July 2003, the CEC staff issued a draft committee report with recommendations to the Governor and the Legislature. Staff found that the intended benefits could be substantial, with estimates of annual benefits ranging from $140 million to over $600 million. These intended benefits would far outweigh the estimates of annual costs. Despite the large benefits, staff recommended that California not proceed with the SFR because of concerns about unintended consequences. Staff expressed concerns that the creation of an SFR would reduce private storage and the total supply of gasoline in California, for example. Staff also argued that private inventories have been increasing in recent years “which reduces the need for SFR public storage.” The report concluded with recommendations for the creation of a state licensing authority for petroleum storage and infrastructure.

2. Purpose and relevance

This paper describes a simulation analysis of the changes in the spot price of gasoline following the disruption of a refinery. The analysis is based on a short-term model of the wholesale gasoline market in California. Compared to previous analyses, the simulations shown here provide a more detailed description of gasoline supply, including the prompt supply from the SFR. The simulations also provide a closer look at the long delays that limit the demand-side response in California’s gasoline market. The model was constructed based on discussions with staff and consultants at the CEC, the reports by Stillwater and Finizza and the theory of commodity spot markets published by Pindyck (2001). The analysis focuses on a SFR with the time swap mechanism proposed in California. The time swap mechanism is a unique feature which is designed to remove legitimate concerns over when supplies from a public reserve would be released into a market.

The issues surrounding the operation of fuels reserves extend beyond the borders of California. In the USA, for example, the federal government operates a strategic petroleum reserve (SPR) as well as a northeast heating oil reserve (NHOR). Other countries, such as Japan and Korea, have a history of government actions to ensure adequate petroleum reserves. And European countries often store reserves in large volumes kept outside the normal distribution channels, with the release mechanisms designed for exceptional circumstances (Stillwater, 2002, pp. 46–52). The analysis presented in this paper demonstrates the applicability of computer simulation modeling to fuel reserves in general.

3. Method of analysis

The analysis is based on the system dynamics approach pioneered by Forrester (1961) and explained in recent texts by Ford (1999) and Sterman (2000). System dynamics models are normally implemented with “stock and flow” visual software to aid in model construction and testing. The gasoline model was implemented with the IThink software from High

<table>
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<tr>
<th>Table 1</th>
<th>Acronyms and units in this paper</th>
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<tr>
<td>AB 2076</td>
<td>Assembly Bill 2076</td>
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<td>CARB</td>
<td>California Air Resources Board</td>
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<td>CEC</td>
<td>California Energy Commission</td>
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<td>MCY</td>
<td>Marginal convenience yield</td>
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<td>NHOR</td>
<td>Northeast heating oil reserve</td>
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<td>SFR</td>
<td>Strategic fuels reserve</td>
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<tr>
<td>SPR</td>
<td>Strategic petroleum reserve</td>
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<tr>
<td>cpg</td>
<td>Cents per gallon, a measure of the price of gasoline</td>
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<td>TB</td>
<td>Thousands of barrels, a measure of gasoline storage</td>
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<td>TBD</td>
<td>Thousands of barrels per day, a measure of gasoline production</td>
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Performance Systems (http://www.hps-inc.com/). The model was designed for highly interactive simulation, a form of simulation sometimes described as a “management flight simulator.” The value of management flight simulators has been described for business systems by Morecroft and Sterman (1994) and for environmental systems by Ford (1999). Flight simulators are models designed with a “user friendly” interface to encourage interactive and frequent simulations. The gasoline model has been designed with such an interface, but the interface is not the focus of this paper. Rather, the paper concentrates on a simulation analysis of the SFR.

Stocks and flows are the basic building blocks of system dynamics models, and Fig. 1 shows the key stock and flows of the gasoline model. Fig. 1a shows the model variables as they appear in the Ithink software. Fig. 1b shows the corresponding variables that would appear in a differential equation to describe the gasoline in private storage. System dynamics models are comprised of a coupled set of nonlinear differential equations, with a separate differential equation for each stock in the model. The differential equations are “solved” through numerical integration, an approach which is valued in many disciplines, ranging from ecology to economics (Ford, 1999; Holling, 1966; Williams and Wright, 1991; Zellner, 2002).

The stock of private storage in Fig. 1a is measured in TB, thousands of barrels. The stock is influenced by two flows, each measured in TBD, thousands of barrels per day. The stock is increased by the flow “excess production adds to storage” and it is reduced by the flow “withdrawals from storage.” The double lines represent the flow into or out of the stock. The remaining variables in Fig. 1a are converters used to help explain the flows. In this example, the flow feeding into the stock is identical to the “Excess Production.” The flow draining the stock is influenced by the “Excess Retail Demand.”

Fig. 2 shows three stocks to represent gasoline in transit toward California. These stocks are designed with vertical slats to remind us that they are “conveyors”, a special category of stock whose outflow is controlled by the timing of the inflow and the length of the transit time (Ford, 1999). The model distinguishes between two types of cargoes arriving from outside of California. The regular cargoes arrive at a constant rate regardless of the disruption. The lower part of Fig. 2 shows two stocks to represent the emergency cargoes on the way to California. Orders for emergency cargoes would be placed shortly after the disruption, and there is a 14-day transit delay before they are received in California and contribute to the “supply from cargos.”

The stocks and flows in the previous diagrams are easy to visualize because it is easy to visualize the flow of gasoline from one location to another. Fig. 3 shows a stock variable used in a somewhat different manner. In
this case, the stock represents the spot price measured in cpg. The flow is the “spot price change” which is measured in cpg/day. This flow is a “bi-flow;” it can cause the spot price to rise or to decline. The flow is controlled by the “fractional daily change in price.” If the supply falls short of the demand, the fractional change is positive, and the spot price increases. If the supply exceeds the demand, the fractional change is negative, and the spot price declines. The “Supply of Gasoline” is measured in TBD and is the sum of:

- refinery production,
- supply from cargoes,
- withdrawals from private storage, and
- supply from the SFR.

The “Demand for Gasoline” is the sum of the retail demand and the wholesale demand to rebuild inventory.

Figs. 1–3 provide a quick look at the main stocks and flows in the model. Before proceeding further with the model description, it is useful to show an example of simulated behavior to illustrate the use of the model. When the simulated dynamics are explained, the paper returns to a description of the assumptions and structure of the model.

4. Example of a simulated disruption

California has around 1000 TBD of refinery capacity. As an example of a simulated disruption, let’s consider a loss of 10% of the capacity for 15 days, as shown in Fig. 4. The disruption begins in the 20th day and ends in the 35th day. The simulation runs for 100 days to allow ample time for the price to return to the equilibrium value shown at the start of the simulation.

For clarity, we assume that the system is in equilibrium at 60cpg during the first 20 days of the simulation. Fig. 4 shows that the combination of refinery capacity and regular cargoes is slightly larger than the retail demand. This means that supply is adequate to meet the demand, but the system is operating with refineries at nearly 100% utilization. When the 100 TBD of capacity goes out of service in the 20th day, the combination of refinery capacity and regular cargoes falls below the retail demand. The spot price increases rapidly during the next 15 days. The refinery is back in operation in the 35th day, and Fig. 4 shows that the price would descend to values below the initial equilibrium. The simulation concludes with a slow recovery to the initial equilibrium conditions.

Californians consume approximately 40 million gallons of gasoline per day (Finizza, 2002, p. 66). If there were no disruption, the total wholesale payments would be 40 million gallons/day multiplied by 60cpg multiplied by 100 days for a total of $2400 million. In the simulated disruption the spot prices vary from day to day, sometimes higher than 60cpg, sometimes lower. The model keeps track of the cumulative wholesale payments during the entire simulation. For the base case in Fig. 4, the total turns out to be $2565 million, $165 million more than if there had been no disruption. In this case, the impact is said to be $165 million. This simple measure is based strictly on the increase in consumer expenditures due to the outage. The impact does not address the lost consumer surplus (Finizza, 2002), a topic which is beyond the scope of the paper.

Fig. 5 shows the simulated behavior of “precautionary storage.” Precautionary storage is defined as total private storage less the storage required for operating reserves. Precautionary storage is constant at 2000 TBD or 2 million barrels during the first 20 days of the simulation. Precautionary storage is reduced during the 15-day interval of the outage. The loss of production is 100 TBD times 15 days or 1.5 million barrels. (Some call the 1.5 million barrels the “disrupted barrels.”) Fig. 5 shows that the precautionary storage is reduced during the 15 days, but not by the entire 1.5 million barrels that one might expect from the “disrupted barrels.” The decline in storage is mitigated somewhat by a small increase in refinery utilization and by a small decline in retail demand.
Fig. 5 shows that precautionary storage increases rapidly around the 35th day of the simulation, the time when the capacity is back in operation and emergency cargoes arrive in California. Precautionary storage reaches around 2.6 million barrels by the 50th day of the simulation. This is the period when spot prices are at their minimum value. The low spot prices cause refinery utilization to fall somewhat. Lower refinery production allows the precautionary storage to gradually return to the 2 million barrels seen at the start of the simulation.

Fig. 6 shows the retail price compared with the spot price with the vertical scaled from 0 to 200 cpg, the same scale used previously. The model assumes that the retailers have 90 cpg in fixed expenses, so the simulation begins with the spot price at 60 cpg and the retail price at 150 cpg, a value shown by Stillwater (2002, p. 95). The spot price increases rapidly during the 15 days of the disruption, peaking at 117 cpg in the 35th day of the simulation. There is an 18-day lag in passing the wholesale price increases to the retail level. The retail consumer would experience the greatest impact around the 40th day. The retail price has risen by around 13% by this time, and the consumers react with a 1.3% reduction in gasoline consumption. This reaction is too little and too late to make a difference in the upward trajectory of the spot price. The small reduction in retail demand appears in the simulation around the time that emergency cargoes have arrived, the refinery is back in operation, and the spot price is descending rapidly. With these assumptions, the demand-side response will lead to a somewhat lower prices when the system bottoms out around the 45th day of the simulation.

Fig. 7 shows the forward price compared with the spot price. The simulation begins with the spot price at 60 cpg and the forward price at 62 cpg. The forward price refers to delivery of gasoline one month in the future. The forward price exceeds the spot price by 2 cpg; the markets may be said to show a “spread” of 2 cpg. The forward price is calculated as an endogenous variable based on the spread to be expected from a “Working Curve” (Working, 1949). With 2000 TB of storage, the expected spread is 2 cpg, a situation called
“contango” in the language of the market (Duffie, 1989, p. 101). According to Keynes (1930, Vol. II, Chapter 29) and Duffie (1989, p. 101), a contango is to be expected when there are surplus stocks and “this contango must be equal to the cost of the warehouse, depreciation and interest charges of carrying the stocks.”

Fig. 7 shows that the market situation changes shortly after the refinery outage appears in the 20th day of the simulation. Within a few days, the spot price has increased sufficiently to exceed the forward price. According to Pindyck (2001, p. 17), the markets may be said to exhibit “strong backwardation.” By the 30th day, for example, the spot price is at 90 cpg, and the forward price is at 78 cpg. Fig. 6 shows that the two prices peak around the 35th day of the simulation. The spot price reaches 117 cpg while the forward price reaches 99 cpg. Within a few days, however, the spot price has descended rapidly, and the markets have returned to the contango situation seen at the start of the simulation.

5. Assumptions for gasoline supply

The supply of gasoline is comprised of refinery production, supply from cargos, supply from the SFR and withdrawals from storage. Refinery production is assumed to vary with a lagged value of the spot price, but there is little room for increased refinery output because the simulation begins with the refineries operating at 99% utilization. Emergency cargoes are ordered in the days following the outage, with the total orders matching the “disrupted barrels” of the outage. However, there is a 14-day delay before the emergency cargoes arrive in California. If the market is to clear, the supply of gasoline must come from the draw down of private storage. Consequently, the key assumptions on the supply side of the model are the assumptions describing the draw down of private storage.

The simulation begins with 21 million barrels of private storage, 19 million of which is needed for operating reserves. The precautionary storage is only 2
million barrels. The model assumes that owners of this storage assign value based on the theory of storage by Pindyck (2001). Pindyck argues that the value of storage may be represented by the MCY, the marginal convenience yield measured in cpg/month. He describes the MCY as the value of the flow of services accruing from holding the marginal unit of inventory, and he uses the terms “marginal convenience yield,” “price of storage” and “marginal value of storage” synonymously. He states that the price of storage will rise sharply as the private storage falls and that we “would expect the demand for storage function to be downward sloping and convex.”

Although Pindyck gives only general advice about the shape of the storage function, he argues that one can estimate the net convenience yield if the markets are to “avoid arbitrage opportunities.” His estimates of the MCY are based on the futures prices, risk-free interest rate, spot prices, and unit cost of physical storage over the interval from 1984 to 2000. A typical value of the inferred spot price is 60cpg; a typical value of the convenience yield is 5cpg/month. He describes the convenience yield for gasoline as “economically significant” and his measure of significance is to compare the convenience yield to the spot price. The monthly marginal convenience yield is said to be 8.1% of the mean spot price.

The model starts the simulation with precautionary storage at 2000 TB and the MCY at 6cpg/month. The cost of storage at 1cpg/month based on the Stillwater estimate of monthly cost to lease storage. Thus, the starting value of the net convenience yield is 5cpg/month, which turns out to be the mean value estimated by Pindyck. The model assumes that 8%/month may be used as a standard value of the percentage net basis. If owners of storage see a Percentage Net Basis of 8%/month, they are willing to release gasoline into the spot market. But if the Percentage Net Basis rises above 8%/month, gasoline is more valuable held in storage. Owners would be reluctant to release gasoline under such conditions.

6. Assumptions for gasoline demand

Recall from Fig. 3 that the demand for gasoline is comprised of the retail demand and the wholesale demand to rebuild inventory. The main demand is the retail demand, which is normally set at 1180 TBD, the Stillwater estimate of the base case demand in the year 2002. The retail demand will respond to changes in the retail price with a price elasticity of –0.1, the middle estimate advocated by Finizza (2002, p. 62). The model assumes that retail prices are comprised of 90cpg in fixed expenses and a delayed pass-through of the wholesale prices. The simulation begins with the retail price at 150cpg, as shown in Fig. 6. Wholesale prices increase rapidly during the outage, but there are substantial delays to pass the price changes through to the retail level. The delays are long and asymmetric, as discussed by Finizza (2002) and originally reported by Borenstein (1992). The asymmetric delays are represented by an 18-day, first order exponential lag for passing increasing prices to retail. The corresponding delay for passing declining prices to retail is 28 days. These are long delays compared to the typical duration of a refinery outage. The overall impact of the long delays is evident in the Fig. 6 simulation for a 15-day outage. Fig. 6 shows that the California consumer feels the main price impact of the refinery disruption after the refinery is back in operation and the emergency cargoes have arrived in California. There is a small consumer response, but this response comes too late to affect the peak price. Instead, the consumer response reshapes the downward trajectory of the spot price. (The consumer response causes the spot price to fall to lower levels around the 45th day of the simulation.)

The other component of the demand for gasoline in the wholesale markets is the demand for gasoline to rebuild inventory. This demand appears when inventories fall to low levels, and the percentage net basis rises well above the standard value of 8%/month mentioned previously.

7. Feedback structure of the model

At the heart of the system dynamics approach is the simulation of information flows that tie the different parts of a system together. The interactions among different parts of the system lead to closed chains of cause and effect which form the positive or negative feedback loops which control system behavior. The standard modeling practice is to make sure the key loops are simulated in the model. It is also useful to identify and discuss the key loops through “causal loop diagrams” like the diagram shown in Fig. 8.

This diagram shows the two loops that normally come to mind when discussing the supply and demand for gasoline. In the top loop, higher spot prices lead (after a delay, marked by the \(//\)) to higher retail prices, a reduction in demand, and an increase in the supply/demand ratio and a subsequent reduction in the spot price. This is an example of negative feedback, noted by the (-) in the middle of the loop. The refinery response loop is the lower loop in Fig. 8. If the spot price were to increase, we would see an increase in refinery production, an increase in the supply/demand ratio and a subsequent reduction in the spot price. Once again we have negative feedback.

The retail demand and refinery production are much larger than other variables in the model, so one might
think that the loops in Fig. 8 will dominate the simulated response to a disruption. But this is not the case. Delays and constraints limit the responsiveness of these loops in the days following a disruption. The refinery loop is slowed by a lag as refinery owners observe and react to changes in the spot price. More importantly, this loop is limited by the starting assumption that 99% of refinery capacity is already in operation at the start of the simulation. The loops in Fig. 8 provide only a small response in the days following a disruption.

Fig. 9 turns our attention to the feedback loops that respond more promptly to a simulated disruption. The upper loop is labeled the storage control loop; it represents the behavior of those who own the gasoline in private storage. Imagine how the owners would react if there were a reduction in refinery production, an increase in the excess demand, withdrawals from storage, a reduction in the gasoline remaining in storage, an increase in the marginal convenience yield and an increase in the net convenience yield. Continuing around the “storage control loop” if the spot price were fixed, an increase in the net convenience yield would lead to an increase in the percent net basis, a sign that gasoline in storage has become more valuable. Owners would then be reluctant to release stored gasoline into the spot market, and their reluctance would slow the reduction of gasoline held in private storage.

But we know that the spot price does not remain fixed in the days following the disruption. It is driven upward by the actions of the “clear the market loop” in the lower part of Fig. 9. This loop acts to raise the spot price whenever the supply falls below the demand. The market-clearing loop raises the spot price until sufficient supply is forthcoming to meet the demand. The main source of supply in the days immediately following the disruption is withdrawals from private storage. Consequently, the market-clearing mechanism acts to raise the spot price to induce owners of storage to release their gasoline into the spot market. This will happen when the spot price rises sufficiently to keep the percent net basis at or below the standard value.

The two loops in Fig. 9 act continuously and without delay in the days following the disruption. The upper loop represents the behavior of owners of storage; the lower loop represents the market. Their combined actions will drive the spot price higher and higher until the disrupted refinery is back in operation or the emergency cargoes arrive from outside of California. With outages of short duration, the increases in spot prices will be capped when the refinery returns to operation. With outages of long duration, the increases in spot prices will be capped when the emergency cargoes arrive.

8. Disruptions with different duration

The base case simulation assumes a 15-day disruption of 100 TBD of refinery capacity. Fig. 10 shows the impact of a shorter disruption; Fig. 11 shows the impact of a longer disruption; Fig. 12 compares the prices in all three simulations to show the sensitivity of the results to the duration of the disruption.

Fig. 10 shows that the spot price would increase during the 10 days that the refinery capacity is out of service. The spot price reaches a peak of 90 cpg in the 30th day and descends slowly over the next 6 days. The slow descent is made possible by the 100% utilization of the refinery capacity. With full utilization, the combination of refinery production and regular cargoes is somewhat larger than the retail demand. This causes a slow decline in the spot price until the 36th day of the
simulation. This day marks the arrival of emergency cargoes. Supply now exceeds demand by a larger margin, and the price descends more rapidly during this interval. The price falls below 60cpg and gradually returns to 60cpg during the second half of the simulation. The impact of the new disruption is $93 million, much lower than the $165 million impact reported for the 15-day disruption.
Fig. 11 shows the simulated response to a 20-day disruption. In this case, the refinery capacity does not return to operation until the 40th day of the simulation. The spot price would increase rapidly, peaking at 124 cpg by the 36th day of the simulation, the day when emergency cargoes begin to arrive in California. The spot price descends rapidly and bottoms out around 51 cpg by the 50th day of the simulation. The remainder of the simulation shows a slow recovery to equilibrium conditions. The simulated impact of this disruption is $184 million, around 12% higher than the $165 million impact for a 15-day disruption.

Fig. 12 compares the spot prices from the three simulations. The comparison shows that the extension from 10 days to 15 days lead to a major increase in the run-up of prices. The peak price is 90 cpg with the 10-day disruption, 117 cpg with the 15-day disruption. The peak is only slightly higher with the 20-day disruption. The impact of the longer disruption is limited by the arrival of emergency cargoes. Recall that orders for these cargoes begin around 2 days after the start of the disruption and that the cargoes arrive after a 14-day transit time. The total lag time for emergency cargoes is around 16 days in these simulations. With these assumptions, disruptions much longer than 15 days are not likely to lead to significantly higher impacts.

9. Disruptions of different size and duration

Fig. 13 summarizes the impacts in nine simulations with disruptions of different magnitudes and duration.

The largest impacts appear in the back row for 150 TBD disruptions. These impacts would appear in the extraordinary case of a loss of 15% of the state’s refinery capacity. This is a major loss, much larger than most historical losses recorded by Finizza (2002, p. 14). However, it is important to simulate these large disruptions because of their huge impact. Indeed, the legislature emphasized the need to protect California from such disruptions when it called on the CEC to examine a disruption of California’s largest refinery over a two-week period. Finizza (2002, p. 76) estimates the disrupted barrels for such an event at 2.3 million. Dividing 2.3 million barrels by 14 days gives the size of the disruption at 164 TBD. Thus, one may think of the “back row” results as indicative of the major disruptions which the legislature had in mind when calling for a study of the SFR. The “back row” impacts range from around $200 million to well over $500 million depending on the duration of the disruption.

The middle row in Fig. 13 represents the loss of 10% of the state’s refinery capacity. This is also a major loss of capacity, and the model shows major impacts ranging from around $90 million to $180 million. The front row results represent the loss of 5% of the state’s refinery capacity. This is a smaller loss of capacity, and impacts are around $40 million. The results in the front row may not seem as important, but smaller disruptions are much more frequent, according to the frequency distributions compiled by Finizza (2002, p. 14). For example, the “average” disruption from Finizza (2002, p. 13) is a 19-day outage of only 21 TBD of capacity. The disrupted barrels would amount to only about 0.4 million, somewhat smaller than the smallest disruption in Fig. 13.

10. Sensitivity analysis

Sensitivity analysis is useful when model parameters are highly uncertain. The gasoline model contains parameters whose estimates come from the literature, from previous studies or from discussions with staff and consultants. As an example of a sensitivity test, this paper focuses on the price elasticity of demand, a key parameter in the previous modeling by Finizza. Recall that the base case estimate is –0.1, based on Finnizza’s review of elasticity studies of US and international gasoline markets. Fig. 14 compares the spot price in three simulations with a 15-day disruption of a 100 TBD of capacity. The middle simulation is the base case result shown previously in Fig. 4: the spot price peaks at 117 cpg around the 36th day of the simulation. If we reduce the price elasticity to zero, the spot price peaks at 122 cpg, only 5 cpg higher. If we double the price elasticity of demand, the price peaks at 112 cpg, only 5 cpg lower. Fig. 14 shows that the peak price is only...
slightly changed by changes in the estimate of the price elasticity of demand.

The variations in Fig. 14 indicate that the estimate of the price elasticity is not crucial to the simulated pattern of results. This input is not particularly important because of the 18-day lag for passing wholesale price increases to the retail level. The price response of consumers is simply too late to make much difference in the upward trajectory of the spot prices. But the consumer response does lead to some differences in the downward trajectory after emergency cargoes have arrived in California.

Fig. 14 provides an example of sensitivity tests conducted by changing one parameter at a time. At this stage of the model development, “one at a time” testing is most useful to increase the learning from the model. In the future, it may be useful to expand the sensitivity analysis to allow simultaneous changes in many parameters across their range of plausibility. Comprehensive testing would allow one to assign confidence bounds to the estimates of the spot price, as explained by Ford (1999, Appendix J).

11. The intended impact of a SFR

Fig. 15 shows the variables that represent the operation of a SFR with the time swap mechanism proposed for California. The simulation begins with 5 million barrels of “Gasoline in the SFR” based on the Stillwater recommendation. The size is split between gasoline in the SFR and gasoline “on the water.” The stock of “Gasoline on the Water” represents the gasoline that has been ordered by those with obligations to return gasoline to the SFR. (Companies with a return obligation can obtain the replacement gasoline anywhere they want, but the most likely source is cargoes shipped to California. So, in that sense, the gasoline is “on the water”.) Since we are using the model to simulate a single disruption, the simulations will begin with the stock of gasoline on the water set at zero; all 5 million barrels will be in the SFR.

The key flow in Fig. 15 is the flow of “gas released from SFR.” This flow moves gasoline into a conveyor stock “Gasoline Transferred to Market” where the gasoline remains for a short interval before it contributes to “supply from SFR.” We assume that traders do not react instantaneously to changes in the spot price. Rather, it makes more sense to assume that traders watch the spot price over a “Price Observation Interval.” This lag time is set at one day, indicating that traders react to the smoothed, average value of spot prices over the previous day. We assume that traders compare the smoothed spot price to the “Average Value of the Traders’ Landed Cost for Return to SFR” to obtain the “Average Margin.” To illustrate, imagine that the spot price has climbed to 80 cpg in the days following a disruption, and the smoothed value of the spot price over the past day has reached 77 cpg. If a trader believes replacement supplies could be obtained for 67 cpg, the trader would expect a margin of 10 cpg if prompt supplies were obtained from the SFR. The average value of the traders’ landed cost is equal to the “Notional cost of External Supplies” a user input controlled by a slider on the model interface.

The “Notional Cost” is a term used by Finizza (2002, p. 70) to represent the average value of the traders’ landed cost for return to the SFR. Page 71 of the Finizza report describes the notional cost of bringing Gulf Coast supplies to California at around 15 cpg above the Gulf Coast price. The cost premium is due to 10 cpg for transport and 5 cpg for meeting CARB requirements. In his example, the Gulf Coast cost was around 8 cpg below the typical spot price in California. This suggests that the notional cost is around 7 cpg higher than the regular spot price in California. If the starting value of the spot price is 60 cpg, the default value of the Notional Cost of External Supplies would be 67 cpg.
To illustrate the impact of an SFR, let’s consider a 15-day disruption of 150 TBD of refinery capacity. This is an extremely large disruption, one that will appear with low frequency. The disrupted barrels is 2.25 million, close to the 2.3 million disrupted barrels that is emphasized in the legislation calling for a study of the SFR (Finizza, 2002, p. 76).

Fig. 15 shows that the spot price would reach the notional cost within two or three days after the outage. After around 4 days, the spot price would exceed the notional cost by the 2 cpg required as the minimum bid for a SFR auction. Fig. 16 shows that the spot price would continue to increase until around the 26th day of the simulation. This upward trend continues for several days because of the delays for traders to observe and smooth the spot price and the delay for gasoline released from the SFR to reach the market. When the gasoline does reach the market, it contributes to supply; daily supply exceeds the daily, and the spot price is driven downward. Within a few days, the spot price has fallen below the notional cost. But the outage continues for 15 days, and emergency cargoes have still not arrived in California. With these conditions, the spot price begins to increase again around the 31st day of the simulation. Within a few days, the spot price again exceeds the notional cost, triggering another round of auctions for supply from the SFR. Fig. 16 alerts us to the possibility that the presence of a SFR will not necessarily “cap” the spot price exactly at the notional cost.

Fig. 17 helps us check whether there is enough gasoline in the SFR to deal with the disruption. The simulation begins with 5 million barrels of gasoline in
the reserve. The reserve falls to around 3.2 million barrels after the two rounds of auctions. The reserve returns to 5 million barrels when the replacement supplies are received after a 6-week delay. In this simulation, the total release of gasoline amounts to around 1.75 million barrels, considerably less than the 2.25 million “disrupted barrels”.

Fig. 18 compares the spot prices in the simulations with and without the SFR. The spot prices are identical during the first 25 days of the simulation. The comparison shows that the SFR leads to substantially lower prices during days 26–54 of the simulation. This benefit is achieved by the release of gasoline into the market. On the other hand, the SFR leads to somewhat higher spot prices during days 55–75 of the simulation.

Recall that the measure of the overall impact of a simulated disruption is the increase in cumulative wholesale payments for 40 million gallons/day of gasoline during the 100-day simulation. Without the SFR, the impact of the large outage is $473 million. With the SFR, the impact is simulated at $1 million. The intended impact of the SFR under these conditions would be $472 million.

12. Simulating an unintended impact with a large disruption

The SFR could have several unintended impacts, impacts that are different from those envisioned by the legislature when it called for the study. Unintended impacts are often mentioned by those with concerns that they will erase the intended benefits of the reserve. However, unintended impacts could work in either direction, either to enhance or to reduce the benefits of the SFR. The Stillwater report (2002, Appendix B) gives an example of benefits that were not necessarily anticipated and which have not been represented in the simulations shown here. Stillwater argues that the SFR could act to link California with gasoline supplies around the world. By providing a clear price for prompt release, the SFR might induce fuels to reach California...
from Asian suppliers who would not consider shipping to the California spot market. These extra supplies might arrive during periods of low cost in Asia rather than during a disruption in California. Additional supplies from foreign sources are an unintended impact which would increase the value of the SFR relative to the simulations shown in this paper.

On the other hand, most discussions of unintended impacts focus on unanticipated impacts which could reduce the benefits of the reserve. For example, some experts are concerned that the creation of a public SFR could cause private companies to carry less precautionary reserves. This is a serious concern for the design of any public reserve, not just for fuel reserves (Meadows, 1970, Williams and Wright, 1991). The possible displacement of private reserves by a public SFR was cited by the CEC (2003, p. 6) as a “critical concern” for a SFR with 2.5 million barrels. But there does not seem to be universal agreement that displacement will be significant. For example, the Stillwater report (2002, p. 70) argues that “It is highly unlikely that the presence of a reserve limited to only 2.3 million barrels and designed with a release mechanism that creates forward liquidity will have any significant impact on inventories currently held by industry.”

As an example of an unintended impact, this paper focuses on the displacement of emergency orders. If the presence of a SFR reduces the apparent need for emergency cargoes, the markets will have less supply around two weeks after the disruption. With less supply, market prices could end up higher than shown in the simulations presented so far. The displacement of emergency orders was discussed with experts and CEC staff, and we arrived at the rough estimate that a SFR might lead to 50% displacement. Recall that emergency orders for the “disrupted barrels” are issued in the days following a disruption. For a 15-day disruption of 150 TBD of refinery capacity, for example, the emergency orders would normally amount to 2.25 million barrels. These orders begin about 2 days after the outage and are spread over a 5-day interval. The gasoline arrives after a 14-day transit delay. However, with 50% displacement, the emergency orders would amount to 1.125 million barrels.

Fig. 19 shows the spot price in the new simulation. The comparison shows that the displacement assumption leads to somewhat higher spot prices during days 47–60 of the simulation. This is the time interval when less emergency cargoes are arriving in California. When the wholesale payments are accumulated for the entire simulation, the impact of the large disruption is estimated at $32 million, higher than the $1 million impact with a SFR that does not lead to displacement. However, the impact of this large disruption without an SFR was simulated at $473 million. Thus, the overall impact of the SFR is estimated at $441 million.

13. Simulating an unintended impact with a small disruption

From this result alone, one might conclude that inclusion of the displacement factor is unimportant in judging the overall impacts of a SFR. But it is important to test the impact of an SFR across a range of disruptions, large and small. With small disruptions, the unintended impacts of displacement can turn out to be much more important, as is shown in Fig. 20.

Fig. 20 shows the spot prices in three simulations of a 15-day outage of 50 TBD of refinery capacity. The simulation shows a $39 million impact if California does not have a SFR. If we repeat the simulation with a SFR, the spot price rises briefly above the notional cost and there is a small release of gasoline from the SFR. The release is only around 250 TB, one-third of the disrupted barrels. The small release delivers some benefits, as shown in Fig. 20. For example, the prices in the two simulations with the SFR peak at 72 cpg rather than...
77 cpg. Also, the prices remain somewhat lower during the interval from the 30th to the 40th day in the simulations. After the 40th day, however, the lowest prices appear in the simulation without the SFR. These lower prices are caused by a combination of refinery production and the arrival of emergency cargoes (which are ordered a few days after the outage begins and arrive after a two-week week delivery delay).

To sort out the various price changes in Fig. 20, the model finds the cumulative wholesale payments for gasoline over the entire simulation. With no SFR, total payments are $39 million. With the SFR and no displacement, the impact is estimated at $32 million. One might say that the intended impact of the SFR is a $7 million benefit. However, if we include the assumption of 50% displacement of emergency orders, the impact of the outage is simulated at $63 million. When the unintended impact is included, the impact of the SFR is a negative $24 million. For this small disruption, the SFR would deliver negative benefits to California consumers.

These two examples are indicative of the pattern of results found across a wide range of disruptions. For large disruptions (i.e., 100 TBD or 150 TBD) the simulations show that the assumption of 50% displacement causes a rather small reduction in the benefits simulated for a SFR. The estimated benefits of the SFR are not reduced in a significant fashion by including the unintended impact. For small disruptions (i.e., 50 TBD), however, we found that the inclusion of 50% displacement could reverse the overall finding on the value of a SFR. Rather than delivering small benefits, the SFR could lead to adverse impacts for California consumers. These comparisons reinforce the notion that it is important to pay attention to both the unintended and the intended impacts of a SFR. These comparisons also demonstrate that unintended impacts can be simulated along side of the intended impacts in the same model.

14. Concluding comments

This paper describes an approach to the analysis of a strategic fuels reserve designed to provide prompt supplies of gasoline in California. The specific results apply to questions of public policy in California. The general method is useful for other states (and other countries) interested in the design of a fuels reserve. The simulation method is notable for its clear display of price and storage dynamics, its representation of the long delays that limit responsiveness on both supply and demand, and the inclusion of unintended and intended impacts within the same model.

The model described in this paper provides a more realistic simulation of gasoline price dynamic than provided by models that were previously available. On the other hand, this model could be improved as well. In my opinion, the most important task for further model development is to compare simulated spot prices with the spot price increases following a typical disruption. This is an extremely challenging task as the data on disruptions is complicated by a wide variety of factors which make it difficult to select a typical disruption suitable for comparison.

Returning to the SFR, one may draw important conclusions based on the simulations presented here. For example, one would expect the SFR to deliver huge benefits for large disruptions. The simulated benefit of a SFR in a single disruption (15-day outage of 150 TBD) was estimated at over $400 million. On the other hand, the simulations for small disruptions show that a SFR could deliver negative benefits to the California consumer. The negative results are small, but their overall impact could be substantial given that small disruptions occur with much greater frequency.

To arrive at single number to summarize the impact of the SFR, the simulated benefits from multiple disruptions should be combined with estimates of the
frequency of the different disruptions. From the results in this paper, one would anticipate that the expected value calculation would be dominated by the frequency of large disruptions. Interestingly, these large disruptions are just the sort of disruptions emphasized by the legislature when calling for the study of the SFR.

References
