CALIFORNIA
ENERGY
COMMISSION

ECONOMIC BENEFITS OF MITIGATING REFINERY DISRUPTIONS

A SUGGESTED FRAMEWORK AND ANALYSIS OF A STRATEGIC FUELS RESERVE

CONTRACTOR REPORT

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ECONOMIC BENEFITS OF MITIGATING REFINERY DISRUPTIONS

A Suggested Framework and Analysis of a Strategic Fuels Reserve

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For

The California Energy Commission

Pursuant to California State Assembly Bill AB 2076

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The US Department of Energy's Energy Information Administration and staff members of the California Energy Commission provided data to the author. The author does not warrant the accuracy of their data. The analysis can be no more accurate than the accuracy of the underlying data. In preparing this report, the author did not have available any individual company data, nor did he meet or visit with any company personnel. He drew upon his general experience with the Atlantic Richfield Company, for which he served as Chief Economist, but did not use any specific information of that company.

Changes in factors upon which the report is based can affect the results. Forecasts are inherently uncertain because of events that cannot be foreseen, including the actions of governments, individuals, third parties, and various other market participants.

This report should be read in conjunction with the Stillwater Associates' Strategic Fuel Reserve report. Any ad hoc criticism of the assumptions or methodologies contained in this report should not be summarily applied to benefits of the SFR as described in the Stillwater Report. Nor should it be read in isolation of that report.

Finally, the study is intended as a high level overview of the issues. More detailed modeling with more resources could alter and/or refine the conclusions herein.

ACKNOWLEDGEMENTS

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GLOSSARY

ANS	Alaska North Slope, term used to designate crude oil of that region
API	American Petroleum Institute
CARB	California Air Resources Board
CBA	Cost-Benefit Analysis
CEC	California Energy Commission
cpg	Cents per Gallon
DOE	U.S. Department of Energy
DTW	Dealer Tank Wagon
EIA	Energy Information Agency
FCC	Fluidic Catalytic Cracker, primary gasoline producing unit in a refinery
FTC	Federal Trade Commission
H2	Hydrogen
HC	Hydro Cracker
HT	Hydro Treater
Jobber	Independent distributor of petroleum products
LA	Los Angeles
LAX	Los Angeles International Airport
mb	Thousand barrels
mbd	Thousand barrels per day
MM	Million
MTBE	Methyl Tertiary Butyl Ether
NY	New York
NYMEX	New York Mercantile Exchange
OMB	Office of Management and Budget
OPIS	Oil Price Information Service
PADD	Petroleum Administration for Defense District.

RFG	Reformulated Gasoline meeting the requirements of the CAAA
SF	San Francisco
SFR	Strategic Fuels Reserve
USGC	US Gulf Coast
VGO	Vacuum Gas Oil
WSPA	Western States Petroleum Association
WTI	West Texas Intermediate Crude Oil

CHARTER

In 1999, following a series of refinery outages that caused significant price spikes in the California fuels markets, the Attorney General's office created a taskforce to investigate causes and recommend solutions to prevent recurrence. The efforts of this taskforce resulted in Assembly Bill 2076, which called for the California Energy Commission:

> "..to examine the feasibility of operating a strategic fuel reserve and to examine and recommend an appropriate level of reserves. If the commission finds that it would be feasible to operate such a reserve, the bill would require the commission to report this finding to the Legislature and request specific statutory authority and funding for establishment of a reserve."

The bill also provided general directions for the work to be performed

> (a) By January 31, 2002, the commission shall examine the feasibility, including possible costs and benefits to consumers and impacts on fuel prices for the general public, of operating a strategic fuel reserve to insulate California consumers and businesses from substantial short-term price increases arising from refinery outages and other similar supply interruptions. In evaluating the potential operation of a strategic fuel reserve, the commission shall consult with other state agencies, including, but not limited to, the State Air Resources Board.
>
> (b) The commission shall examine and recommend an appropriate level of reserves of fuel, but 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 refiner over a two week period. In making this examination and recommendation, the commission shall take into account all of the following:
>
> (1) Inventories of California-quality fuels or fuel components reasonably available to the California market.
>
> (2) Current and historic levels of inventory of fuels.
>
> (3) The availability and cost of storage of fuels.
>
> (4) The potential for future supply interruptions, price spikes, and the costs thereof to California consumers and businesses.
>
> (c) The commission shall evaluate a mechanism to release fuel from the reserve that permits any customer to contract at any time for the delivery of fuel from the reserve in exchange for an equal amount of fuel that meets California specifications and is produced from a source outside of California that the customer agrees to deliver back to the reserve within a time period to be established by the commission, but not longer than six weeks.
>
> (d) The commission shall evaluate reserve storage space from existing facilities.
>
> (e) The commission shall evaluate a reserve operated by an independent operator that specializes in purchasing and storing fuel, and is selected through competitive bidding.

This Study was performed within the specific framework of the Legislation, to answer as a minimum the questions asked, by the stated deadline. In addition, in cooperation with the consultant retained by the Commission for this study, Stillwater Associates of Irvine, CA, the Commission deemed it appropriate to evaluate other factors that contribute significantly to the volatility of California's fuel markets, such as breakdowns in market mechanisms for gasoline, and the inadequacy of the logistics infrastructure serving the fuels market.

INTRODUCTION

In 1999, following a series of refinery outages that caused significant price spikes in the California fuels markets, the Attorney General's office created a taskforce to investigate causes and recommend solutions to prevent recurrence. The efforts of this taskforce resulted in Assembly Bill 2078, which called for the California Energy Commission:

> "... to examine the feasibility of operating a strategic fuel reserve and to examine and recommend an appropriate level of reserves. If the commission finds that it would be feasible to operate such a reserve, the bill would require the commission to report this finding to the Legislature and request specific statutory authority and funding for establishment of a reserve."

The bill also provided general directions for the work to be performed that are pertinent to this report: (*italics are the author's*)

> The commission shall examine the feasibility, including *possible costs and benefits to consumers and impacts on fuel prices for the general public*, of operating a strategic fuel reserve to insulate California consumers and businesses from substantial short-term price increases arising from refinery outages and other similar supply interruptions.
>
> The commission shall examine and recommend an appropriate level of reserves of fuel, but 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 refiner over a two-week period. In making this examination and recommendation, the commission shall take into account …*the potential for future supply interruptions, price spikes, and the costs thereof to California consumers and businesses.*

As part of that effort, the Energy Commission asked Dr. Anthony Finizza to conduct an economic study of the economic implications of refinery disruptions in California and develop a framework for evaluating other options. The framework is applied to the Stillwater Associates' study of the Strategic Fuel Reserve. The Commission also asked the author to review relevant other studies and determine if their conclusions were still supported by more recent information. Finally, the Commission asked the author to examine the likelihood, the size, and duration of future disruptions, to determine the potential benefit of instituting a fuel reserve, and an analysis of the optimal size of the Strategic Fuel Reserve.

EXECUTIVE SUMMARY

Gasoline prices in California are more volatile than in the rest of the country. Volatility has increased since the introduction of CARB Phase II gasoline and has remained at high levels since 1999. The factors that lead to this volatility, including the "island" aspect of California, the unique specifications of the fuel, and others, are not seen to be abating in the near future. Gasoline price volatility is significantly greater than for jet and diesel fuel. Gasoline price volatility costs California consumers hundreds of millions dollars per year on the average.

Refinery disruptions, along with inadequate infrastructure, unique CARB Phase II gasoline specifications, and geographical & price-arbitrage isolation of California that make it difficult to offset a disruption, are the main causes of this price volatility. Refinery disruptions, which have occurred roughly once per month since 1996, are generally short-lived and small, with a number of notable long and severe disruptions. Retail price spikes, however, linger for up to six to eight weeks after the onset of the disruption. Disruptions have an immediate impact on wholesale prices, which get transmitted to retail prices with a lag, following an asymmetric pattern whereby the rise is faster than the fall. Disruptions are particularly troublesome in the summer blending season, when alternative gasoline supplies are not as readily available.

Price spikes due to a refinery disruption in either Northern or Southern California are transmitted throughout all of California, but not to other refining centers like the U.S. Gulf Coast or New York harbor. These spikes are more pronounced when levels of inventories are below normal.

Although this study addresses the economic impact on the state caused by refinery disruptions, and examines how a Strategic Reserve might lessen those impacts, it must be viewed in the overall context of the Stillwater Associates report on the Strategic Fuels Reserve (SFR). The innovative solutions introduced in that report propose to "connect" the State of California to external supply sources through a time-swap mechanism. Since this is a thoroughly new concept for a Strategic Reserve in the author's experience, the traditional tools of economic analysis can only approximate its benefits to the California consumer. If one accepts the proposition that California is, indeed an "island" in terms of gasoline supply and if the proposed SFR can "link" California to the rest of the world, then one is led to conclude that the economic benefits to consumers of the time-and-price bridging power of the proposed SFR is an *order of magnitude* above the cost estimates contained in this ancillary study.

The potential benefit of implementing the full SFR as proposed by the Stillwater report accrues from avoiding part of the massive addition to consumer costs that would occur if refinery disruptions behave according to the frequency, size, and severity as evident in the 1996 to 2001 time period.

The amount of additional storage required to offset the rare, large refinery disruption is, on average, significantly less than that suggested by the California Legislature. Given the significantly favorable benefit to cost that is projected for the Stillwater SFR proposal, however, the minor cost benefits from optimizing SFR inventory levels are secondary.

The calculations used to derive the optimum size for the SFR have been based on historical data. They do not take into account the possibility of significant increases in gasoline imports, or supply disruptions that may impact the California gasoline markets after phase out of MTBE. In any event, the unique SFR time-swap mechanism, and its private sector tank features as recommended by Stillwater Associates create a dynamic element not usually found in government sponsored Strategic Reserves. The optimum size of the SFR must, therefore be evaluated in conjunction with its function as an open-access gateway for lower cost gasoline supply to the state.

In summary, the benefit of the SFR to the California consumer of avoiding price spikes is projected to be about $400 million per year against an annualized cost of $20 million. The benefits can rise to $700 million or fall to below $200 under a range of reasonable assumptions. Even at the low value, the benefits are an order of magnitude above the projected costs of the SFR. In addition, the SFR will likely provide additional benefits in the form of lower average gasoline prices on the order of $150 - 350 million per year.

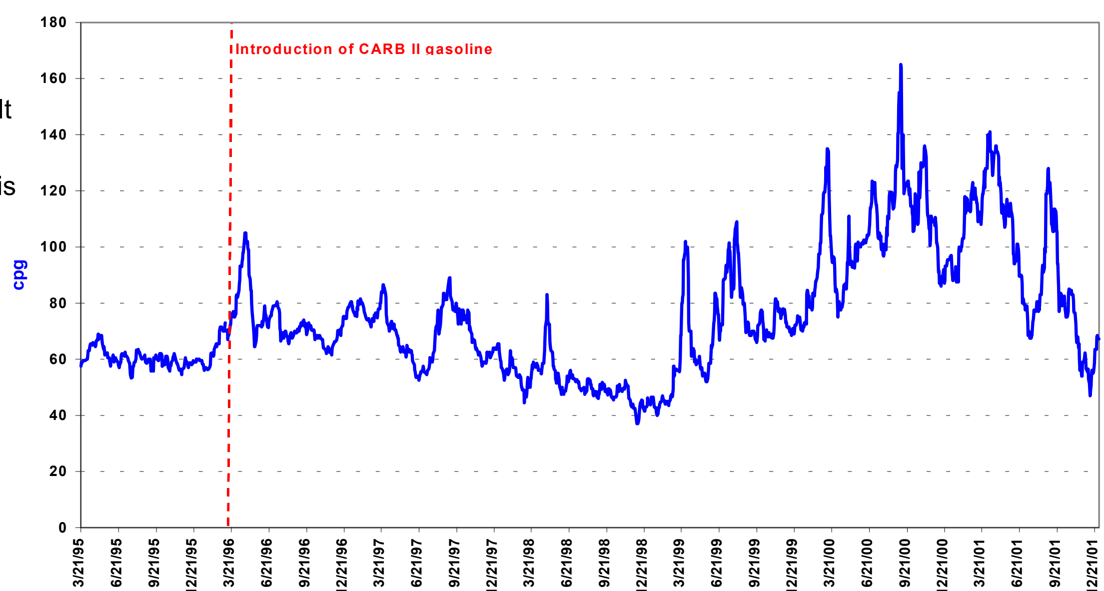
1 GASOLINE PRICE VOLATILITY

Commodity industries are inherently unstable. For most commodities, the intrinsic value of the product to the end consumer is much higher than its production cost, but competitive pressure keeps market prices near the cash cost of the leading producer except for brief periods of physical shortage when prices will soar to whatever level the market will bear. Gasoline pricing in California is no exception to this principle, and below, some of the factors contributing to price volatility will be analyzed in more detail.

1.1 Current Supply

Gasoline prices in California are more volatile than in any other region of the United States. A cursory look at data for California suggests that the volatility of gasoline prices has increased over the last several years and most notably, since the introduction of CARB Phase II gasoline in March 1996. Figure 1-1 plots the daily spot price for RFG in Los Angeles since early 1995.

Figure 1-1 – LA Spot RFG Regular Gasoline Price[1]

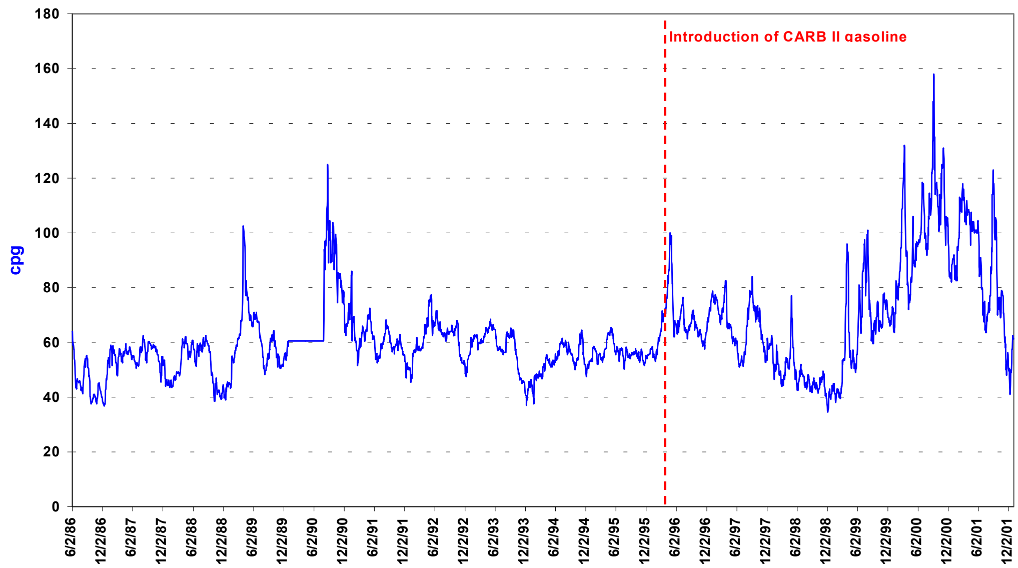


It is important to note that increased price volatility is a feature of the California landscape. The volatility has increased since 1986, as shown in Figure 1-2, which shows the trend in pricing for

[1] Source EIA and CEC data..

conventional gasoline, necessary to look back before 1995, when CARB specifications became effective.

Figure 1-2 – LA Spot Regular Conventional Gasoline



The report uses as a measure of volatility, the standard deviation of log changes in prices, $\log_e(p_t/p_{t-1})$. Table 1.1 presents the variance of returns and the appropriate F-values for the test of equality of the variances.

Table 1.1 – F-Values to Test Log Change Gasoline Prices

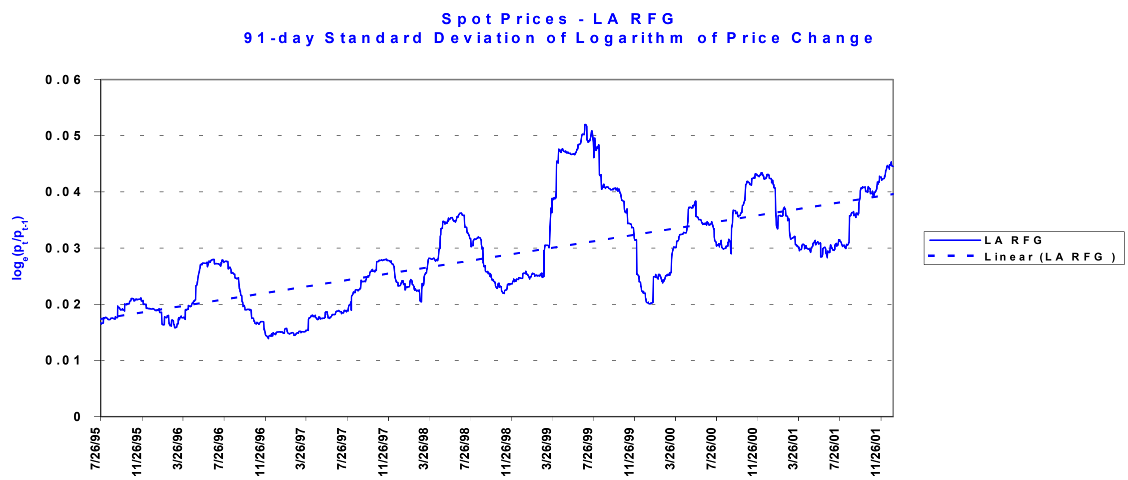
Year	Variance (x 1000)	$F=\sigma_1^2/\sigma_2^2$ (Year vs. Prior Year)	Difference in Variance Significant?
1995	3.14		
1996	4.50	1.43	Yes
1997	4.61	1.03	No
1998	8.41	1.82	Yes
1999	14.70	1.75	Yes
2000	13.20	1.11	No
2001	13.22	1.00	No

The statistical significance of the change in volatility, as measured by the variance (the square of the standard deviation) in log price changes over time, can be tested.[2] Notice in Table 1.1

[2] The test of significance for the difference between variances of two samples is the F-test. If the value of F calculated from the two years, $F=\sigma_1^2/\sigma_2^2 > F\varepsilon$ corresponding to n_1-1, n_2-1 degrees of freedom, then the hypotheses that the years are from the same population is rejected at the level ε. $\sigma_1^2=n_1 s_1^2/(n_1-1)$ and

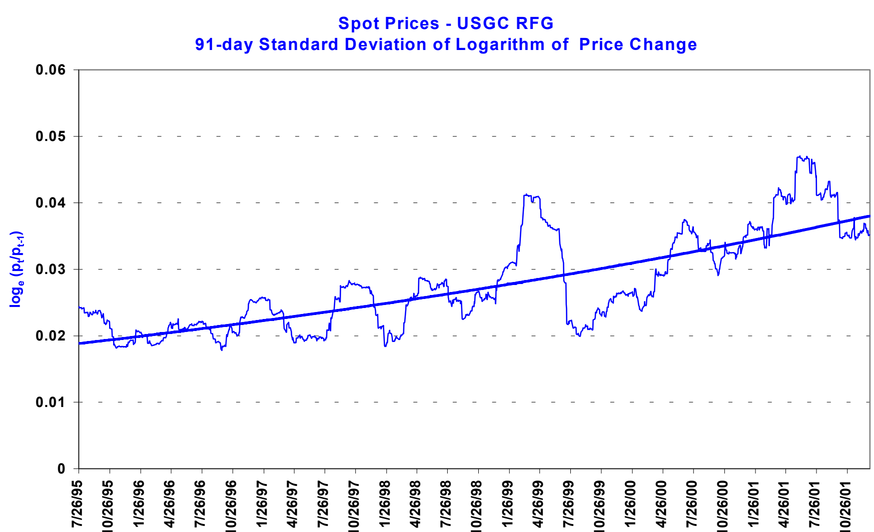
that the variance increases for 1996, 1998 and 1999. This Illustrates that one can reject the hypothesis that the variance in adjoining years is the same in 1997, 2000, and 2001[3]. Figure 1-3 show the steady increase in volatility for the Los Angeles reformulated gasoline market.

Figure 1-3 – Price Volatility of Los Angeles RFG



This increase in volatility is also evident in Gulf Coast prices, although not as significant as in California. (Figure 1-4)

Figure 1-4 – Price Volatility US Gulf Coast RFG



$\sigma_2^2 = n_2 s_2^2/(n_2-1)$ where s_1^2 and s_2^2 are the variances of the two years and n_1, n_2 are the number of observations in the two years. $F\varepsilon \sim 1.25$ for the .05 confidence level and the number of yearly observations.

California gasoline is also more volatile than New York RFG and is increasing relative to New York gasoline. (See Figure 1-5 and Table 1.2).

Figure 1-5 – Gas Price Volatility in California and New York

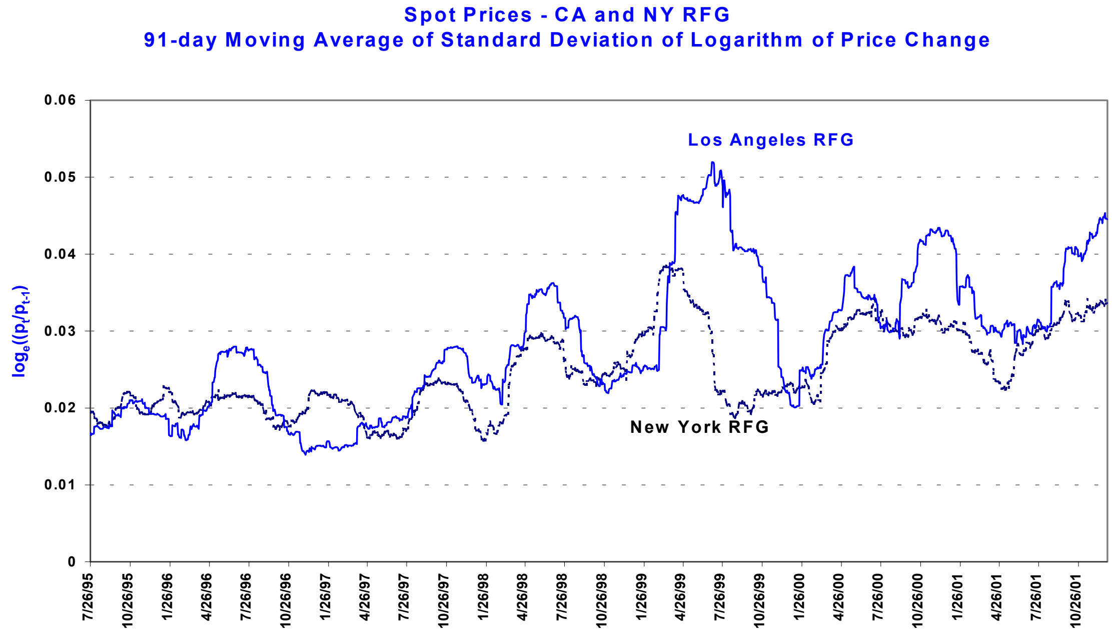


Table 1.2 - Comparison of Price Volatility: LA RFG vs. NY RFG

Year	LA RFG Variance (x 1000)	NY RFG Variance (x 1000)	LA Statistically Higher than NY?
1995	3.14	3.74	No
1996	4.50	4.35	No
1997	4.61	3.61	Yes
1998	8.41	7.25	No
1999	14.70	7.23	Yes
2000	13.20	9.43	Yes
2001	13.22	8.87	Yes

[3] The results do not change if one were to use as a measure of volatility, the standard deviation of prices.

Most of the volatility in gasoline prices is accounted for by the volatility in gasoline itself, and not its feedstock, crude oil. (See Figure 1-6 and Figure 1-7.)[4]

Figure 1-6 – RFG Less WTI

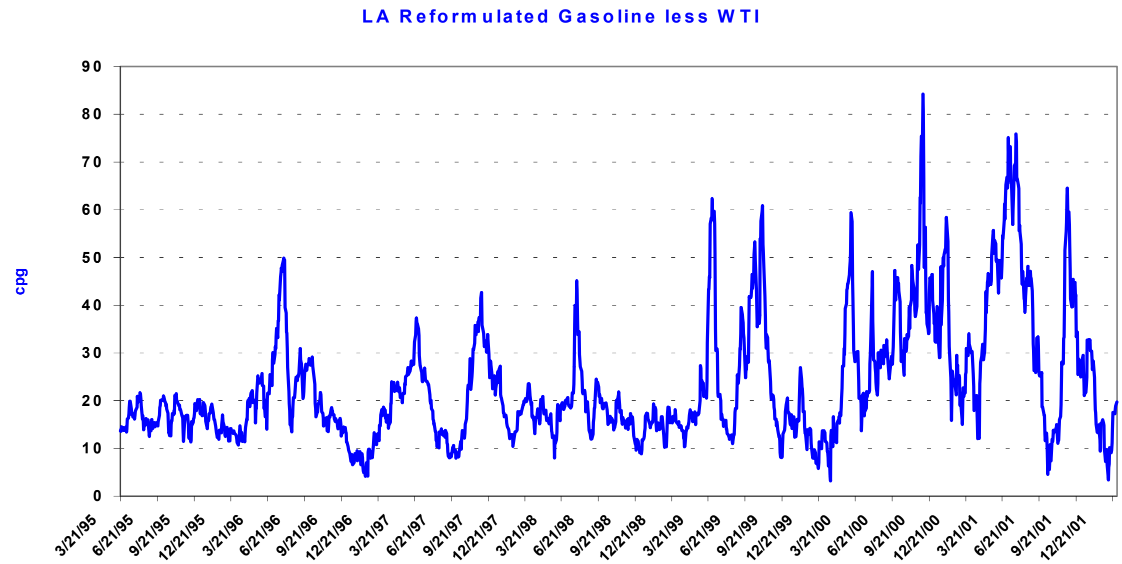
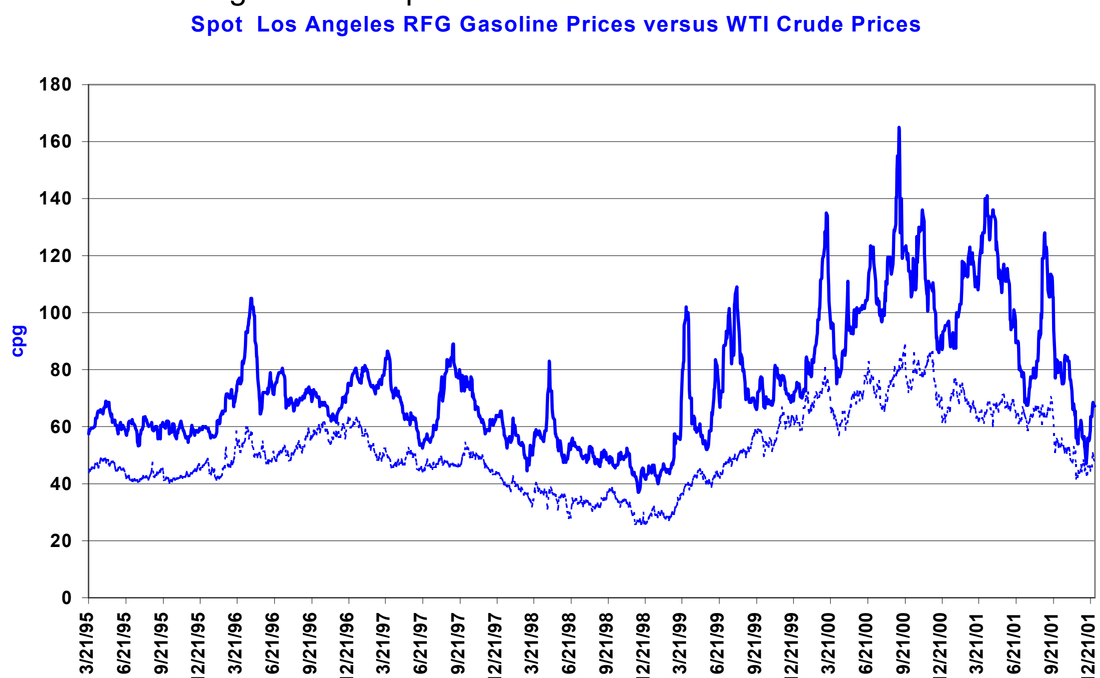


Figure 1-7 – Spot LA RFG versus WTI Crude



[4] The conclusion does not change if ANS is used instead of WTI.

1.2 Price Volatility of Other Products

As shown in Table 1.3, diesel and jet fuel prices are less volatile than gasoline in California. Moreover, gasoline price volatility is greater than jet and diesel fuel in each and every year of the sample, although the volatility of RFG versus jet fuel is close in 1996 and 1997.

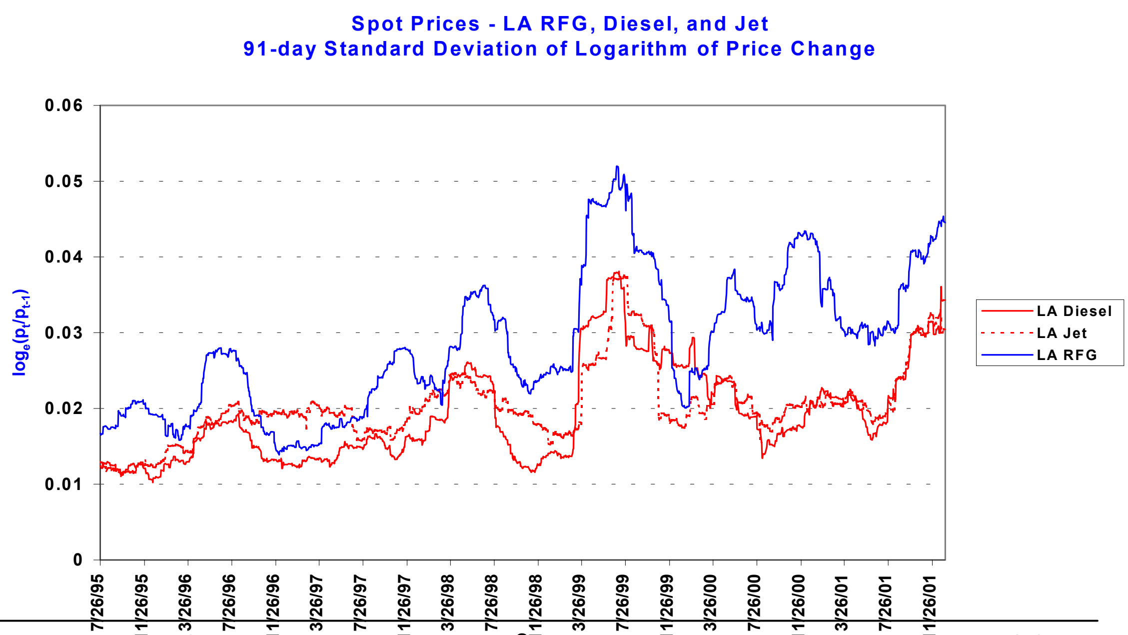
Table 1.3 – Variance in Log Change of RFG, Jet and Diesel Prices

	Variance (x 1000)			F-Value	
	RFG	Diesel	Jet	RFG vs. Diesel	RFG vs. Jet
1995	3.14	1.40	1.57	2.25*	2.00*
1996	4.50	2.41	3.45	1.87*	1.30*
1997	4.61	2.25	3.59	2.05*	1.29*
1998	8.41	3.57	4.09	2.36*	2.06*
1999	14.70	8.41	6.91	1.75*	2.13*
2000	13.20	4.19	4.45	3.15*	2.96*
2001	13.22	7.30	6.65	2.08*	2.00*
Total	**10.02**	**4.32**	**4.49**	**2.32***	**2.23***

*=Statistically significant.

Figure 1-8 shows the moving average of the standard deviation for daily spot prices for these products. RFG has a higher average standard deviation with more pronounced movements.

Figure 1-8 – Moving Average St. Dev. of RFG, Jet & Diesel Prices



The variance of all fuels has increased over time. In each year, gasoline is more volatile statistically than either diesel or jet. (See Table 1.3)

The lower volatility in jet fuel is due to a number of factors that are relevant to the issue of gasoline market isolation and lack of storage that have played a key role in the proposed SFR:

- Jet fuel is a readily fungible commodity, traded worldwide to the same specifications.
- There are no specific import barriers for jet fuel, i.e., there is no Unocal patent to be concerned about.
- There is a deep and liquid forward and futures market against which import shipments of jet fuel can be hedged.
- The airline consortium at LAX has ample storage to cushion disruptions.

In short, the jet fuel market in California has a de facto SFR due to the LAX consortium. It is sometimes argued that jet fuel is more elastic than gasoline. For Los Angeles, that may not be true. For one, Los Angeles is in chronic short supply. Also, although jet fuel is an international commodity, airlines have limited flexibility to “fill up” at other locations without altering flight patterns.

Diesel fuel volatility is less than gasoline for a number of reasons. Diesel fuel has more flexible specifications and is more fungible. Additionally, jet fuel and diesel are somewhat linked in the refinery system through substitute capacity: if increased diesel supply is needed, refiners can blend jet fuel into diesel.

1.3 Reasons for Increased Volatility

A number of authors have commented on the reasons for the increased price volatility in gasoline[5]. These reasons include:

- *Tight capacity utilization in California refineries.* One source of increased supply during a refinery disruption is increased output from underutilized local refineries to make up for the shortfall. Since California refiners have been running at over 95% of nameplate

[5]Borenstein (2000), Stillwater Associates (2002), and Verleger (2000), for example.

capacity, significant incremental gasoline supply is not available from increased output to moderate a price spike.

- *Low inventories in California versus the rest of the country*. Commodity prices such as gasoline are highly sensitive to inventories, so relatively low workable inventories, on the order of 5 days (finished gasoline at refineries) poses an extra burden on California gasoline producers.

- *Geographic isolation of California.* After drawing on inventories, California refineries would have to replenish disrupted supplies from imported finished gasoline or blending components. The time delay in obtaining these alternative sources, either from the Gulf Coast or foreign sources, exacerbates the price volatility.

- *Difficulty in making California grade gasoline.* California Phase II gasoline, introduced in March 1996, is more difficult to make and more costly than gasoline in other parts of the country[6] as well as gasoline in California prior to 1996. This difficulty reduces flexibility during disruptions.

- *Blending around the Unocal patent*. The Unocal patent requires additional fees for these refiners who chose to license with Unocal. Major refiners, so far, have chosen to blend around the patent, which causes additional constraints on making CARB II gasoline.

- *Inelastic gasoline demand.* In addition to an inelastic gasoline supply, as determined by many of the items listed above, the demand for gasoline is highly inelastic (non-responsive to price). Consumers are not able to quickly bring down a price spike by changing their usage of gasoline. In addition, the lagged pass-through effect does not allow the consumer to observe the price effect of disruptions immediately.

- Lack of Access and Import Infrastructure Constraints.

[6] Historically, there are only a limited number of refineries throughout the world that have made California Phase II gasoline and supplied it to this market.

Most observers believe that there are no signs that this volatility will decrease in the near future.

1.4 Conclusions about California's Price Volatility

The analysis of California's gasoline pricing yields the following conclusions. Gasoline price volatility:

- Is higher than in the rest of the country.
- Has increased since the introduction of CARB II
- Is usually higher than in the Gulf Coast and New York
- Has increased relative to the Gulf Coast and New York
- Has increased over time, but was relatively unchanged from 1999 to 2001.
- Has been higher than either jet and diesel fuel, which are approximately equal in volatility

2 CHARACTERIZATION OF REFINERY DISRUPTIONS

Refinery disruptions are unplanned events involving a complete or partial loss of production capacity. Of particular interest for this study are disruptions that affect the core gasoline producing units of a refinery such as distillation, coking and cracking.

2.1 Data

In a study of potential shocks to California's supply of transportation fuels that could result from the 2001 electricity crisis, the Department of Energy's Energy Information Administration (EIA) conducted a study of refinery disruptions during the period from early 1996 through early 2001[7]. The underlying data, derived from third party sources, were not independently corroborated with the refiners involved. Only a few of the incidents were reported in the general public press.

The EIA identified 65 disruptions from OPIS reports. Only 49 of these contained information as to size (in thousand of barrels per day gasoline impact) and duration (in weeks) of the disruptions. A cursory look at price data suggests an additional 15 periods of severe gasoline price volatility not identified with a refinery disruption occurred over the same period. Some of these may have been refinery turnarounds or related to crude oil movements. Only the 49 identified parametrically were used in this report.

The author has adjusted the EIA data for:

- Minor errors in the data
- Removal of refinery disruptions that were classified as 'rumor' but not borne out by the data[8]
- Improved alignment of dates to correspond to impacts,

A summary of the data is given in Attachment A.

According to the DOE data, refinery disruptions with measurable impact and duration occurred roughly monthly over the five-year sample period. The disruptions averaged 21 mbd and lasted

[7] Energy Information Administration (2001).

[8] This will be analyzed as a sensitivity in Section 6.

2.7 weeks on average. The total lost production to disruptions (referred to here as "disrupted barrels") averaged 393 mb.

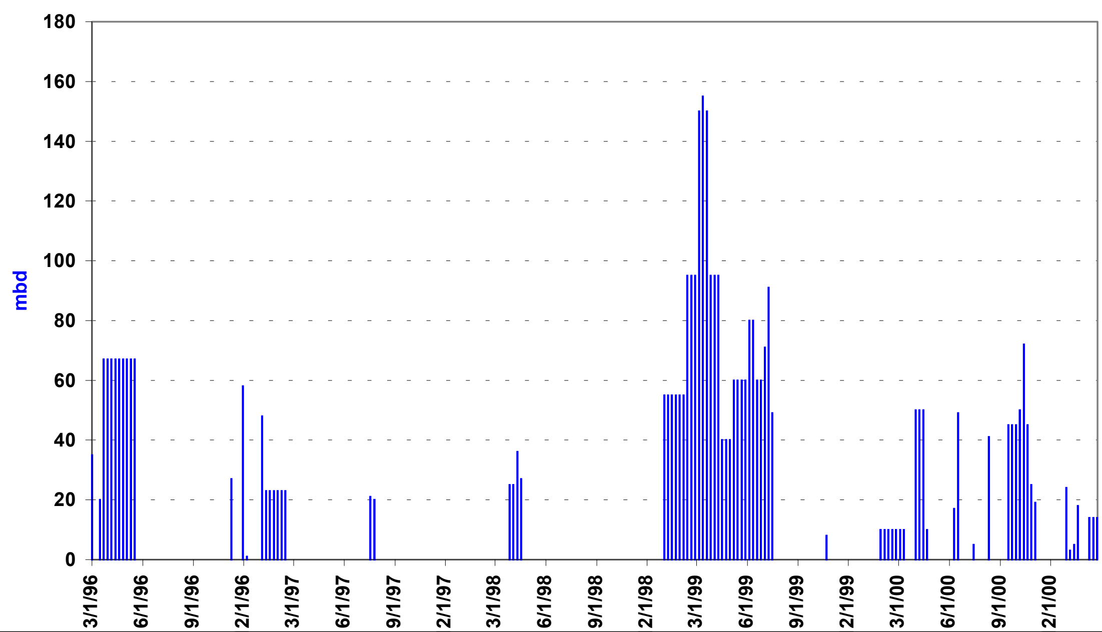
Table 2.1 – Summary Statistics of Refinery Disruptions

	Average	**Median**	**Standard Deviation**	**Range**
Weekly Size of Disruption (mbd)	21	19	15	1 - 67
Duration (weeks)	2.7	1.0	3.9	1 - 11
Number of Days Between Disruptions	38	7	64	0 - 259
Total Disrupted Barrels (mb)	393	144	1280	14 - 6160

2.2 Frequency of Refinery Disruptions

Each bar in Figure 2-1 represents disruptions on a weekly basis. If a disruption, for example, is 20 mbd for two weeks, it would appear as two side-by-side bars of 20 mbd each. If a disruption of 20 mbd in one refinery occurs during the same week as a 30 mbd disruption in another refinery, it would be shown as a bar of 50 mbd. Notice the concentration of disruptions in spring 1999 and to a lesser extent in late 2000.

Figure 2-1 – Weekly Refinery Disruptions

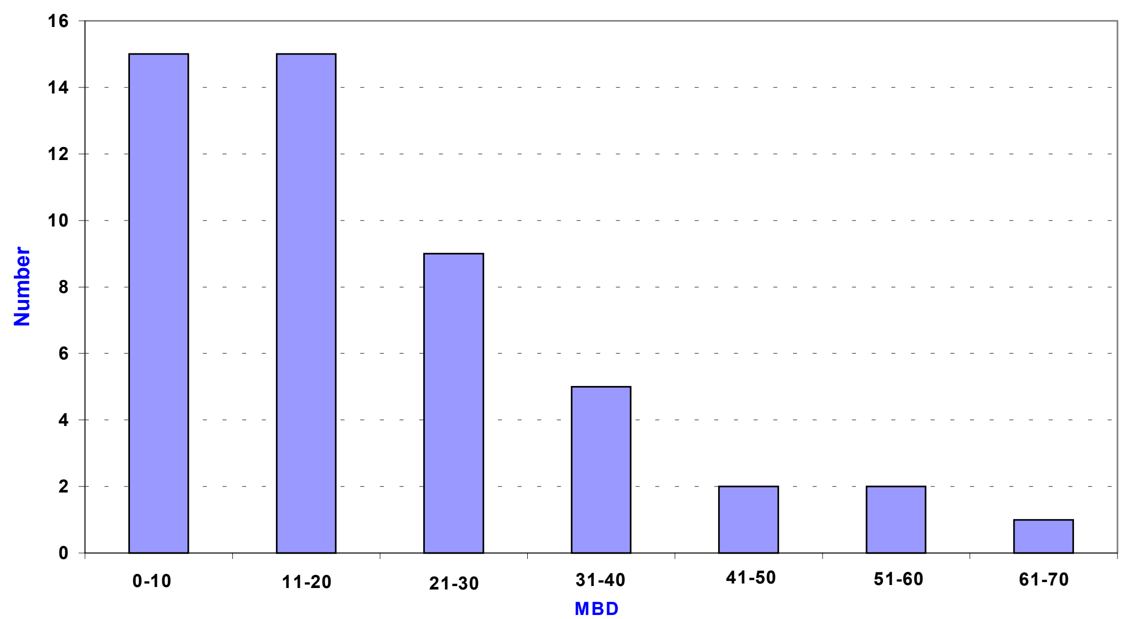


California refineries experienced eight disruptions in 1996 after the introduction of CARB Phase II gasoline. The frequency of occurrence abated in 1997 and 1998, falling by 60% over the 1996 rate. The frequency of disruptions intensified in 1999 and 2000 before falling again in 2001. The 1999 episodes were particularly painful due to the duration of an average disruption (5.7 weeks) more than twice the average (2.7 weeks) over the sample period.

2.3 Size of Disruptions

Refinery disruptions in California averaged 20.8 mbd with standard deviation 2.7 mbd. They ranged in size from 1 to 67 mbd. The size distribution given in Figure 2-2 is skewed to the right with thirty of the refinery disruptions below the average in size. Only five had more than a 30 mbd impact.

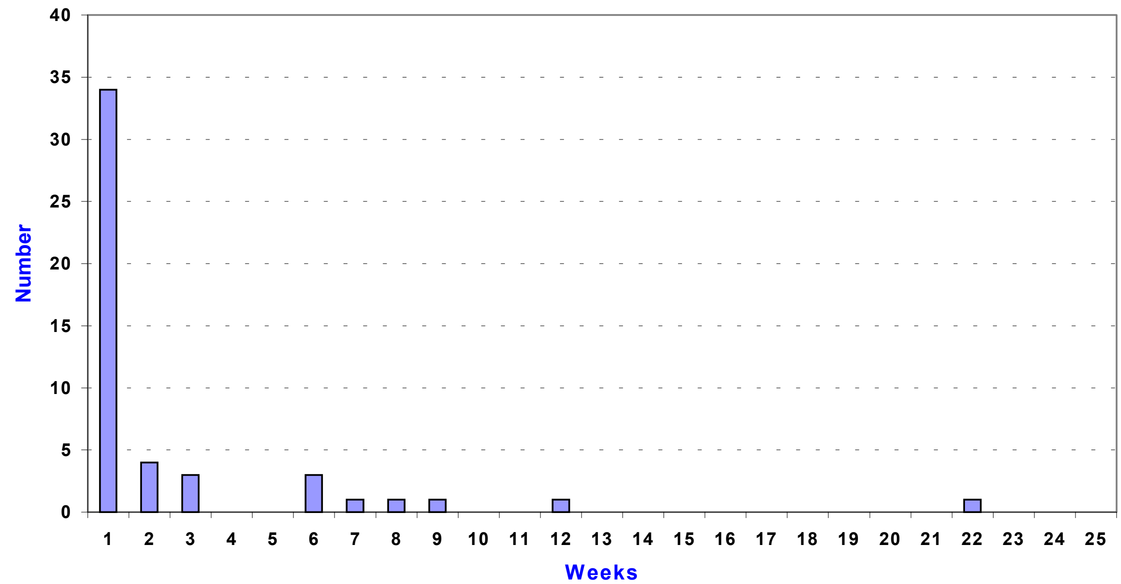
Figure 2-2 – Size Distribution of California Refinery Disruptions



2.4 Duration and Coincidence of Disruptions

The typical refinery disruption was short-lived. The average length of a refinery outage was 2.7 weeks with a standard deviation of 3.9. The modal and median value was 1 week, which represented 34 of the 49 disruptions. Figure 2-3 shows a cluster of disruption lengths from 1 to 3 weeks, another from 6 to 9 weeks, and finally two outliers at 12 and 22 weeks.

Figure 2-3 – Duration of California Refinery Disruptions



Another feature of the refinery disruptions is that they can occur simultaneously. During the 263-week sample, disruptions occurred at four refineries at the same time twice, three refineries at the same time seven times, and there were 221 weeks where there were two refinery outages simultaneously. The distribution of disruptions by the number of refineries that were disrupted during a given week is given in Figure 2-4 and Table 2.2.

Figure 2-4 – Number of Refineries Experiencing Disruptions

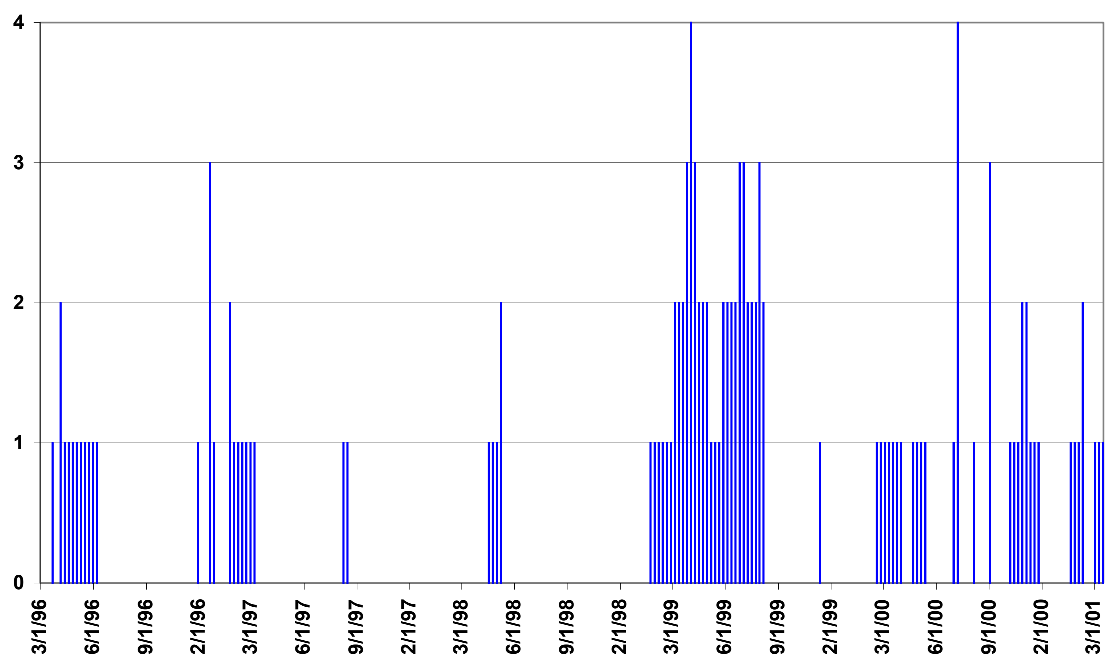


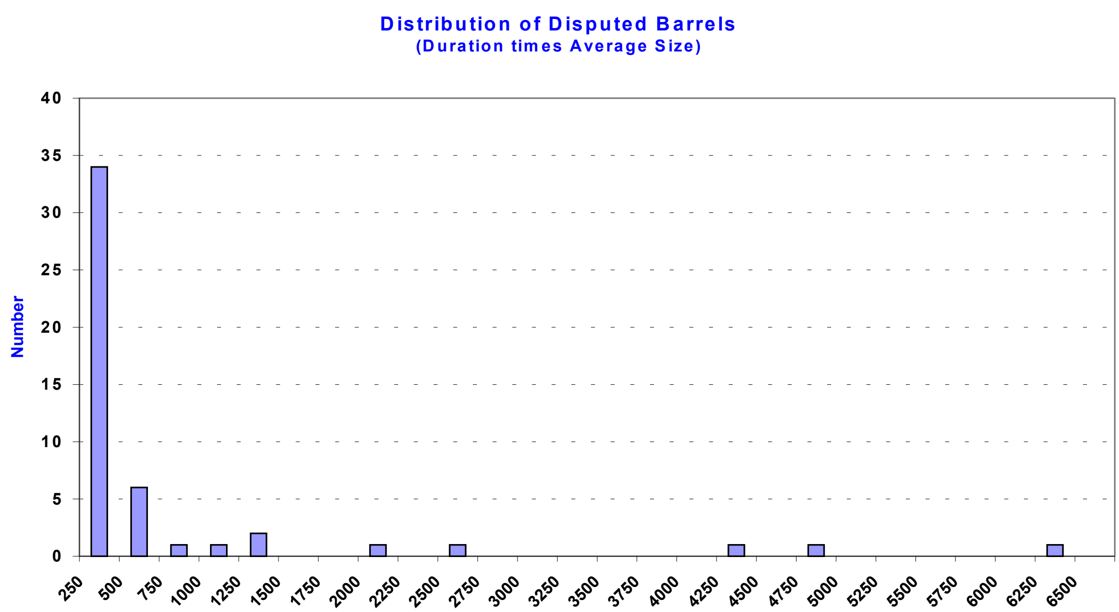
Table 2.2 – Number of Weeks with Disrupted Refineries

Number of Disrupted Refineries During a Week	Number of Weeks	%
0	176	66.9%
1	58	22.1%
2	20	7.6%
3	7	2.7%
4	2	0.8%
>4	0	0.0%
Total	**263**	**100.0%**

2.5 Size of Total Disruptions

The calculation of size times duration of disruptions yields total disrupted barrels. This distribution is given in Figure 2-5.

Figure 2-5 – Distribution of Size of Disruption times Duration



Notice the large number of disruptions that are 250 MB and under, a small cluster between 500 and 1500 MB, and then five outliers with total disrupted barrels in excess of 2 million barrels. Three of the five outliers exceed 4 million barrels.

2.6 Disruptions over Time

It is interesting to note that the frequency, size, and duration of disruptions vary considerably over the years. The highest frequency year, 2000, was mild in comparison to 1999, which had significantly greater average size and duration than 2000. The year 2001 (through March) had the lowest frequency, duration, and size of all the years. (Table 2.3).

Table 2.3 – Frequency, Size and Duration of Disruptions by Year

Year	Number of Weeks Considered	Frequency		Size	Duration
		Number of Disruptions	Frequency*	mbd	Weeks
1996	41	8	.018	25.9	2.1
1997	52	4	.007	22.3	2.3
1998	52	4	.007	22.0	1.3
1999	52	10	.017	27.2	5.7
2000	53	16	.027	17.9	1.9
2001	10	7	.063	10.0	1.3
Total	**260**	**49**	**.017**	**20.8**	**2.7**

*Note: There were 11 refineries in the survey, so the frequency is calculated as disruptions divided by refineries plus weeks.

Table 2.4 – Refinery Disruption Size and Length over Time

	Weekly Average Size		Disruption Length	
	Average	Standard Deviation	Average	Standard Deviation
1996 (partial)	26	2.1	21.4	2.8
1997	22	2.3	2.2	2.5
1998	22.0	1.3	12.4	0.5
1999	27.2	5.7	17.7	6.8
2000	18	2	13.1	1.9
2001 (partial)	10.2	1	7.7	0.8

The data do not support the hypothesis that large disruptions last for long periods. The average size and duration of refinery disruptions are not highly correlated (R^2=.28 in Figure 2-6). This suggests that the one can treat duration and size as being independent events. The duration and total size of disruption are, however, highly correlated (Figure 2-7).

Figure 2-6 – Refinery Disruptions: Impact vs. Duration

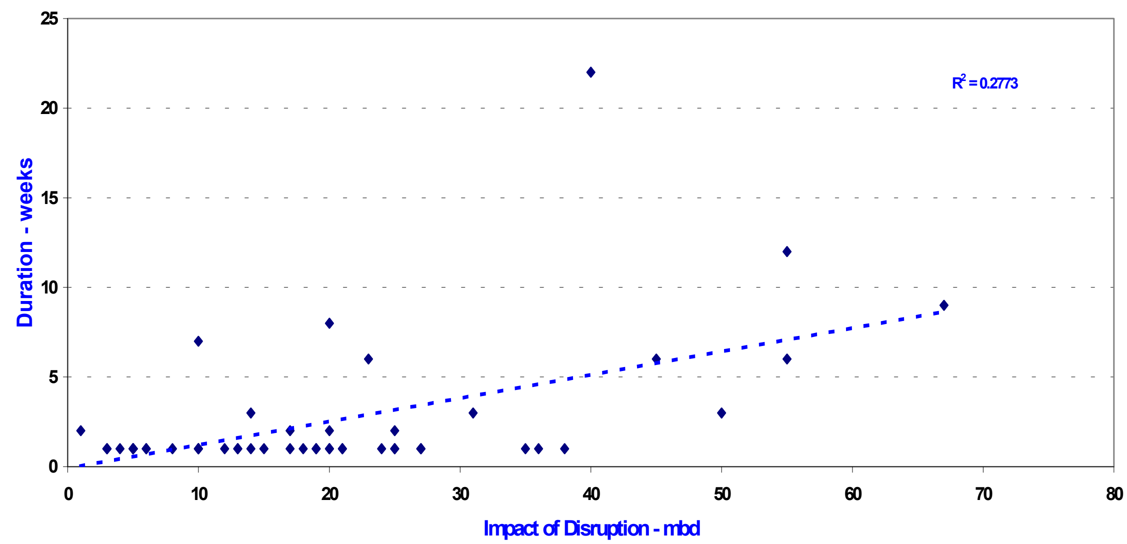
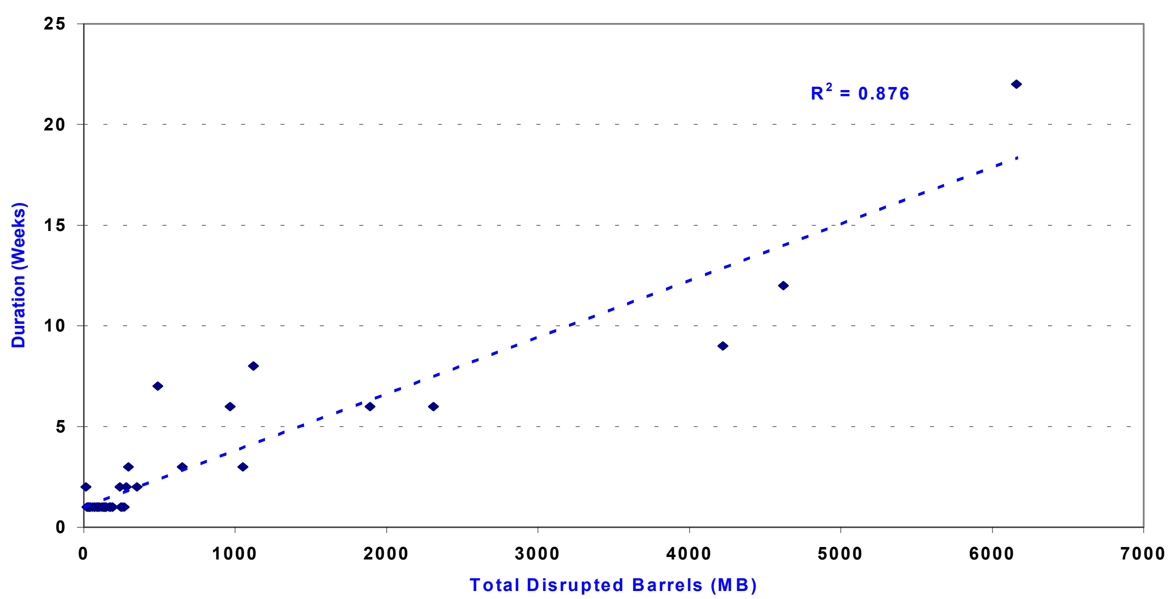


Figure 2-7 – Refinery Disruptions: Disrupted Barrels vs. Duration



2.7 Seasonal Timing of Refinery Disruptions

The summer gasoline-blending season extends approximately from mid-March to November 1 in Northern California and from the end of February to November 1 in Southern California, or about 65% of the year. The number of disruptions that occurred in the summer blending season was also 65% of the total. The total barrels disrupted, however, occurred disproportionately in the summer blending season (74% of the total). (See Figure 2-5)

Table 2.5 – Distribution of Disruptions by Blending Season

	Summer Blending	Winter Blending	Summer % of Total	Winter % of Total
Disruptions	32	17	65%	35%
Disrupted Barrels (impact times duration)	21,014 mb	7,413 mb	74%	26%
Length of Blending Season	North: 33 weeks South: 35 weeks	North: 19 weeks South: 17 weeks	65%	35%
Barrels Produced in Season			67%	33%

2.8 Classification of Refinery Disruptions

It is useful to categorize refinery disruptions by average size versus average length. Choosing rough breaks in the data, refinery disruptions are broken down by region, size, and duration in Table 2.6. The preponderance of disruptions is short-lived and small.

Table 2.6 – Classification of Refinery Disruptions by Region, Duration & Size

	Southern California			Northern California			All Refineries			
	Short	Medium	Long	Short	Medium	Long	Short	Medium	Long	Total
Large >30 mbd	2	1	2	1	1	3	3	2	5	10
Medium 10-30mbd	13	1	0	5	3	2	18	4	2	24
Small <10 mbd	9	1	1	4	0	0	13	1	1	15
Total	**24**	**3**	**3**	**10**	**4**	**5**	**34**	**7**	**8**	**49**

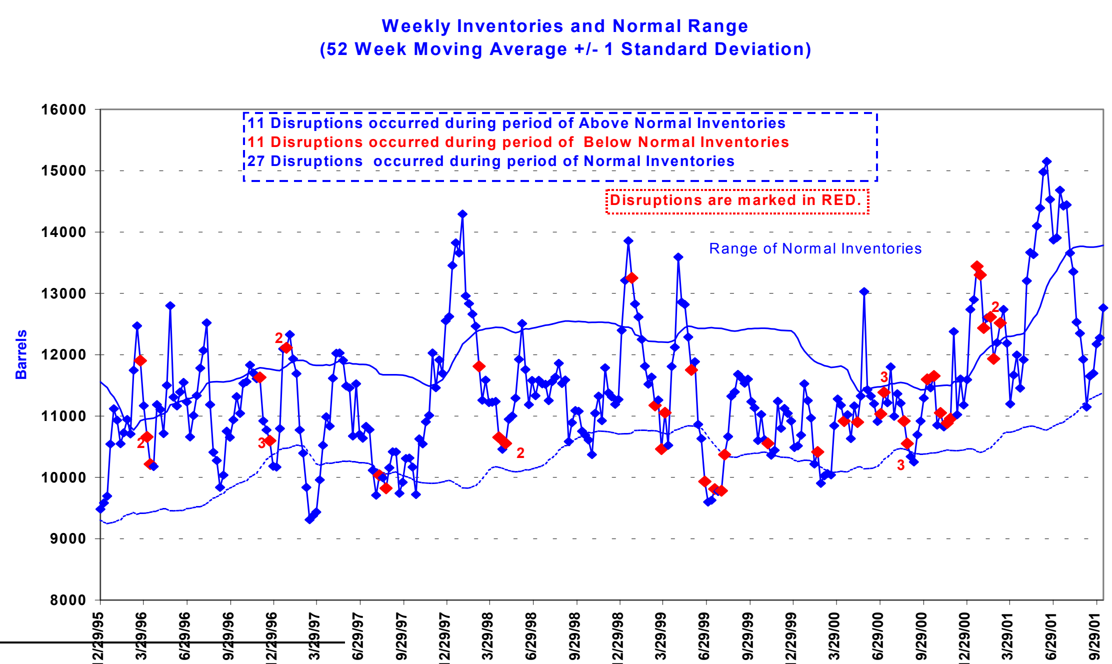
Short = 1 week or less; Medium = 2 to 3 weeks; Long > 3 weeks

2.9 The Role of Inventories

In petroleum markets, producers (as well as consumers and third parties) hold inventories to avoid stock depletions, minimize the costs of adjusting production over time, and optimize product delivery. Since inventories can reduce production and marketing costs as demand conditions change, they should reduce short-run price fluctuations. Since inventories cannot be prudently reduced below some minimal level, "… price volatility tends to be greatest during periods when inventories are low."[9]

The obvious relationship is widely used by itself to model price movements. The finance literature, however, specifies a different relationship. The spread between spot and futures prices and the level of inventories follow what is known as the "Working" curve, after Holbert Working who first derived the relationship[10]. If one were to view the spread as the extent of backwardation in product markets, then when inventories are relatively low, the spread is greatest (steepest backwardation). We are more likely to draw a close relationship of inventories and the spread between spot and futures prices, than we are with inventories and the level of prices. We are, however, able to perform a qualitative analysis of the relationship of spot prices with normal inventories. Normal inventories here are defined as the range plus and minus one standard deviation of a 52-week moving average of inventories.[11]

Figure 2-8 – Inventory Levels during Disruptions



[9] Pindyck (2001) p.4.

[10] See for example Williams (1986) and Verleger (1993).

[11] The conclusions in this section remain the same if seasonality in inventories is considered.

Figure 2-8 shows the level of refinery inventories (finished gasoline and blendstocks) on the normal range of inventories. It is not surprising that there is an equally likely chance to have a refinery outage (a disruption, but not necessarily a price spike) when inventories are below normal as above normal (11 disruptions occurred when inventories were below normal, 11 disruptions occurred during periods of above normal inventories, and 27 during periods of normal inventories.) What is different is that during period of below normal inventories, the price response is magnified since refineries cannot draw on "excess" inventories to ameliorate the outage.

Figure 2-9 – Spot Gasoline Prices with Indicated State of Inventories

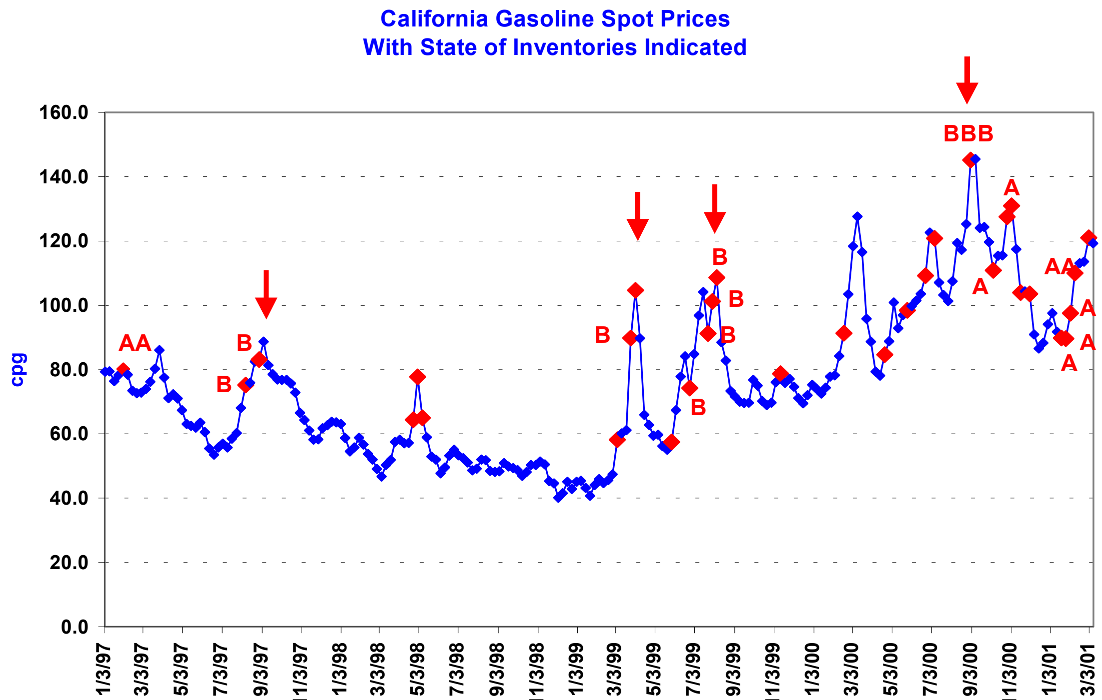


Figure 2-9 illustrates the pattern of California Spot Gasoline Prices with an indication of the state of inventories at the time of disruption. The red diamonds indicate refinery disruptions. An "A" indicates a period of above normal inventories, "B" below normal inventories, and no label indicates normal inventories. [Multiple letters indicate multiple disruptions.] The price spikes are more pronounced whenever inventories are below normal. It appears that when inventories are edging toward the low end of the range, and the market is uncertain about the length of the disruption, prices respond to the danger in inventories falling below the acceptable levels.

2.10 Conclusions: Characterization of Disruptions

In summary, refinery disruptions in California:

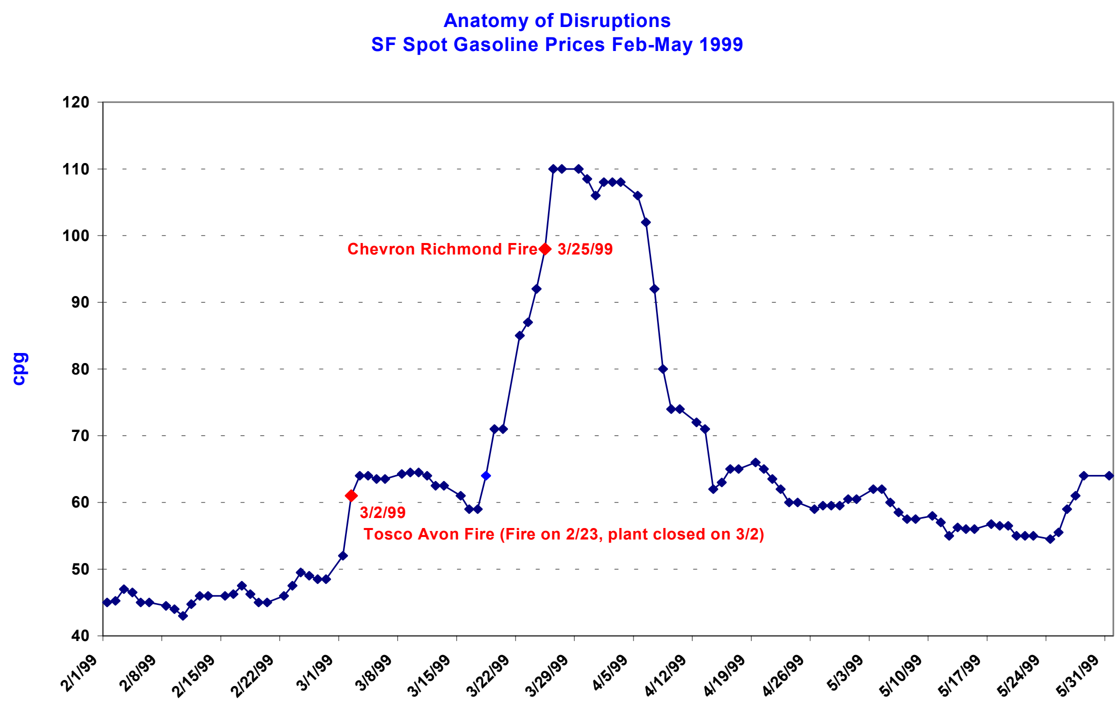
- Have occurred once a month on average since 1996
- Have caused average production loss per incidence of 21 mbd with several larger disruptions
- Are generally short-lived with an average duration of 2.7 weeks, although some can last 6 to 8 weeks
- The short-lived disruptions generally also tend to involve less loss of capacity, while long ones tend to be large
- Occur in both summer and winter blending seasons in proportion to the time, but have a more pronounced price effect during the summer blending season.

3 ANATOMY OF SPECIFIC REFINERY DISRUPTIONS

In order to illustrate the points made in Sections 1 and 2, a more detailed examination of specific refinery disruptions is instructive. (Refineries will be referred to by their name at the time of the disruption.) Refinery disruptions do not always have an immediate impact on prices. Figure 3-1 shows spot price movements in San Francisco in early-1999. This was a period of severe unplanned disruptions in the Bay Area refineries. The February 23, 1999 Tosco crude unit fire did not have an impact on price immediately, but on March 2, 1999 when it was announced that Contra Costa County would shut the refinery down for the longer term, the gasoline prices spiked up. A later disruption at Chevron's Richmond refinery caused spot prices to surge once again.

It is interesting to note the spot price behavior after the Tosco Avon fire. After an initial run up, spot prices fell off gradually, until it became clear that the refinery would be disrupted for a sustained period. The refinery was out for over five months.

Figure 3-1 – San Francisco Spot Price Movements in Early 1999



This price responsiveness is also seen later in 1999 (Figure 3-2). A non-refinery disruption, the Olympic, Washington Liquid Fuels Pipeline ruptured and caught fire on June 10, 1999. Spot prices responded immediately. In July, a Chevron Richmond refinery explosion and a mishap at Mobil's Torrance refinery caused two more spikes.

Figure 3-2 – San Francisco Spot Price Movements May – August 1999

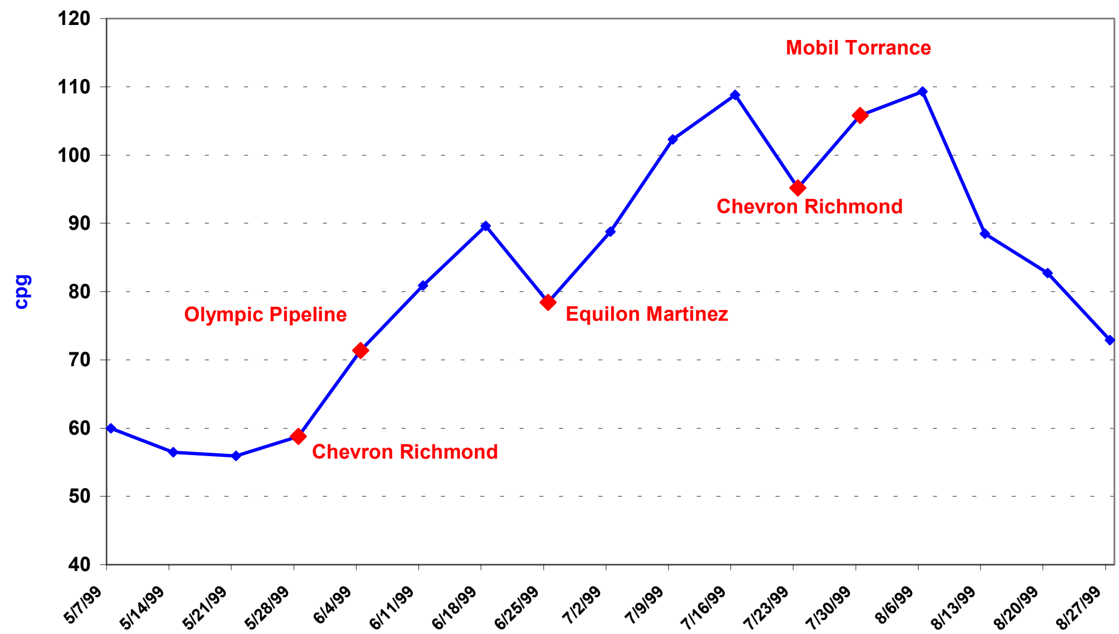
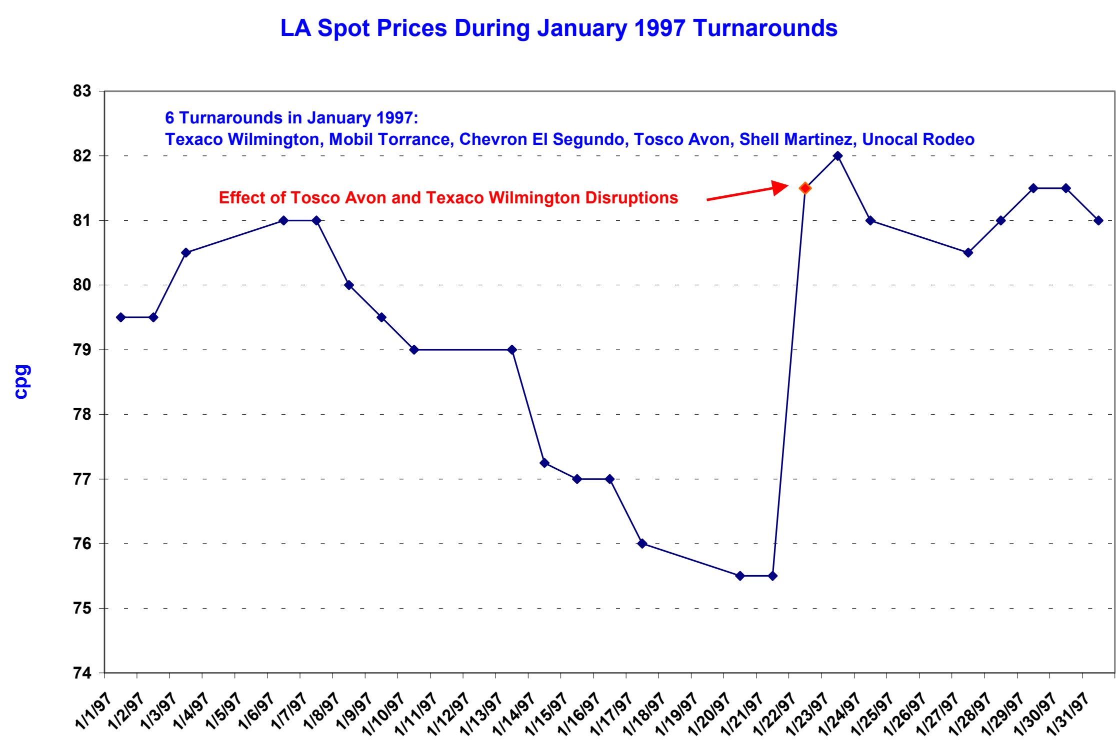


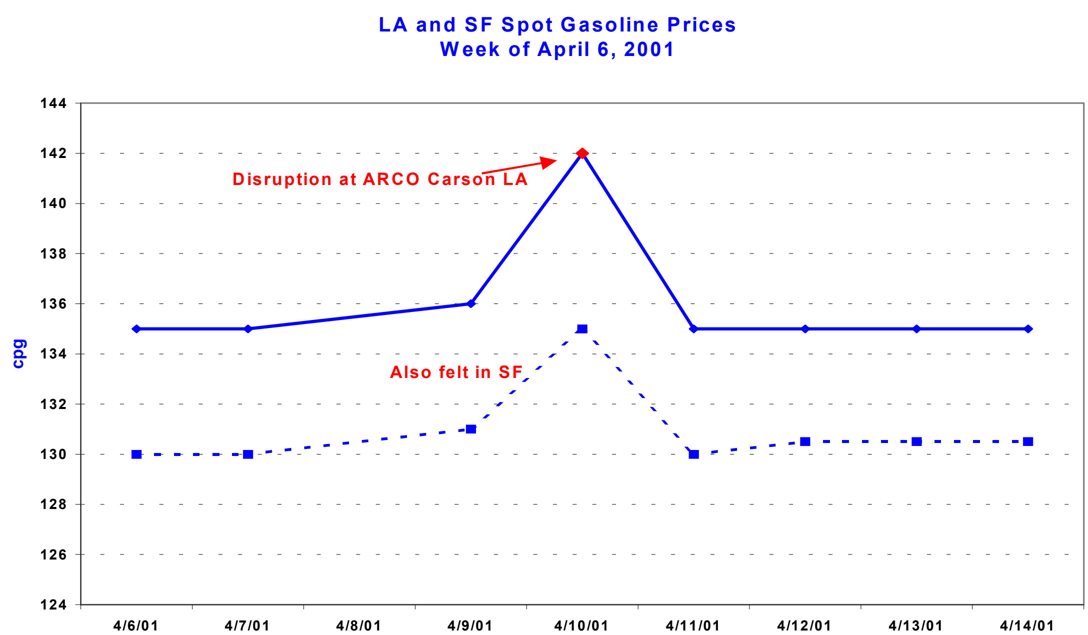
Figure 3-3 – Price Effect of Turnarounds and Disruptions



Planned turnarounds do not affect prices unless they happen to coincide with a disruption. Refiners plan their turnarounds in the "off season" and take precautions to have enough alternative sources of gasoline. There, of course, is still the chance that another refinery could have a disruption during a heavy turn-around season. This occurred in January 1997. Figure 3-3 shows Los Angeles Spot Gasoline prices. Texaco Wilmington. Mobil Torrance, and Chevron El Segundo planned turnarounds in the south, while Tosco Avon, Shell Martinez, and Unocal Rodeo scheduled turnarounds in the north. Prices actually fell through that period until both Texaco Wilmington and Tosco Avon had disruptions.

A disruption in either part of California can affect all of California. The California gasoline system, while disconnected to the rest of the US, is more linked between North and South. While there is no pipeline flow that moves gasoline between North and South, there is a large volume of gasoline that flows from the Bay Area to Los Angeles by barges and through inter-refinery exchanges. As such, a price impact in one part of the state will affect the other part of the state. This is clearly shown in Figure 3-4.

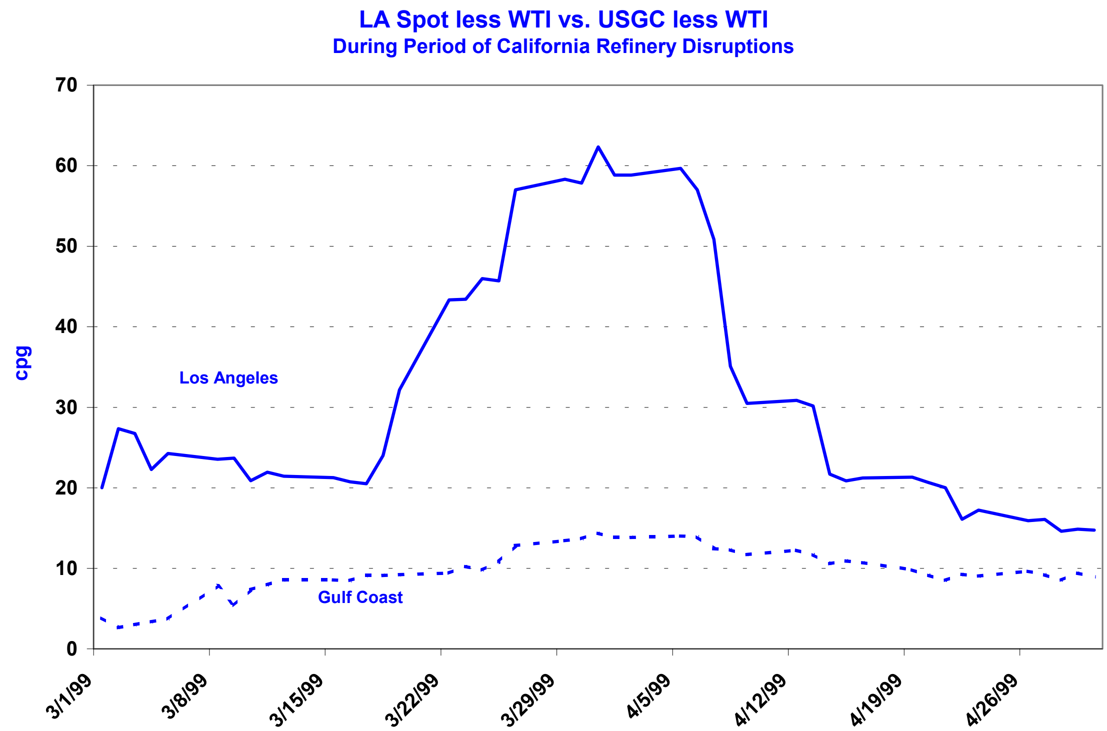
Figure 3-4 – Transmission of Price Spikes throughout California



While price spikes get transmitted throughout California, they do not get transmitted to the Gulf Coast[12], as shown in Figure 3-5. Both price curves have the effect of crude price movements excluded from them. During mid-1999, a number of refinery disruptions, primarily in Northern California, caused a sharp spike in gasoline spot prices. The impact on the Gulf Coast was minimal.

[12] It is possible, and likely, that price spikes get transmitted to neighboring states that rely on California refineries.

Figure 3-5 – Non-Transmission of Price Spikes Outside California



Finally, not all disruptions lead to price spikes. In early 1999 there were three refinery disruptions in Northern California, Exxon Benicia, Tosco Avon, and Chevron Richmond. Figure 3-6 shows price movements in early 1999 along with three horizontal bars that depict the duration of three refinery disruptions: Exxon Benicia, Tosco Avon, and Chevron Richmond. The figure indicates prices did not spike upward during the Exxon Benicia 12 week disruption until the Tosco Martinez refinery disruption occurred. This was largely due to the large amount of inventories on hand at the time. The price spike abated after the Exxon Benicia refinery resumed normal operations, only to spike again when the Chevron Richmond outage occurred. Price spikes in this period only occurred when there were two refineries went out at the same time.

While most spot price rises translate into retail prices increase with a lag, not all price spikes get automatically transmitted. Figure 3-7 shows price behavior during a disruption episode in early Fall 2000. Spot prices rose from $1.09 per gallon in early October to $1.35 a gallon by early November on the basis of outages at the Mobil Torrance and Arco Carson refineries. One of the disruptions occurred during planned maintenance. This period was at the tail end of the summer driving season and right before the winter blending season. Retail prices did not rise, but fell by approximately 3 cpg over the five-week period that spot prices were increasing.

Figure 3-6 – Three Disruptions in Early 1999

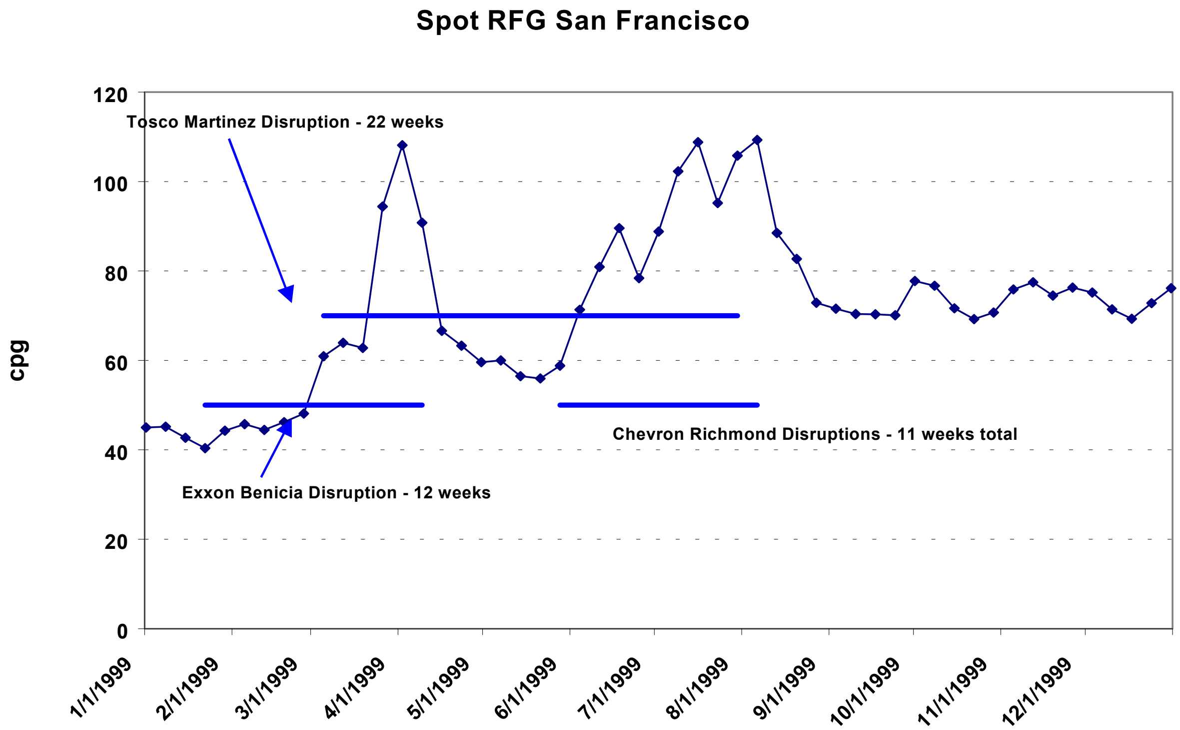
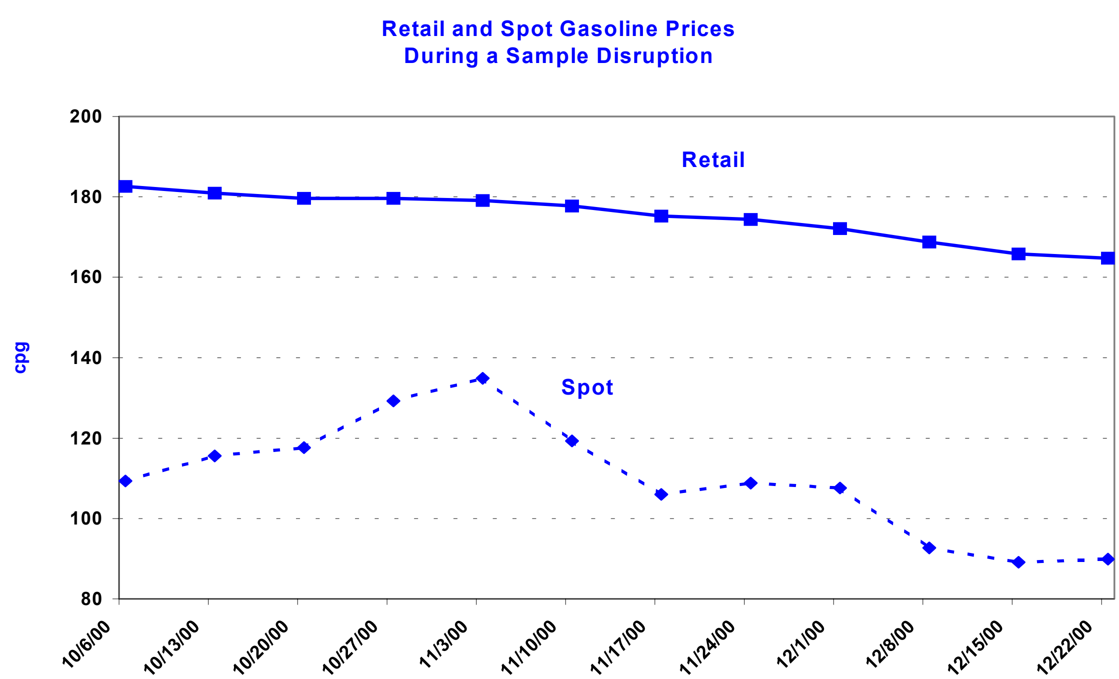
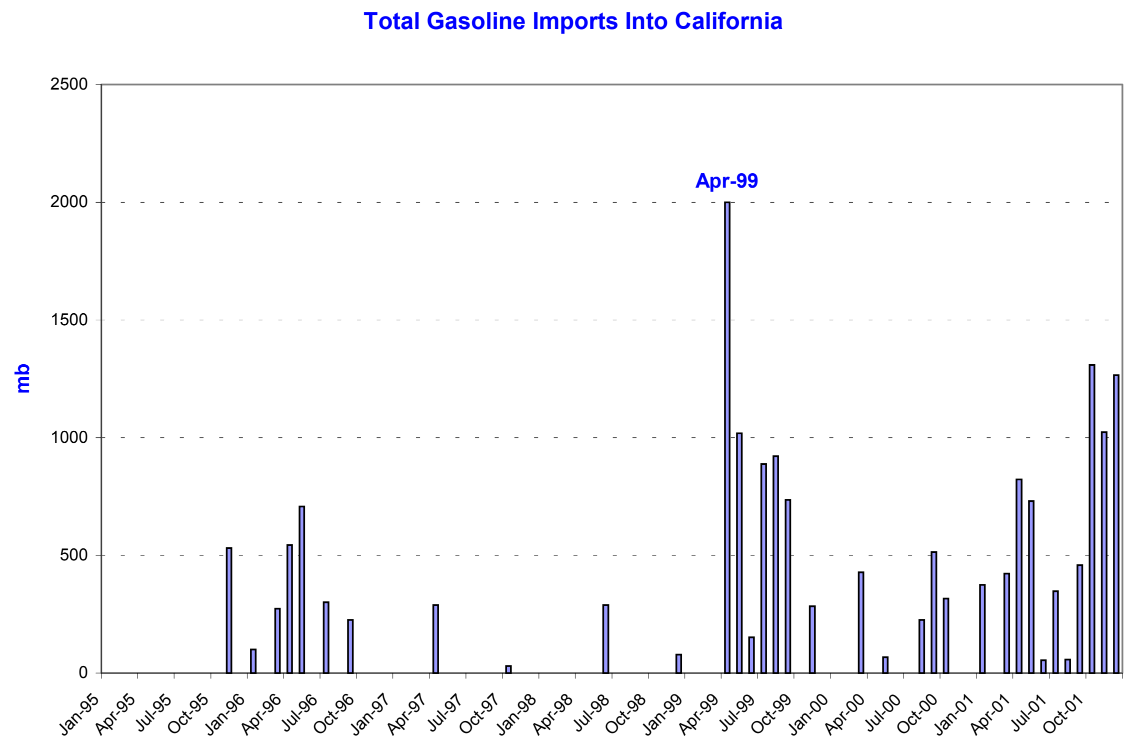


Figure 3-7 – Example of Spot Price Spike without Retail Price Effect



Refineries act immediately to source alternative gasoline supply during disruptions. Figure 3.8 shows the sharp increase in gasoline imports in the month of or following major disruptions. Of course, with the lag in delivery time, the disruption has already had its impact on spot prices.

Figure 3-8 – Gasoline Imports to California



In summary:

- Refinery disruptions normally have an immediate impact on spot prices, but in some instances the impact can be delayed
- Refinery disruptions normally cause a spot price spike and a companion retail price spike, except during some instances over the winter months
- Planned turnarounds do not affect prices unless coincident with a disruption
- A refinery disruption in either part of California affects all of California

- Price spikes are not transmitted to the Gulf Coast, but may be transmitted to neighboring states (not studied).
- Refiners respond immediately to try to offset disruptions by increased sourcing of gasoline from other areas.
- The time delay to ship these cargoes from distant refineries means that wholesale price rises can continue until the additional supplies arrive in California.

4 PRICE IMPACT OF DISRUPTIONS

As shown above for certain disruptions that were analyzed in detail, most but not all refinery disruptions create a price spike. In this section, a systematic analysis will be presented on how disruptions affect the California gasoline market.

4.1 General Description of the California Gasoline Markets[13]

The California gasoline market has a layered structure, formed by three separate but interrelated markets:

Spot. The spot market, primarily trades at the refinery level, is essentially an over the counter market, with deals negotiated on an individual basis between participants. Reporting of deals and posting of pricing by reporting services such as OPIS or Platt's occurs when both buyer and seller confirm the deal. In the California spot market, which includes deals made for supplies into Nevada and Arizona, there are between 20 and 30 active participants. Traded gasoline volumes are typically 25 MB (approximately 1 million gallons) and are delivered into a pipeline at a place and time specified by the buyer. The spot market moves with the perceived change in refinery product supply and demand.

Rack. The rack market consists of wholesale buyers such as independent retailers and bulk customers who operate their own truck fleet ("jobbers") and who take delivery of their product at a truck loading rack situated at a terminal, or sometimes directly at the refinery. Rack pricing for gasoline is broken into two segments: Branded and Unbranded. Pricing of gasoline for these two classes of trade is complex, dynamic and interrelated. Branded gasoline wholesalers are subdivided into classifications of "jobbers" and DTW (Dealer Tank Wagon) accounts. DTW prices represent the wholesale price paid by the dealer to a refiner for gasoline delivered in bulk to that dealer's retail outlets. Often the DTW price is higher than the unbranded rack, plus transportation. The branded dealer has, in effect, traded off the opportunity to take advantage of steep wholesale price declines during periods of oversupply, for a greater consideration of security of supply and an acceptable guaranteed margin over the long term. Imbedded in the DTW price is the deemed value of the use of a company's brand name.

Jobbers are those companies that service the market sector from the refiners' truck loading racks to end-user retail and bulk consumer accounts. They establish credit lines with the

[13] This section relies heavily on Stillwater (2002).

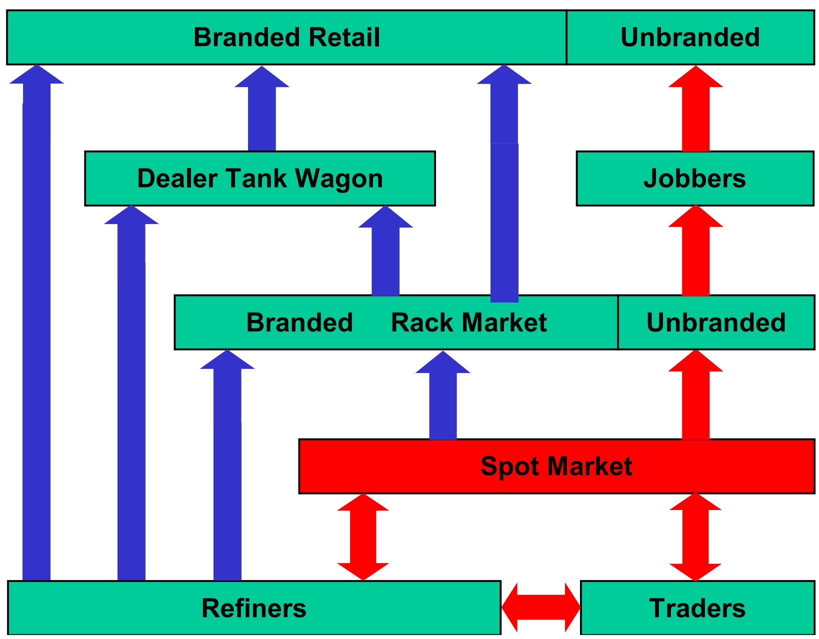
refining companies sufficient to service their customer base and pick up their loads against pre-negotiated contracts. A jobber may service both branded and the unbranded accounts.

Rack market participants may buy branded products destined for branded stations, or unbranded products destined for independent service stations or commercial/industrial accounts. In general, branded rack prices tend to move in relation to street prices. Unbranded rack prices tend to move with the spot market.

Retail. The retail market, where pump prices are posted, are normally set relative to prices of other local gasoline stations. They include Federal and State excise tax plus local sales taxes.

Figure 4-1 shows these relationships schematically.

Figure 4-1 – Structure of the California Gasoline Market



4.2 Price Movements

Figure 4-2 shows the behavior of prices during a typical disruption. The price response at the time of a disruption is almost immediate. Spot prices react first, followed by unbranded rack, and then by branded rack. After prices peak the price reaction is in the same order: spot prices lead the way down, followed by unbranded rack, then branded rack. The difference between the price run up and its trajectory back down is that branded rack prices tend to be sticky on the way down.

Figure 4-2 – Wholesale Price Movements during a Disruption

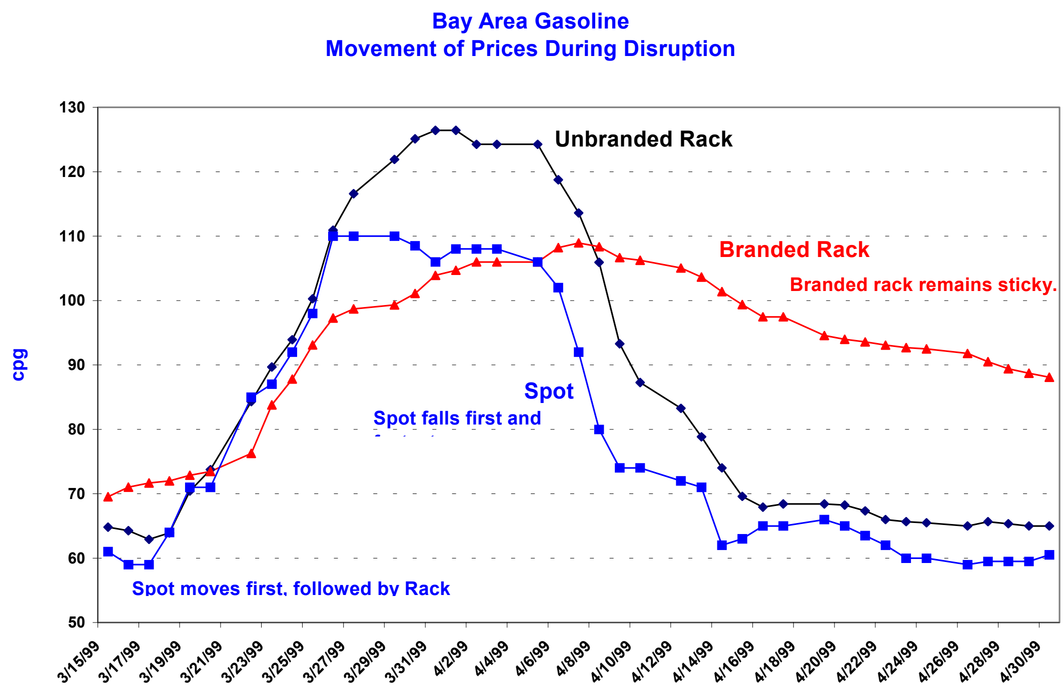
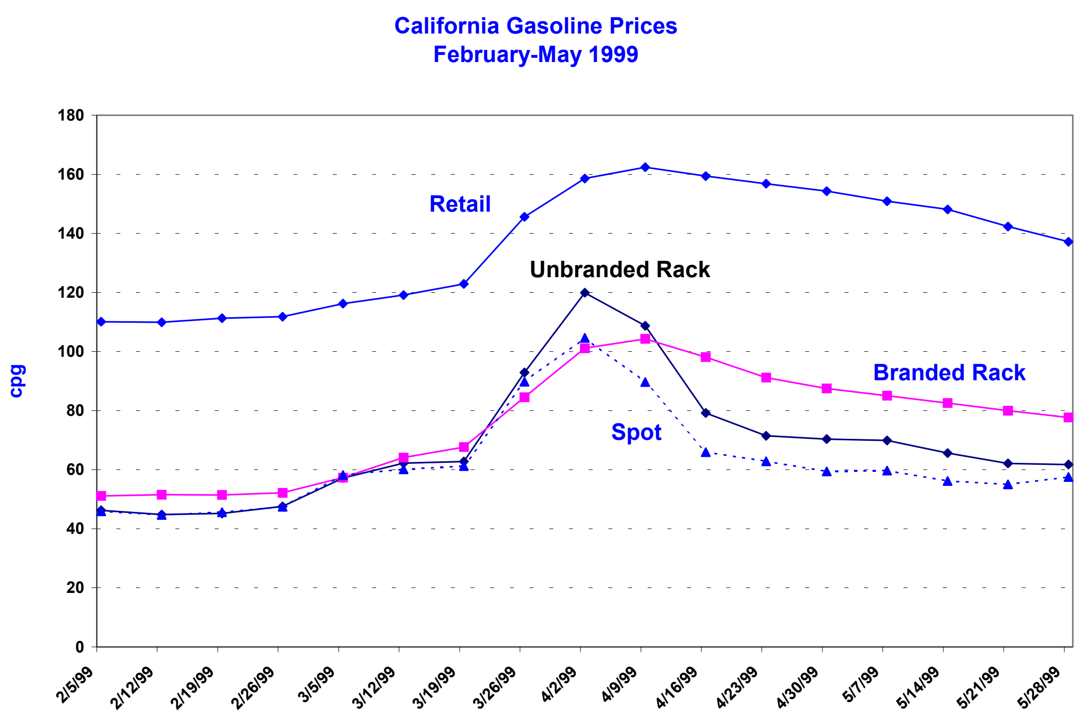


Figure 4-3 traces the movement of retail and wholesale prices. Here, retail price effects clearly linger longer than wholesale prices. They fall slower than they rise.

Figure 4-3 – Retail and Wholesale Movements during a Disruption



Prices at the various market stages are highly correlated, both on a level basis (Table 4.1) and change basis (Table 4.2). Considering changes in price movements in the latter table, the unbranded rack price tracks the spot price most closely. Retail pricing, which includes a significant mark-up from federal, state and local taxes, follows the movements of branded rack most closely.

Table 4.1 – Correlations of Prices for Various Stages of Gasoline Sales

Gasoline Price	Retail	Branded Rack	Unbranded	Spot
Retail	1.0	0.94	0.88	0.86
Branded Rack		1.0	0.97	0.96
Unbranded Rack			1.0	0.99
Spot				1.0

Note: A correlation of 1.0 indicates the variables move in exactly the same way.

Table 4.2 - Correlations of Changes in Prices For Stages of Gasoline Sales

Gasoline Price	Retail	Branded Rack	Unbranded	Spot
Retail	1.0	0.70	0.55	0.45
Branded Rack		1.0	0.77	0.63
Unbranded Rack			1.0	0.92
Spot				1.0

4.3 Asymmetry of Price Changes

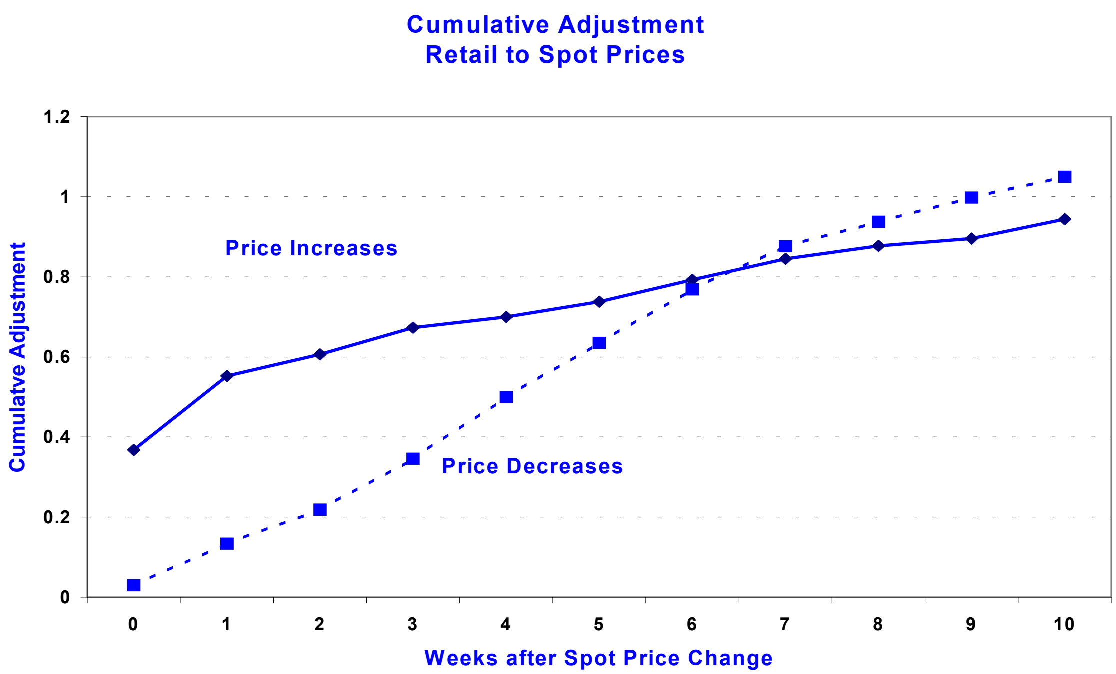
Studies have suggested that there is a statistically significant asymmetry between wholesale and retail prices. A number of studies have suggested that the wholesale to retail pass-through is virtually complete within four to eight weeks from onset of the disruption. The author has applied these models to the California data. Using a model developed by Borenstein, et. al.[14], the author calculated the price response function for spot price increases and decreases.

[14] Borenstein, Severin, Colin Cameron, and Richard Gilbert (1992). “Gasoline Prices Respond Asymmetrically To Crude Oil Price Changes?” National Bureau of Economic Research, Working paper No. 4138, August 1992

The response weights shown in Figure 4-4 suggest that by the sixth week, the price response is virtually complete. But, one will notice that the cumulative response of price increases in the second week is about .6 while the cumulative effect of price decreases in the two week period is only about .2. So, one infers that the cumulative adjustment of retail prices to changes in wholesale prices occurs faster than when wholesale prices decrease. The cumulative adjustment, however, equates by the sixth week.

The regression equation is given in Attachment D.

Figure 4-4 – Cumulative Adjustment of Retail Price to Wholesale Price Changes



The price impact of refinery disruptions can last 6 to 8 weeks. Figure 4-5 shows the price response to a number of refinery outages in Los Angeles refineries. Note that the spot price rises substantially at the occurrence of the disruption, then slowly falls off. The spot price crosses two measures of return to normalcy, the 91-day (three-month) moving average of prices and a new price minimum, between six and eight weeks after the initial disruption.

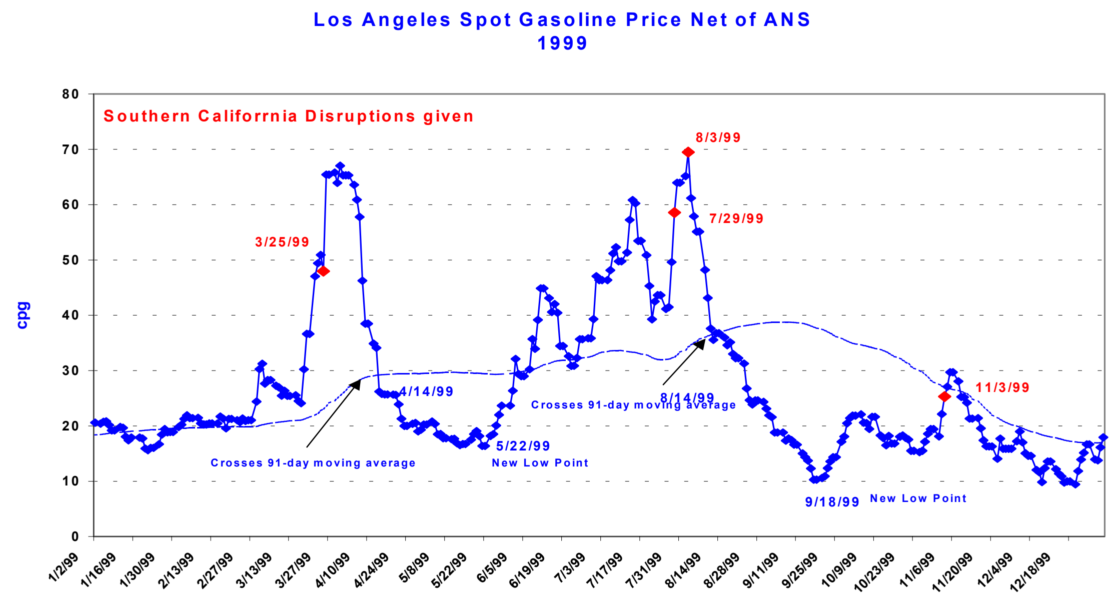
This asymmetry was also found by Duffy-Deno[15] in the Salt Lake City market. Various explanations have been offered for the asymmetry, including market power, search costs, consumer response, and refinery adjustment costs. The author's belief is that the phenomenon

[15] Duffy-Deno, Kevin (1996). "Retail price asymmetries in local gasoline markets," *Energy Economics*, 18, pp. 81-92

has a more benign explanation. Adopting the arguments of Balke, et. al.[16], if consumers accelerate their gasoline purchases to beat further expected increased in prices, they will increase inventories in their gasoline tank, hence accelerating the price rise. On the downside, consumers may fear running out of gasoline and do not slow their purchases to bring the inventories in their tank back to normal.

It should be noted that the EIA study[17] (1999) of prices changes in the Midwest gasoline market finds price asymmetry but concludes that it is largely a statistical artifact due to lagged adjustments.

Figure 4-5 – Disruption Duration during a Sample Disruption



4.4 Price Impacts – Conclusions

In summary:

- The rise and fall of prices caused by a disruption are asymmetric
- Retail price effects linger longer than other prices.
- Price spikes are more pronounced during periods of low inventories

[16] Balke, Nathan, Stephen Brown, and Mine Yucal (1998). "Crude Oil and Gasoline Prices: An Asymmetric Relationship?," *Economic Review*, Federal Reserve Bank of Dallas, pp. 2-10, First Quarter 1998

[17] Energy Information Administration (1999). "Price Changes in the Gasoline Market: Are Midwestern Gasoline Prices Downward Sticky?" (DOE/EIA-0626), February 1999

- Prices at the various market stages are highly correlated.
- The wholesale to retail pass-through is virtually complete within 4-8 weeks

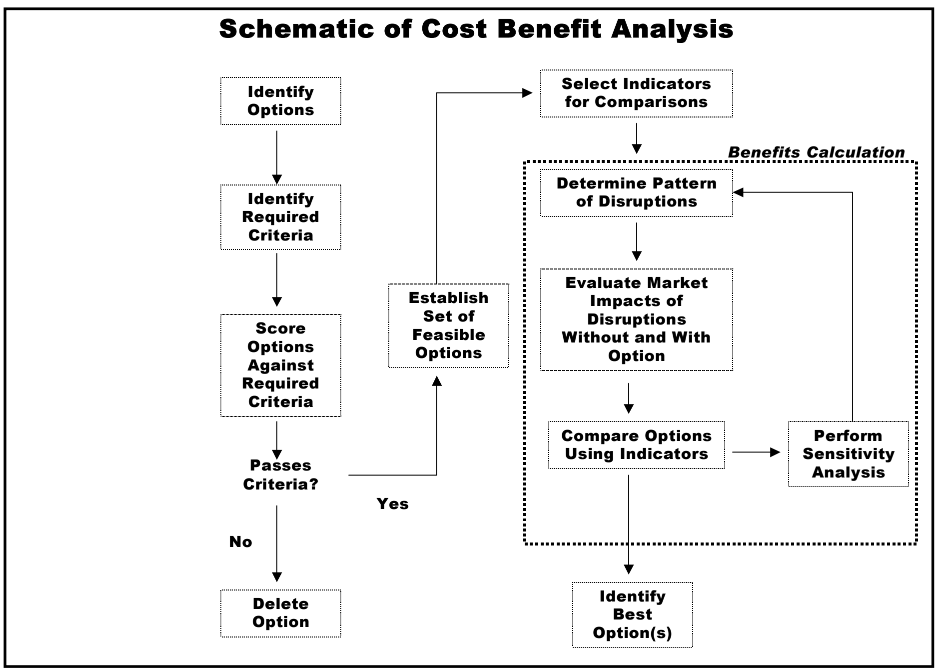
5 FRAMEWORK FOR ECONOMIC ANALYSIS

The State of California has a number of options available to it for the potential abatement of price spikes associated with unplanned refinery disruptions, including the option of doing nothing. These various options can be compared on the basis of generally accepted cost benefit analysis principles[18].

5.1 Cost – Benefit Analysis

Cost Benefit Analysis (CBA) is an organized framework to compare alternative policies on the basis of net benefits to society. The CBA process can be separated into the following steps: (Figure 5-1)

Figure 5-1 – Cost Benefit Analysis



1) Specify the set of feasible options

2) Identify the required criteria for consideration of an option and score the option on meeting the required criteria

3) Identify the set of benefits and costs to consider

[18] See Boardman (2002), Gramlich (1997), and Layard (1994).

4) Identify the economic indicators to use for comparisons and evaluate the economic impacts **without** and **with** the option

5) Perform sensitivity analysis on leveraging assumptions of the options

6) Identify the best option(s) from the analysis.

5.2 Set of feasible Options

A number of options to mitigate the price spikes associated with unplanned refinery outages have been proposed. They include:

- Strategic Fuel Reserve
- Fast track authority to allow expedited siting of storage facilities
- Additional storage built by the State that would be available to private holders
- Subsidy to private holders of inventory
- Incentives for in-State independent refiners to expand their facilities to increase CARB Phase III gasoline production capacity
- Incentives for nearby out-of-state refineries, such as those in Washington State, to upgrade their facilities to increase CARB Phase III production capability
- Demand-reduction programs
- Conversion of proprietary systems to common carrier status
- Long-term procurement of gasoline by the State
- Importation of non-compliance gasoline with a 15 cpg waiver

There are, of course, additional options and it is possible that some of the preferred options may face political impediments. The Stillwater Report identified a potential market imperfection that the demand for additional storage by refiners may be thwarted by restrictive permitting requirements by local and state government or refiners' fear of shifting environmental rules. Some or all of the options cited above may, in fact, do more harm than good in resolving the perceived market imperfection. The first step in the analysis is to examine if the options have the ability to satisfy some necessary conditions to mitigate price spikes in a timely manner. In short, the analysis must address: Does the option effectively reduce or eliminate the perceived market imperfection?

The first step in the cost-benefit analysis is to narrow the options down to those that can solve the problem, that is, test the set of proposed options against a set of identified criteria.

Stillwater consultants and other market commentators have suggested a set of requirements that the options must satisfy[19]. They are:

- *Is the option capable of mitigating price spikes from disruptions in a timely manner?* That is, can the mechanism respond fast enough to prevent a rise in price that would be transmitted on to the consumer? This is the necessary, central feature of the option and must be satisfied for it to be further considered. As shown in Section 3, California refiners respond quickly to a disruption, but their option of sourcing imports or shipments from the Gulf Coast take too long to quickly mitigate the price spike.

- *If a price mechanism, such as an auction, is envisioned as part of the option, is it non-discriminatory and non-manipulative?* California consumers are all too familiar with problems associated with electricity deregulation. Much play has been made of the ineffectiveness of the auction scheme for incremental power. In a number of articles, Paul Klemperer[20] has warned about the problems with auction design. Citing the fact that the "devil is in the details," he notes that the two critical features of auctions that matter are attracting entry and preventing collusion. He notes that choosing an ascending auction, one in which the bids are raised until the highest bid wins the auction, can deter entry and could possibly lead to collusive activity. Conversely, he suggests that a sealed bid auction, one in which the bidder provides one and only one bid, can avoid signaling to eliminate collusion. He further notes that this may still lead to inefficient outcomes. In a number of cases, he has proposed

[19] There may be additional criteria to test against.

[20] Klemperer (2001).

a hybrid of these methods. The auctioning mechanism, if there is one, must be tested against relevant auction theory and practice.

- Will the proposed option provide a disincentive for the holding of private inventories, i.e. “crowd out” or offset private inventory holder’s actions? Stated conversely, does the option provide an incentive for private storage at some point? Williams and others[21] have warned about the potential crowding out of private inventories by public inventories. In work examining the formation of the US Strategic Petroleum Reserve in the early 1980s, Williams and Wright[22] showed that one-third to two-thirds of incremental public storage was offset by compensating decreases in private inventory holdings. Since the options considered here have mechanisms that might have a public aspect to them, the option must be evaluated on its effectiveness and potential offsets.

- *Does the option promote forward liquidity in the gasoline market?* The Stillwater Report and Verleger[23] cite the need to promote forward liquidity to foster movements of imports and shipments from outside the region. Both believe this is a necessary condition for adequately mitigating excess price volatility. The Stillwater study illustrated the risk inherent in 2000 for refiners to bring cargoes to the West Coast. Gregg Haggquist[24] has codified five elements that are required for a physical basis for a forward market.

    1) Common delivery point
    2) Diversity of market participants
    3) Common or fungible specification
    4) Robust transaction flow
    5) Accessibility by a cross-section of suppliers

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[21] Williams (1986), Verleger (2000), Williams and Wright (1991).

[22] Williams, Jeffrey and Brian Wright (1982). “The roles of public and private storage in managing oil import disruptions,” *The Bell Journal of Economics*, 13, No.2, pp. 341-353

[23] Verleger, Philip (2002). Prepared statement before the Permanent Subcommittee on Investigations of the Senate Governmental Affairs Committee, May 2, 2002

[24] Haggquist, private communication (2002)

Each option should be examined against these requirements to ensure that it promotes improved forward liquidity.

5.3 Scoring the Options

The options should first be scored against conditions that will confirm the effectiveness of the proposed solutions, i.e., will they mitigate price spikes and promote security of supply of gasoline to California consumers.

If they pass this review, then the various alternatives can be evaluated on the basis of their net social benefits, where we ask: Do the societal benefits outweigh the costs?

Table 5.1 shows a proposed schematic to screen options that do not pass the litmus test provided by the necessary conditions.

Table 5.1 – Preliminary Economic Screening of Options

Option: / Criteria:	SFR	State Builds Storage Tanks	…	Non-Compliance Gasoline Waiver
	Option 1	*Option 2*	…	*Option N*
Timely mitigation of the price spike				
Non-discriminatory price mechanism				
Crowd out private inventories				
Provide forward liquidity				
… etc.				

5.4 The Cost-Benefit Paradigm

After satisfying the necessary conditions, the resultant feasible options are then compared on the basis of benefits versus costs, that is, net benefits (benefits less costs) with the option versus without the option.

On the cost side, one must include all incremental costs, including capital costs, operating costs, working capital (e.g. initial fill of the SFR), etc. on an annualized basis. If there is environmental degradation, such as the option of supplying non-compliance gasoline, they must be monetized[25] and included as a cost (or a negative benefit).

On the benefit side, one must identify all the economic benefits (including fees collected) that society receives with and without the option in place. Two principal impacts should be considered in the cost-benefit analysis:

1) Lower average spot prices, due to the reduction in volatility that the option produces, given that it can be triggered in a timely manner. (As stated earlier, the theory suggests that price volatility and spot prices will both be lower with increased storage.)

2) Reduction (chopping the spike) of price spikes from refinery disruptions. Not all disruption spikes can be mitigated without cost or with certainty. As one example, during large disruptions, market psychology may “take over,” and run the spot price higher than expected or required. Also, the cost of using an option, such as an SFR, would require restocking that imposes an implied cost on it use and hence a higher spot price. Economic analysis should, as much as practicable, consider these effects.

5.5 Welfare Model Paradigm

The paradigm needed to calculate the economic impacts and benefits is a variant of the welfare model. This is depicted in the following stylized charts[26]. Figure 5-2 illustrates the supply and demand conditions in the gasoline market before and after a disruption. The shaded areas in Figure 5-3, Figure 5-4, and Figure 5-5 illustrate three measures of benefits to avoiding price spikes: (1) the loss in consumer surplus, (2) the loss in societal welfare, and (3) the increase in the consumer’s gasoline bill from the disruption, respectively.

The concept of consumer surplus measures the extra value consumers derive from their consumption compared with the value measured at market prices. Similarly, producer surplus

[25] There are numerous studies that quantify environmental costs.

[26] More representative supply and demand curves for the California gasoline market are given in Section 6.

is the extra value received by producers above their marginal costs. Social welfare is the sum of consumer and producer surplus. The loss in social welfare is the change in the sum of consumer and producer surplus after change in a policy.

Figure 5-2 – Impact of a Disruption on Consumer and Producer Surplus

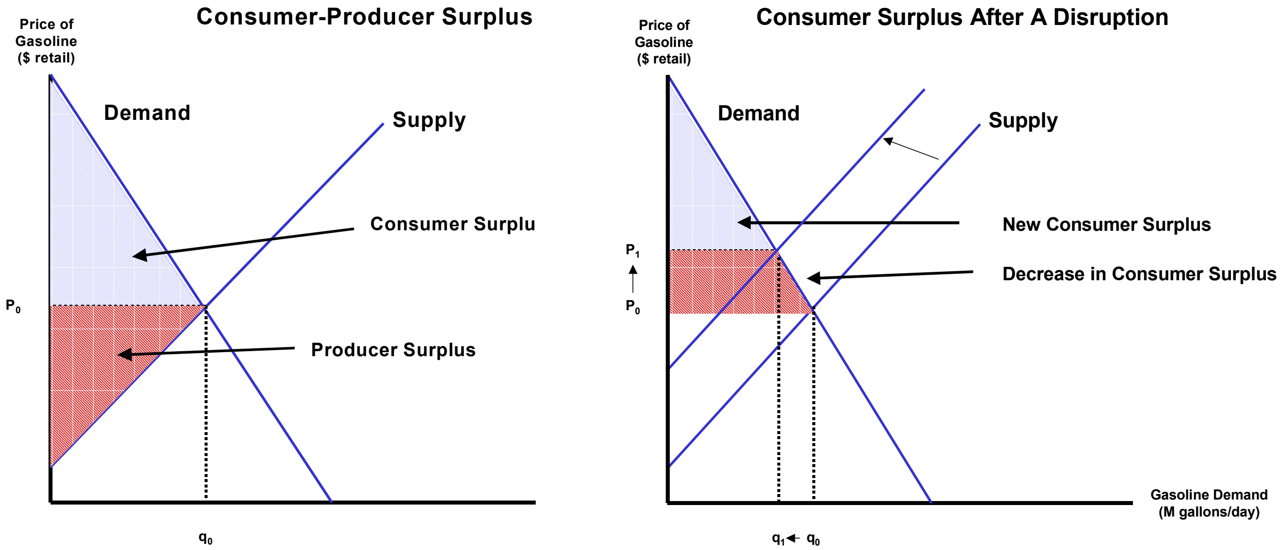


Figure 5-3 – Producer Surplus after a Disruption

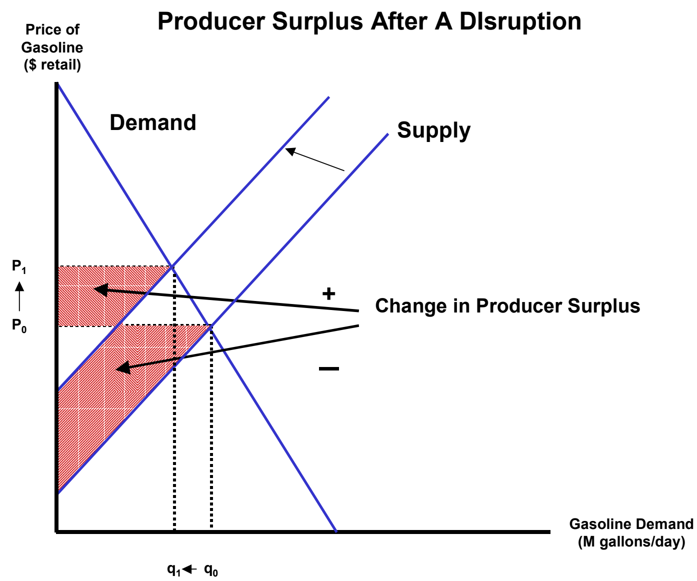
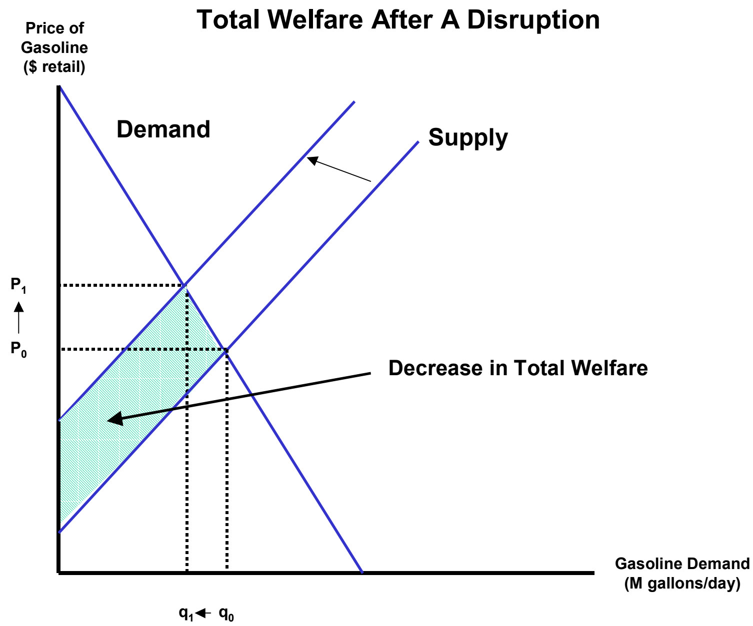
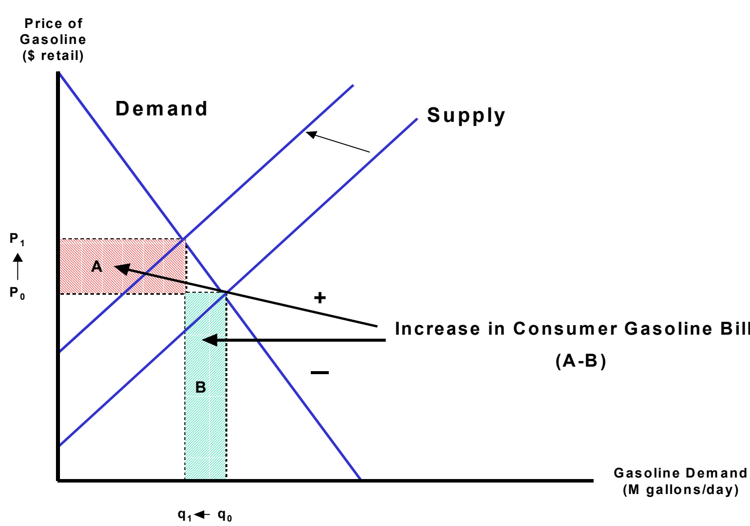


Figure 5-4 – Total Welfare after a Disruption



Most often, cost-benefit analysis uses net social welfare (shown in Figure 5-4), the sum of consumer and producer surplus changes, as the appropriate indicator of the benefit from a policy change. Here, however, the recommended measure is just the consumer benefit portion, the change in consumer surplus (the benefit is the avoidance of the loss in consumer surplus.) for two reasons: (1) The benefits accruing to producers will not largely stay in California, and (2) The California Legislature in AB 2076 specified the calculation of net consumer benefits.

Figure 5-5 – Change in the Consumer Gasoline Bill after a Disruption



Also, the federal government Office of Management and Budget states that "consumer surplus provides the best measure of the total benefit to society from a government program or project."[27]

The graphs presented in this section are for expository purposes. The analysis of feasible options will require quantification of the demand and supply elasticities and particular shape of the demand and supply curves. Since many commentators on the proposed options might use one of the other alternative indicators, it is advisable to carry along all three measures in subsequent analyses. It should be noted that in many instances, the net change in social welfare is often small, because of largely offsetting changes in consumer and producer surplus.

The implementation of these concepts for the SFR envisioned in the Stillwater Report is presented in Section 6. Each of the three indicators of benefits is calculated in that illustrative analysis.

5.6 Evaluation of Benefits under Uncertainty

A central feature of all the options to be considered is that they face a future environment of refinery disruptions. The economic analysis must consider plausible alternative refinery disruption environments in the cost benefit analysis.

The particular frequency, size, and duration of future refinery disruptions cannot, of course, be known in advance. Future disruptions may follow a similar pattern to the 1996-2001 period, become more frequent and severe due to even more stringent environmental regulations, or even abate due to improved refinery practices as a result of learning. These alternative patterns will change the size of potential benefits accruing to options employed. These alternatives can be explored through use of powerful statistical simulation techniques. The estimation of economic benefits can be done prospectively using assumptions about uncertainty by generally accepted Monte Carlo techniques. This approach allows for explorations around key assumptions, including supply and demand elasticities, and size, duration, and frequency of disruptions.

The approach can explicitly allow for:

- Different price spike impacts during high and low inventories.
- Multiple disruptions at one time as has happened in the past four years

[27] OMB (1992), p.6

- A probability distribution over disruption durations
- A probability distribution over disruption sizes
- Alternative specification of disruption occurrences.
- Alternative specification of short-term supply and demand elasticities

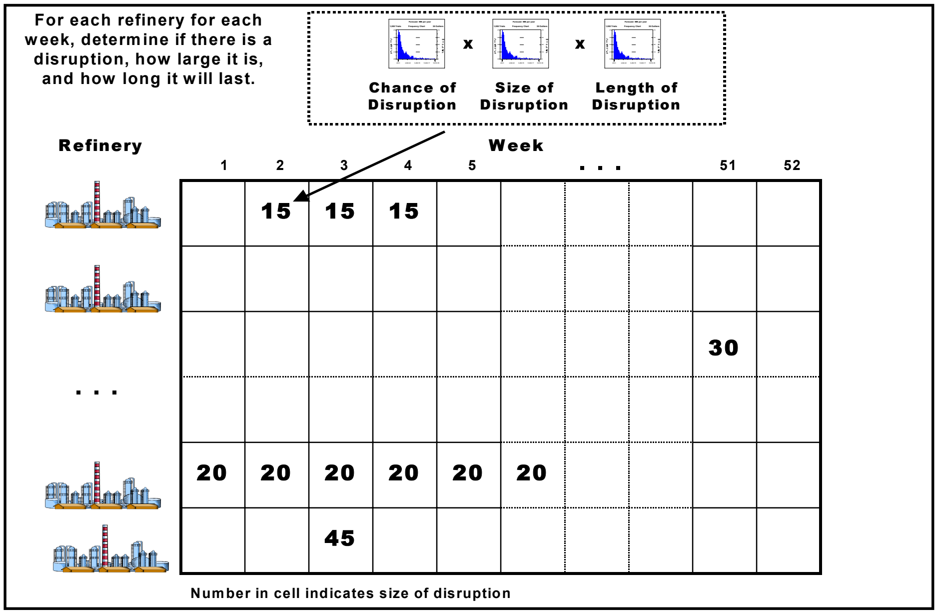
As a baseline, one can estimate the frequency, size, and duration of refinery disruptions from the database of California disruptions from early 1996 through early 2001.

The resultant output will include a distribution of economic benefits. From that, one can ascertain the expected value (central tendency) and the range of certainty around it. In addition, other useful cases can be run. For example, one might assert that 1999, a particularly bad year for disruptions, is an anomaly (a “10-year flood”) and should be excluded. Or, one can assume that refiners will face 1998, a benign year, over and over again. These and other scenarios can be explored to see how robust the economic benefit estimates are.

In order to clearly account for low inventory conditions, winter and turnaround conditions, which have different elasticity or frequency parameters, and to ensure that we do not double count refinery disruptions, the benefits are simulated over a 52-week period for 11 representative refineries[28]. In this approach, each week, for each refinery, a random draw is taken from the disruption, size, and length statistical distributions to determine if a disruption has occurred, and, if so, what size and length. (The spreadsheet ensures that a refinery that is down for more than one week will not suffer another outage until the current outage is over.) The spreadsheet then calculates the total disrupted barrels, and then estimates the price response given the supply and demand elasticities. The model can distinguish between high and low inventory positions. (See the schematic in Figure 5-6.))

[28] This model was developed by Dr. Anthony Finizza. Please arrange for its use directly from the author: afinizza@aol.com or afinizza@uci.edu.

Figure 5-6 – Refinery Disruption Tableau



5.7 Consideration of the Economics of the Inventory Behavior

Since most of the options involve gasoline inventory issues, the economic analysis should consider results of the growing literature on inventory behavior.

In recent work on the dynamics of price, production, and inventories for commodities, Robert Pindyck[29] shows how prices, production, and inventories are determined in two interconnected markets: a cash market for spot product sales and a market for storage.

He shows that the cash market is in equilibrium when net demand for product equals net supply. His model depicts this equilibrium in terms of the inverse demand function:

$$P = f(\Delta N, z_d, z_s, \varepsilon)$$

where P is the spot price, ΔN is the change in inventories, z_d are demand-shifting variables, z_s are supply-shifting variables, and ε is the error term.

He describes the demand for storage function as an inverse demand function,

$$\psi = g(N, \sigma, z_d, \varepsilon)$$

[29] Pindyck (2001a), (2001b).

where ψ is the marginal convenience yield (price of storage), N is inventories, σ is the volatility of prices, z_d represents demand shifting variables (now including the spot price of gasoline), and ε is the error term.

The marginal convenience yield, the price of storage, equals the value of services from holding a marginal unit of inventory. Values of the marginal convenience yield can be directly measured whenever there are future prices through the arbitrage equation relating it to spot prices, and futures prices, the risk free rate, and the cost of physical storage.

The inference from his work and others is that:

- Price volatility is greater during periods of low inventory
- An increase in price volatility, such as might be caused by disruptions, should increase the need for inventories to buffer increases fluctuations in supply and demand, which increase the chance of outages.
- Increased price volatility raises spot prices and the cost of storage.

6 ECONOMIC EVALUATION OF THE SFR PROPOSED BY STILLWATER

The framework outlined in Section 5 can be applied to the SFR proposal suggested by Stillwater Associates.

6.1 Preliminary Scoring of SFR Option

Using Table 5.1 as a guide, the SFR proposal by Stillwater can be scored under the four necessary criteria described.

6.1.1 Timely mitigation of the price spike

The proposal is to divide the SFR into two separate operational entities, to be fully integrated with each of the refining centers in the Bay Area and the Los Angeles Basin respectively. The direct linkage of the SFR to the logistic system ensures that the use of its storage will produce a more timely response to outages than long haul shipments from the Gulf Coast or foreign locations.

6.1.2 Non-discriminatory price mechanism

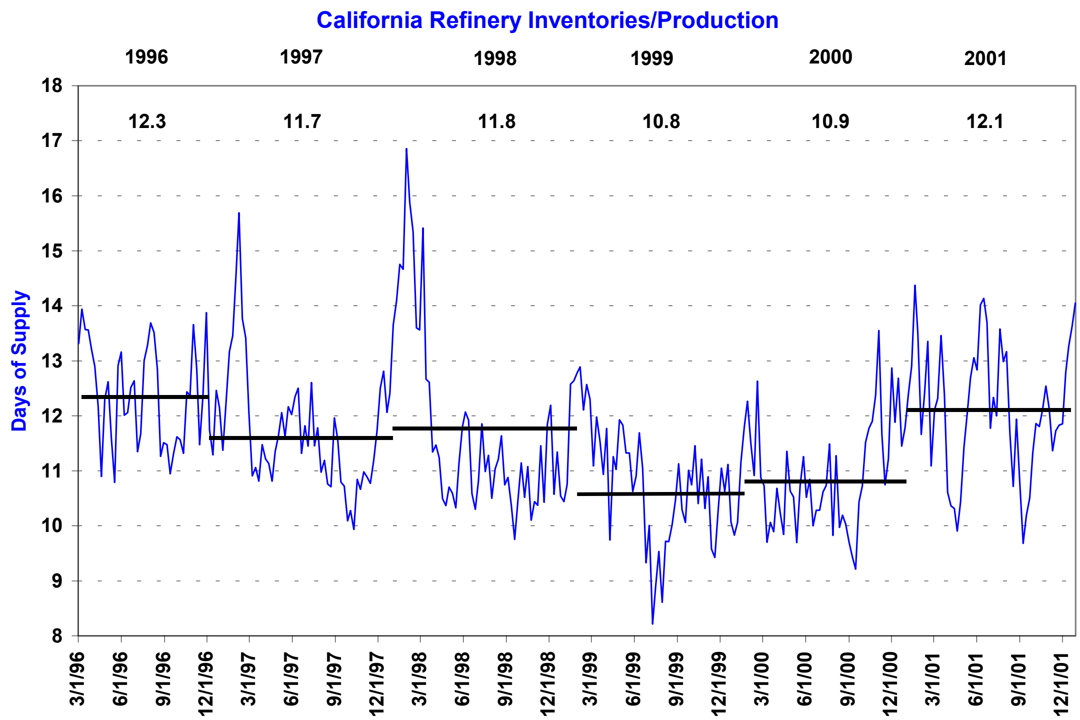
This feature is possible given a careful construction of the auction mechanism. This feature cannot be evaluated yet, since the details have yet to be described. Since the proposal is to not have arbitrary trigger mechanisms but to allow continuous access to the reserve in the form of time swaps for a fee, with open access for qualified parties, it seems likely that the pricing system will be non-discriminatory.

6.1.3 Crowd out private inventories

The Stillwater report suggests that the refinery industry does not hold much inventory above working levels. A cursory look at inventories in relation to production at California refineries (Figure 6-1) suggests that refiners held about 12 days of supply during periods of normal activity (e.g. 1996, 1997, and 2001, years of minimal disruptions) and drew down their inventories in response to severe disruptions in 1999 and 2000.

As stated earlier, the theory of inventory behavior suggests that refiners would hold increased precautionary inventories during periods of high price volatility. While refiners appeared to have added to inventories after the period of severe disruptions, they did not add to inventories beyond historical holdings on a day of supply basis. This seems to confirm the Stillwater perspective that there has not been an increase in precautionary inventories as price volatility increased. Still, it can be argued that the 12 days of supply contains some precautionary inventories and that some would be offset by inventories in the SFR. Under that view, precautionary inventories reductions should be expected to be minimal.

Figure 6-1 – California Refinery Inventories in Days' Production



Since the current proposal also includes facilitating the building of additional commercial tankage for use by private parties, it could well be that average industry inventories will increase rather than decrease as a result of the proposal.

6.1.4 *Provide forward liquidity*

The Stillwater report illustrates how the SFR will increase forward liquidity. The time swap mechanism proposed for accessing the reserve volumes for a fee effectively exposes the value of the backwardation and allows importers a physical means to lock in prices and costs for future deliveries, removing the risks imposed by market fluctuations.

6.2 Summary of Preliminary Screening

It appears that the SFR proposal passes the initial test of feasibility. It should be compared against scoring of the other alternatives. A summary is provided in Table 6.1.

Table 6.1 – Preliminary Scoring of the Stillwater SFR Option

Option: / Criteria:	Stillwater SFR	State Builds Storage Tanks	…	Non-Compliance Gasoline Waiver
	Option 1	*Option 2*	…	*Option N*
Timely mitigation of the price spike	Yes			
Non-discriminatory price mechanism	Likely, but will have to be confirmed in detailed design			
Crowd out private inventories	Minimal,			
Provide forward liquidity	Yes			
… etc.				

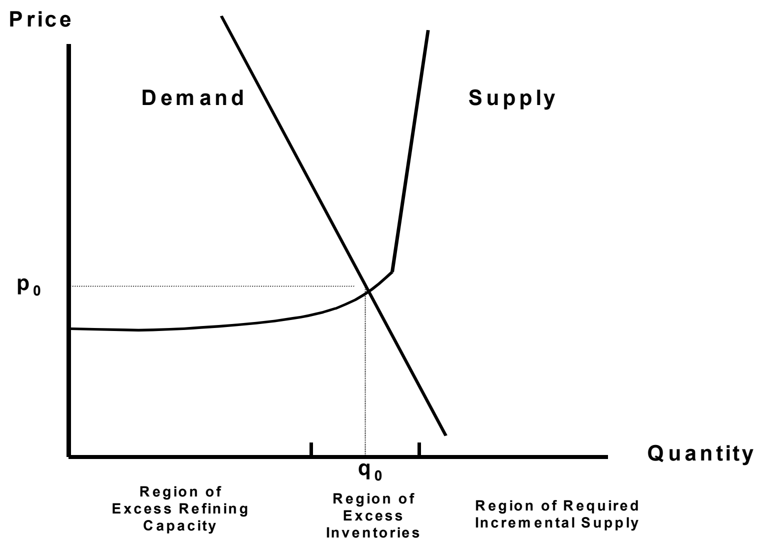
6.3 Supply-Demand Representation of the California Gasoline Market

In order to evaluate the potential economic benefits of the proposed SFR, the short-term supply and demand of gasoline in California needs to be examined.

6.3.1 Without the Proposed SFR

Figure 6-2 illustrates the short-term gasoline market in California. The demand curve is highly inelastic. The supply curve is flat (elastic) for production up a point close to full refinery capacity utilization. The current market is at capacity, so this region is not where the industry is operating. The next region of the supply curve, which is more inelastic, is the region where supply could be sourced out of precautionary inventories. The industry does not have excess inventories during most of the year but operates this way typically during winter and turnaround periods. Finally, the last region represents the inelastic part where supply would be sourced out of high cost imports.

Figure 6-2 – Short-Term Gasoline Supply and Demand without SFR



For this study, the above construct is approximated by that given in Figure 6-3. The supply curve is flat up to the point of full capacity and excess precautionary inventories, at which point it become highly inelastic to reflect the high costs of sourcing imported product. Note that there is no producer surplus in this approximation.

Figure 6-3 - Supply and Demand Curves Without SFR

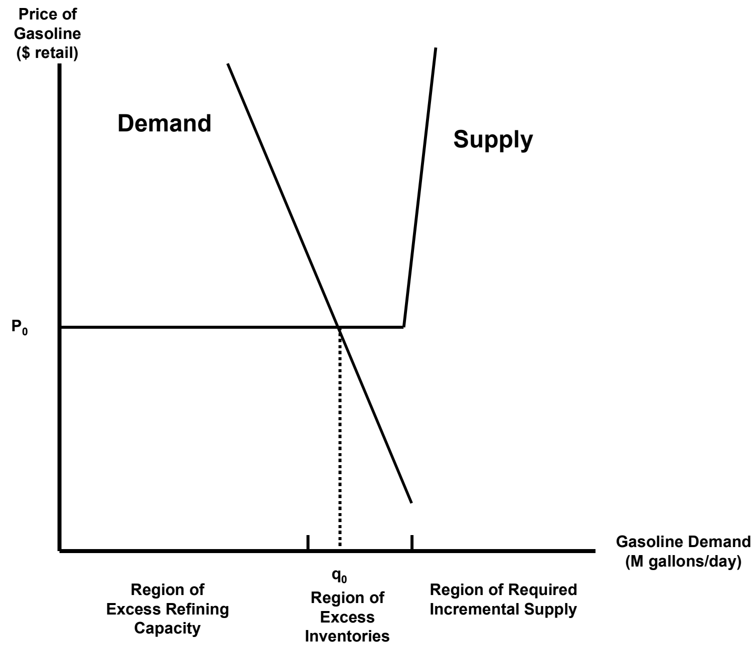


Figure 6-4 and Figure 6-5 illustrate the price impacts of two types of disruptions, the first large relative to the level of precautionary inventories and the second small relative to precautionary inventories.

Figure 6-4 - Price Impact Under a Large Disruption – Without SFR

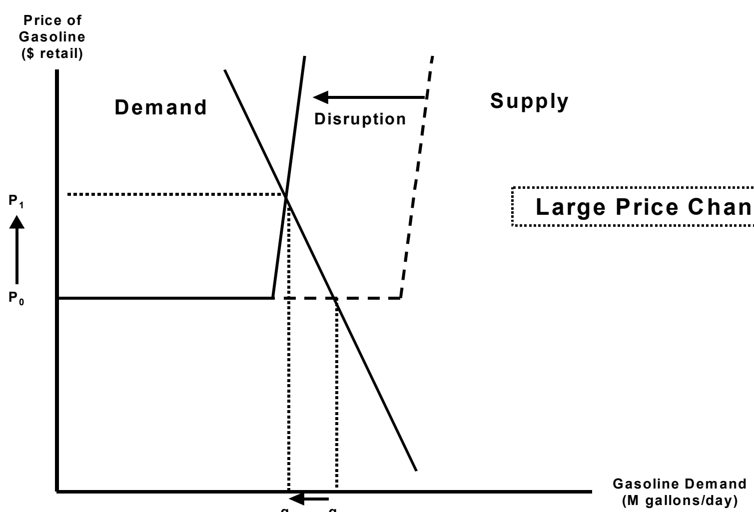


Figure 6-5 - Price Impact Under A Small Disruption – Without SFR

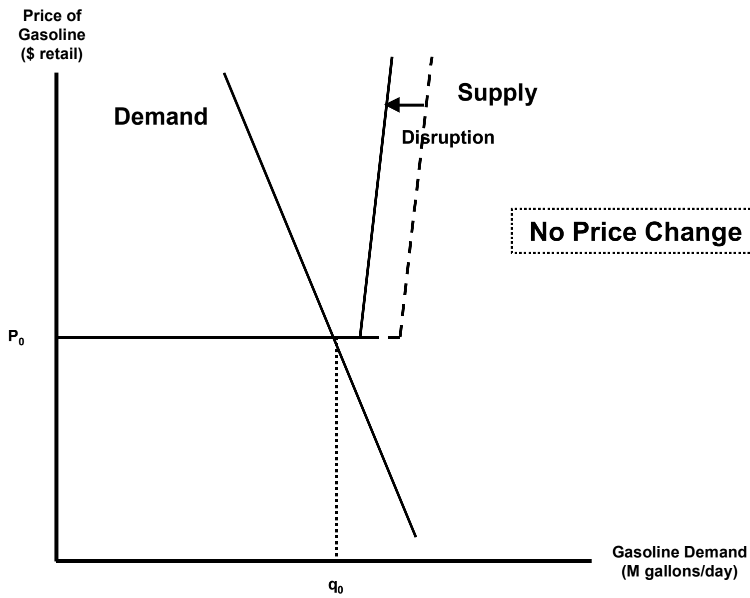


Figure 6-6 and Figure 6-7 show the increase in the consumer gasoline bill and the decrease in consumer surplus for a supply disruption **without** the SFR.

Figure 6-6 – Increase in Consumer Gasoline Bill Due to Disruption Without SFR

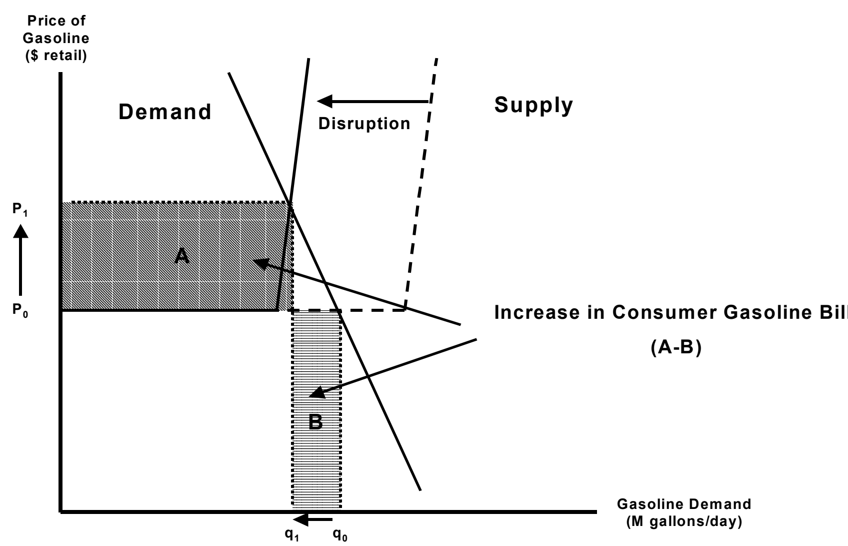
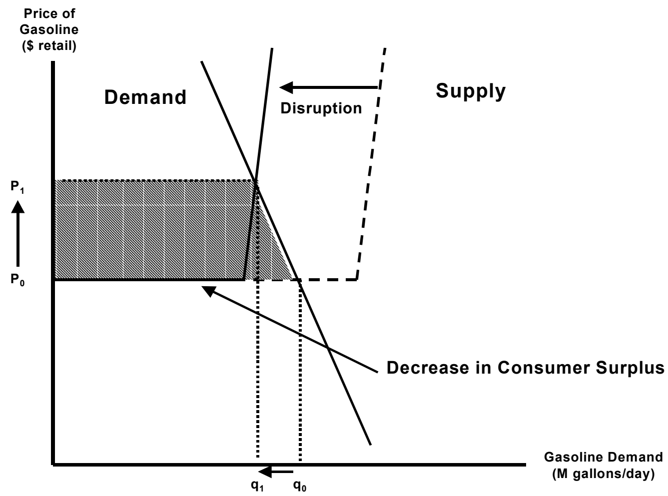


Figure 6-7 - Decrease in Consumer Surplus Due to Disruption Without SFR

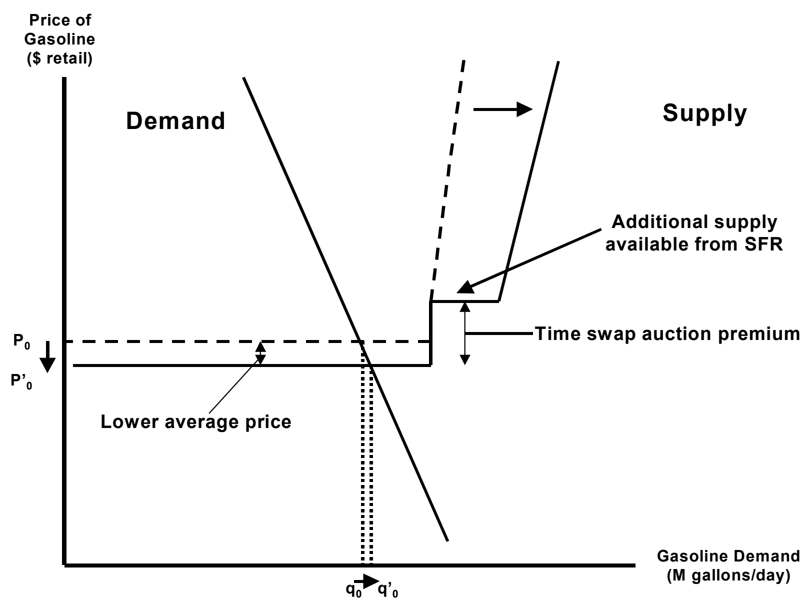


During a disruption, incremental supplies are sourced out of precautionary inventories and then from distant sources. Prices rise to clear the market in accordance with their elasticities. Prices return to normal, with a lag, after the disrupted barrels are replaced. In the interim, the consumer faces a lower consumer surplus and a higher gasoline bill (on all barrels sold during the disruption). A static calculation of these measures under representative demand and supply elasticities is given in Section 6.

6.3.2 Supply-Demand Response with the Proposed SFR

After the introduction of the SFR, the net total system precautionary inventories will be larger (SFR offset by small reductions, if any, in private inventories) and the supply responsiveness with respect to imports will be greater. So, the supply curve will shift by the net change in inventories plus become more elastic. The additional cost of accessing the SFR, labeled the time-swap auction premium, is discussed below. This is shown in Figure 6-8. This suggests that there is a net social benefit through lower "average" prices in the absence of a disruption. This should be included in the benefits.

Figure 6-8 – Short-Term Gasoline Supply and Demand with SFR



With the SFR and during a similar size disruption, the impacts on the measures of welfare loss are, of course, smaller, since the higher level of precautionary inventories will mitigate a price rise. (See Figure 6-9 – Price Impact of a Large Disruption With the SFR.) When comparing the net benefits of the SFR, the **without SFR** effects as shown in Figures 6.6-6.7 must be compared to the **with SFR** effects shown in Figures 6.10-6.11.

Consider the case of the impact of a disruption during a period of low or no precautionary inventories. The net benefit to the consumer is the avoidance of the price spike that would have occurred without the SFR less the amount of the spike that cannot be avoided with the SFR (e.g. the time swap auction premium that represents the cost of sourcing a replacement barrel via a time swap). For this, we need to compare the resulting price-quantity equilibriums under two cases, **without** and **with** the SFR. This is shown in a stylized description of the price effect in Figure 6-12 for a representative gasoline price change. The net benefits (which must be applied to all barrels consumed during the price spike) are shaded.

Figure 6-9 – Price Impact of a Large Disruption With the SFR

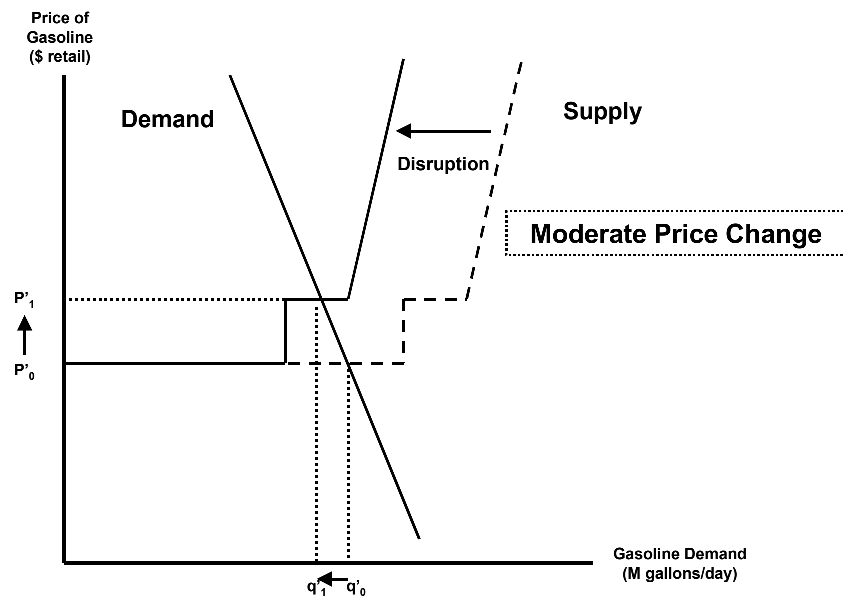


Figure 6-10 – Increase in Consumer Gasoline Bill with SFR

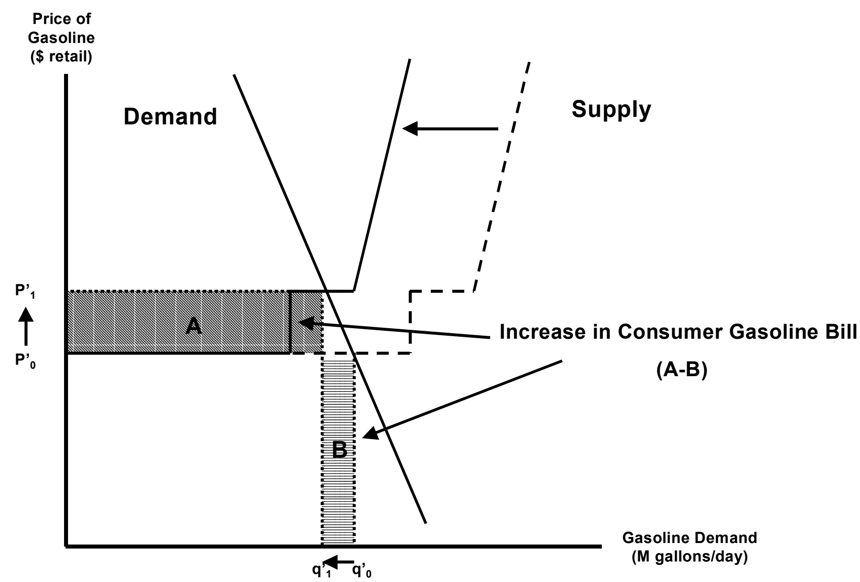
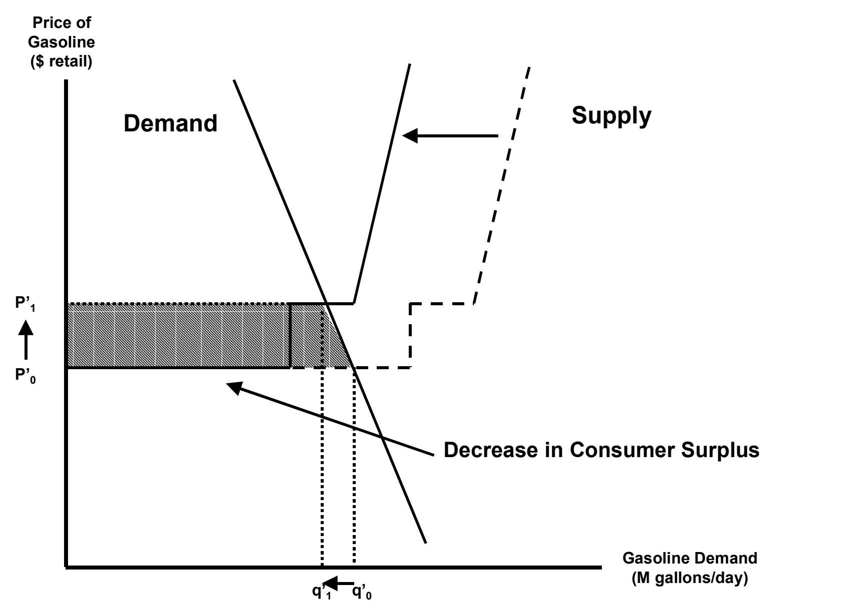
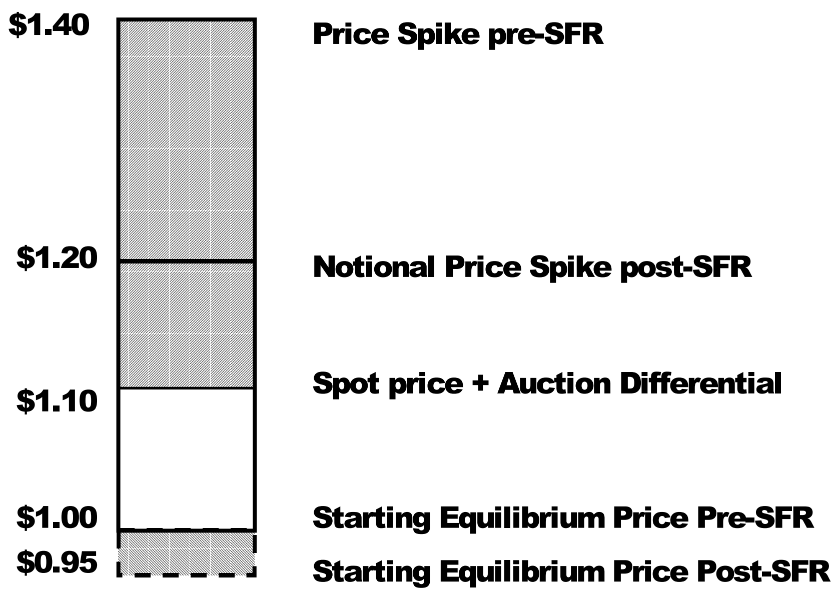


Figure 6-11 – Decrease in Consumer Surplus with SFR



- Even under the most benign combination of alternative assumptions, that disruptions have lower occurrence and that the SFR mechanism can only offset spikes in excess of 15 cpg, the economic benefits are over $ 140 million.

Figure 6-12 – Price Effect for a Representative Price Change



6.4 Demand and Supply Elasticities

In order to quantify the benefits that can accrue to the existence of an SFR, we are required to estimate the short-term gasoline demand and supply price elasticities in the current environment **without** the SFR and then **with** the SFR.

6.4.1 Use of Elasticities

The *price elasticity of demand* is the percentage change in quantity demanded divided by the percentage change in price. If the elasticity is less than 1 in absolute value, the demand for that commodity is inelastic. So, a demand price elasticity of – 0.1, for example, suggests that a 2% fall in demand would indicate a price increase of 20% [2%/(-0.1)=20%]. The larger the absolute value (price elasticity of demand is negative) of the price elasticity, the more sensitive demand is to given change in price. Demand is more sensitive the more there are close substitutes for a product. In the short run, demand is less elastic than in the long run, since there are more opportunities for substitution over time.

The price elasticity of supply is the percentage change in quantity supplied for a given percentage change in price. The value of the supply elasticity is positive, because an increase in price will stimulate additional supply. The elasticity of supply depends on the level inventories that can be supplied into the market and the amount of spare capacity in the refinery industry that can serve as a source of additional supply. Supply is likely to be more elastic the longer the time period, since the firm can adjust its production to new conditions.

6.4.2 Estimates of Demand Elasticity

Although there have been no published studies of the demand price elasticity for gasoline in California to the author's knowledge, there have been a number of empirical calculations of the price elasticity of demand for gasoline for US and international gasoline markets by various economists. (See the Bibliography for a useful list of papers.) The studies report a wide range of estimates, due to their choice of estimation procedure, data sample, and different time frames for analysis.

It is widely acknowledged that gasoline demand is highly inelastic. Thus, small changes in the availability of supply (e.g. a disruption) will have a large effect on gasoline prices. It also means, of course, that small errors in forecasting the elasticity will have large effect on the results.

Three complete surveys of elasticities are worth mentioning. Carol Dahl, in 1986 and 1995 and with T. Sterner in 1991, has examined most studies of demand elasticity for gasoline. In her most recent survey, she distinguished among short-term, intermediate-term, and long-term elasticities of demand. We are interested in the short-term elasticity. This author corrected a number of obvious errors to compile the results in Table 6.2. It is interesting to note that there are often outliers in the estimates that badly skew the results when using the mean of the sample. For example, (See Appendix C) in her 1995 study, Dahl reported one estimate of –2.13 by Franzen and an estimate of +. 03 by Gately. The inclusion of the Franzen estimate in the mean, in particular, skews the results.

The average of the 25 elasticity estimates is -.19, or -.116 if the two outliers are removed. As expected, this is virtually identical with the median of the 25 estimates.

The elasticity estimates do not change materially from her 1986 survey to her 1995 survey.

This author has added seven estimates made after 1995 to Table 6.2. The mean and median of those are in line with the Dahl results.[30]

Of particular interest is the elasticity estimate of -.05 provided by the Western States Petroleum Association on their website tutorial, *Gasoline 101*. This estimate is too low (in absolute value), although a comparison of data for the 1998 and 1999 summer driving season by Stillwater[31] also indicates the same highly inelastic behavior in a response to supply disruptions in 1999.

Table 6.2 – Estimates of Demand Elasticities in the Literature

Surveys of Studies	Mean	Median	Range
Dahl (1995)	-.19	-.10	+. 03 to –2.13
Dahl and Sterner (1991)	-.19	-.18	-.08 to -.41***
Dahl (1986) **	-.15*	-.125*	-.01 to -.52
Post-1995 Individual Studies	Mean	Median	Range
Verleger (2002) Senate Testimony	-.1		
FTC (2001) Midwest Gasoline Investigation	-.2		-.1 to -.4
Perry (2001)	-.05		
WSPA (2001) (PIRINC study)	-.05		
Borenstein (2000)	-.15		
Kayser (2000)	-.23		
API (Porter) (1996)	-.19		

[30] The author has noted a number of studies that use results of the Dahl and Dahl–Sterner work, and quote the range of elasticities that are provided by those authors. Examining the tables in those original works, however, it is clear that the linkage between conclusions and tables are in conflict. For example, Dahl and Sterner quote a mean of short-run estimates, which include inadvertently non-short-term data. Underlying data from their work are given in Appendix C.

[31] Stillwater SFR Report, June 2002

Haughton & Sarkar (1996)	-.15		-.12 to -.17
8 Individual Studies	-.14	-.15	
Std. Deviation of 8 Individual Studies	.07		

*Calculated by this author.
** Estimate is for monthly and quarterly models. Dahl cited -.29 for yearly models.
***Range of means.

Molly Espey (1996, 1998) provides two "meta-analyses" of elasticities. In her creative work, she explained the elasticity estimates (used as dependent variables) on the basis of characteristics of the study (independent variables). Examples of these explanatory variables include functional form, lagged structure, region, time interval, etc.

She concluded, in part, that:

- The short-term response of gasoline demand to price changes is quick, with virtually all the short-run response occurring within a month. (Our results suggest that at the end of four-weeks, over 75% of the price effect is passed-through, but that the full effect takes six weeks, and that the full episode is from 4-8 weeks.)
- Short-run gasoline demand price responsiveness seems to have declined over time.
- The price responsiveness in the United States is significantly different than other countries, usually Canada and European countries. (This study excludes non-US estimates.)
- Static models appear to overestimate short-term elasticities.

Her most important conclusion for our purposes is that "models that include some measure of vehicle ownership and fuel efficiency capture the 'shortest' short-run elasticities by effectively measuring the influence of price and income changes on driving only. Models that omit one or both of these variables would measure … an intermediate or long-run elasticity."[32] Examining the elasticity estimates in the studies in Table 6.2 indicates that those studies that conform to the statement by Espey have lower (in absolute value) demand elasticities. A prime example is the work by Gately. The mean of his elasticity estimates are -.096 and .10, respectively. For purposes of measuring the

[32] Espey (1998) p. 288. The author wishes to thank Sy Goldstone of the California Energy Commission for bringing this to his attention.

short-term impacts of supply outages, it seems appropriate to choose -.1 as the “best estimate” for the demand elasticity.

6.4.3 Estimates of California Gasoline Supply Elasticity

Gasoline supply in California is highly inelastic as well, because of the boutique fuel specifications, the very limited storage, and the long supply routes from alternative sources. During a disruption, alternative supply options in the short-run are primarily from inventory and increased production at other refineries. Given the tight capacity prevailing in California refineries, inventory changes are the primary alternative source.

There do not seem to be any credible estimates of gasoline supply elasticity. It is widely acknowledged, however, that gasoline supply is highly inelastic, and more inelastic than demand in the short-run. Many analysts assume supply is fully inelastic. For our purposes, we use .05.

6.4.4 Combined Supply-Demand Effect

The effect of a shock, such as that caused by a refinery disruption and the subsequent market reaction, is comprised of both demand and supply effects. Given the lack of estimates for the supply elasticity and given the belief that the supply effect is much smaller that the demand effect, the report uses a range of elasticities that captures the uncertainty around the demand and supply effect. Many analysts adopt the approach of assuming the supply curve is fully inelastic[33]. While this simplification should not have a material impact on the results, we choose to explicitly consider both supply and demand effects. Using the most likely value of the demand elasticity and the assumed supply elasticity, we get -.15 for the best estimate of the combined effect. In order to capture the uncertainty around both estimates, the analysis in later sections uses the range of -.10 to -.20 for the combined effects.[34]

6.4.5 Empirical Support for Demand and Supply Elasticity Estimates

In early 1999, due to two disruptions in Northern California, retail prices rose from 112.1 cpg to 162.4 cpg, a 45% rise. In that period, gasoline production fell from about 928 mbd to 844 mbd, a 9% fall, and inventories offset part of this reduction, being down

[33] See Borenstein (2000), Bulow (2001), Verleger (2002).

[34] For medium-term supply problems, such as the tightness envisioned due to problems of an MTBE phase-out, the analysis should use a value of about -.5.

20 mbd, for a total supply fall of 6.9%. This implies an elasticity of -.153, which is close to our estimate.

There are four clean periods for which we can observe price reactions to refinery outages. These periods have low or normal inventories, do not have crude price movements, and do not have any overlapping outages that confound the estimation. A table of these price impacts and the implied combined demand and supply price elasticities is given in Table 6.3. The mean value of -.143 conforms to our assumption.

Table 6.3 – Estimates of Combined Demand & Supply Price Elasticities

Outages	Size (mbd)	Inventory Character	Implied Elasticity
01/24/97	25	High (Winter)	-.200
08/08/1997	21	Low	-.108
04/17/1998	28	Normal	-.137
07/23/1999	31/51/49	Low	-.125
		Average	**-.143**

6.4.6 *Supply Elasticity with the Proposed SFR*

Supply should become more responsive after the introduction of the SFR. We can turn to the work by Pindyck to attempt to quantify this approach, using the demand for storage function introduced in Section 5,

$$\psi = g(N, \sigma, z, \varepsilon)$$

where ψ is the marginal convenience yield (price of storage), N is inventories, σ is the volatility of prices, z represents demand shifting variables (including the spot price of gasoline), and ε is the error term.

Values of the marginal convenience yield can be directly measured whenever there are future prices through the arbitrage equation relating it to spot prices, and futures prices, the risk free rate, and the cost of physical storage. We, however, do not have estimates of the futures price, so we will employ a proxy variable.

We take demand-shifting variables to include monthly dummy variables, the spot price of gasoline, and measure volatility as described before. Since this equation is part of joint equilibrium with the cash market, we need to estimate it by Two Stage Least Squares with appropriate instrumental variables. The resulting equation [35]suggests that an additional million barrels of storage would depress the spot price by about 3-5 cpg on average and increase the supply elasticity by .05. A 1 cpg reduction amounts to a $145 million dollar lower consumer gasoline bill per year.

A detailed model of the California market would be required for these empirical estimates to be more credible.

6.5 Economic Benefit of the Proposed Strategic Fuels Reserve

This section derives estimates of the economic benefit of an SFR through (1) lowering the average spot price (via reduced volatility and increased supply responsiveness) and (2) the ability to truncate the price spikes attributed to refinery disruptions.

Removing an entire spike by replacing disrupted barrels from storage, of course, is highly unlikely and, since it would have to be timed perfectly, not alter consumer perceptions, and not deplete inventories below minimal acceptable levels. The analysis will first illustrate the maximum potential benefit to give an idea of what is at stake and then calculate the likely offsets to this.

The Strategic Fuel Reserve outlined in the Stillwater Associates' report is a dynamic inventory where a fraction (assumed to be 50 mbd, but to be determined) is available to be auctioned off on a daily basis. The reserve may be idle on most days. The characterization of the benefit that can accrue to the California consumer depends on details that have yet to be determined. The key element affecting that benefit include:

- To what extent does the SFR open the California market to potential suppliers that might not normally wish to take the price risk during the long supply journey?
- How quickly the SFR can supply the market?
- How successful is the mere existence of the SFR in muting price spikes associated with rumor?

[35] See Appendix F for the econometric results.

A full analysis will not be possible until these questions have been answered.

6.5.1 Maximum Potential Benefit

Today, California consumers use about 14.5 billion gallons of gasoline a year or roughly 40 million gallons per day. At an average retail price of $1.50 per gallon, California consumers pay $60 million per day for gasoline. Each 1 cpg above the average retail price translates into an additional $400,000 per day. The associated consumer surplus approaches $200 million per day, that is, the surplus over the California consumer's willingness-to-pay.

As shown in Section 2, refinery disruptions have occurred on average about 10 times per year and last for three weeks and take 2% of the gasoline supply out, on average. The price spikes associated with the 2% outages, if not filled out of precautionary inventories, can increase retail prices by 10% and more.

6.5.2 Static Analysis of Benefit during an Average Disruption

The following is an illustrative example, with parameters that may have existed at the onset of the 1999 refinery disruptions. Assume a $1.50 retail price, consumption of 40 million gallons of gasoline per day (14.5 billion gallons per year), and a combined price elasticity of – 0.15. With an average size disruption (2%), the gasoline price increases to $1.70 in accordance with the assumed elasticity. The daily change in the consumer gasoline bill and in consumer surplus is given in Table 6.4. These values show how much is at stake if the disruptions can be mitigated.

Table 6.4 – Changes in Welfare after a Sample Disruption

Elasticity = - 0.15	Before Disruption $ MM/day	After Disruption $ MM/day	Change $ MM/day
Consumer Surplus			-7.92
Consumer Gasoline Bill	60	66.64	+6.64

Since the average disruption is 19 days (2.7 weeks) and there are about ten disruptions per year, the figures in Table 6.4 would have to be multiplied by 200 to express them on an annual basis.

So, even partial mitigation of some of the spikes can reap large economic benefits. The rest of the section turns toward applying the concepts introduced in Section 5 to quantify the economic benefits. For this we first need to determine the likelihood of future refinery disruptions.

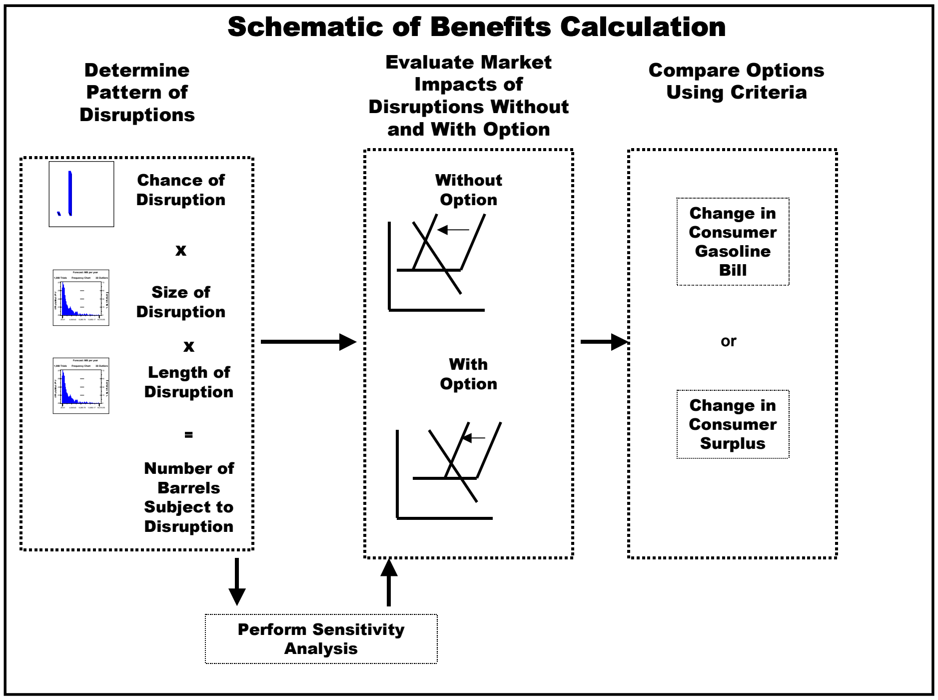
6.6 Monte Carlo Approach to Calculating Economic Benefits

6.6.1 Model

A rich approach to modeling the economic impact of refinery disruptions is through Monte Carlo analysis. This approach derives statistically the distribution of likely total disrupted barrels and then applies the price elasticity of gasoline supply shocks to measure the implied price effect. This analysis proceeds by combining statistically the chance of a refinery disruption, the likely size of a disruption, and the length of the disruption. This is all done assuming draws from relevant probability distributions[36]. (See Attachment E for details on the assumed distributions.)

Figure 6-13 depicts the Monte Carlo model for conducting benefits analysis. As indicated in Figure 5-6, for each week, a random draw is chosen to establish if a refinery suffers a disruption and, if so, how large and long will it last? The model then calculates the economic impact of the disruption without and with the SFR, using elasticities provided earlier. The “with the SFR” calculation allows the spot price to rise by the assumed auction premium, which is a variable in the model. The model then calculates the benefits measures, change in consumer gasoline bill and change in consumer surplus. The model is next used for sensitivity analysis by varying the key assumptions of the user’s choice. The particular set of alternatives is given in Section 6.6.4.

Figure 6-13 – Schematic of Benefits Calculation



The required inputs to the model are:

- Demand elasticity (short-term)
- Supply elasticity (short-term)
- Size of market
- Retail price of gasoline
- Chance of a disruption (per week)
- Probability distribution of size of disruptions (mbd)
- Probability distribution of length of the disruption (weeks)
- Auction differential (cpg)
- Frequency of high Inventories

[36] It is possible to calculate a closed form of the joint distribution, although that approach will not allow for ease of sensitivity analysis.

6.6.2 Statistical Parameters for Monte Carlo Analysis

Chance of a Disruption. Either a disruption can occur or not occur. The probability of a refinery having a measurable disruption during a week is .017, that is, the chance of a given refinery having a disruption in a given week is 1.7%. Since there are 11 refineries in the sample, the chance of a disruption is = 1- $(.983)^{11}$= .172 or a 17.2% chance of at least one disruption during a week.

Distribution of Disruption Sizes. Using the historical data presented in Section 2, the distribution of disruption sizes (mbd) is approximated by the Lognormal distribution.

Distribution of Disruption Duration. The distribution of duration of disruptions (in weeks) is approximated by the Lognormal distribution using historical data.

6.6.3 Base Case Assumptions

For the Base Case, the three key assumptions of disruptions are the historical values for 1996-2001. (See Table 6.6). The price elasticity assumptions of -.10 for demand and .05 for supply are taken from Section 6.3. In addition to these previous discussed inputs, there are four additional assumptions, the first two of which will be considered in the sensitivity analysis.

Retail price. We assume $1.50 per gallon.

Auction premium. When the SFR is operational during a refinery disruption, the auction differential will set the spot price of gasoline. Another way of looking at this is that the prevailing market cost of gasoline plus auction price paid to “borrow” the SFR barrels to be returned at a specified later date sets the marginal price of gasoline. Since the differential is not known with precision, we need to estimate this premium by examining market conditions for providing gasoline from non-California regions, PADD 3 and imports. It is the premium that establishes how much of the price spike the SFR can eliminate – the portion of the “notional” price spike above the auction premium. The base assumption is 10 cpg. A numerical example will help explain this. Consider the behavior of LA and USGC spot prices around a representative refinery disruption. (See Table 6.5 and Figure 6-14.)

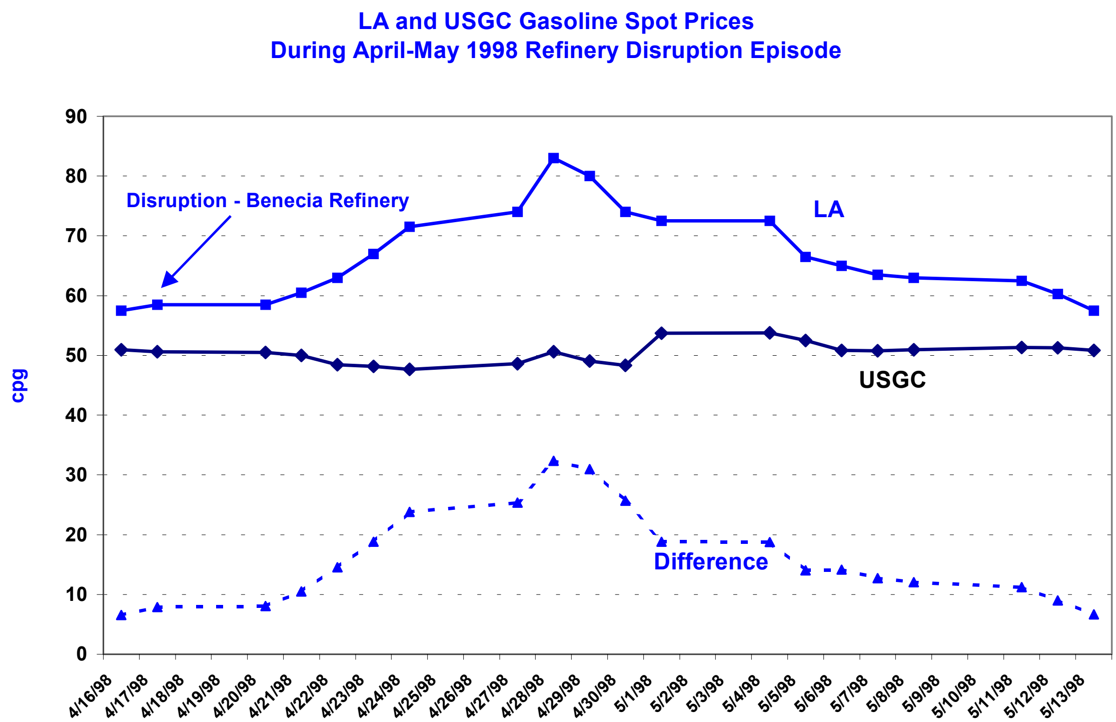
Table 6.5 – Gasoline Prices LA and USGC

	USGC Spot RFG Price	LA Spot RFG (CARB) Price	LA less USGC	Notional USGC CARB delivered to LA
4/16/98	50.93	57.50	6.57	65.93
4/17/98	50.60	58.50	7.90	65.60
4/20/98	50.48	58.50	8.02	65.48
4/21/98	50.00	60.50	10.50	65.00
4/22/98	48.45	63.00	14.55	63.45
4/23/98	48.18	67.00	18.82	63.18
4/24/98	47.68	71.50	23.82	62.68
4/27/98	48.63	74.00	25.37	63.63
4/28/98	50.63	83.00	32.37	65.63
4/29/98	49.03	80.00	30.97	64.03
4/30/98	48.33	74.00	25.67	63.33
5/1/98	53.70	72.50	18.80	68.70
5/4/98	53.75	72.50	18.75	68.75
5/5/98	52.48	66.50	14.02	67.48
5/6/98	50.83	65.00	14.17	65.83
5/7/98	50.78	63.50	12.72	65.78
5/8/98	50.95	63.00	12.05	65.95
5/11/98	51.30	62.50	11.20	66.30
5/12/98	51.25	60.25	9.00	66.25
5/13/98	50.85	57.50	6.65	65.85

On April 17, 1998, the Exxon Benicia refinery had a disruption. Spot prices in LA rose from 57.5 cpg to 83 cpg on 4/28/98 before falling back to 57.5 cpg on May 13, 1998, a month after the disruption. Spot prices in the USGC moved only a few pennies over this time. It appears that Exxon mitigated the disruption by bringing gasoline from the Gulf Coast that landed in late April and early May, about the time of the moderation in spot prices. At the time of the refinery disruption, the cost to transport product from the Gulf to the West coast was about 10 cpg and the cost to produce CARB was about 5 cpg over USGC gasoline. So, the notional cost of delivering CARB from the USGC was

15 cpg above the USGC RFG price. On or about April 22, 1998, LA and USGC CARB prices were in parity. Had the SFR been in place, a market participant could have bid 6 cpg for the immediate delivery of gasoline and back filled it with USGC gasoline without incurring a loss. The spot price spike would have been capped at about 64 cpg in this example. The economic benefit accruing to this scheme would have been the avoidance of running the spot price to 83 cpg, a difference of 19 cpg.

Figure 6-14 – USGC-LA Gasoline Price Differential during Disruption

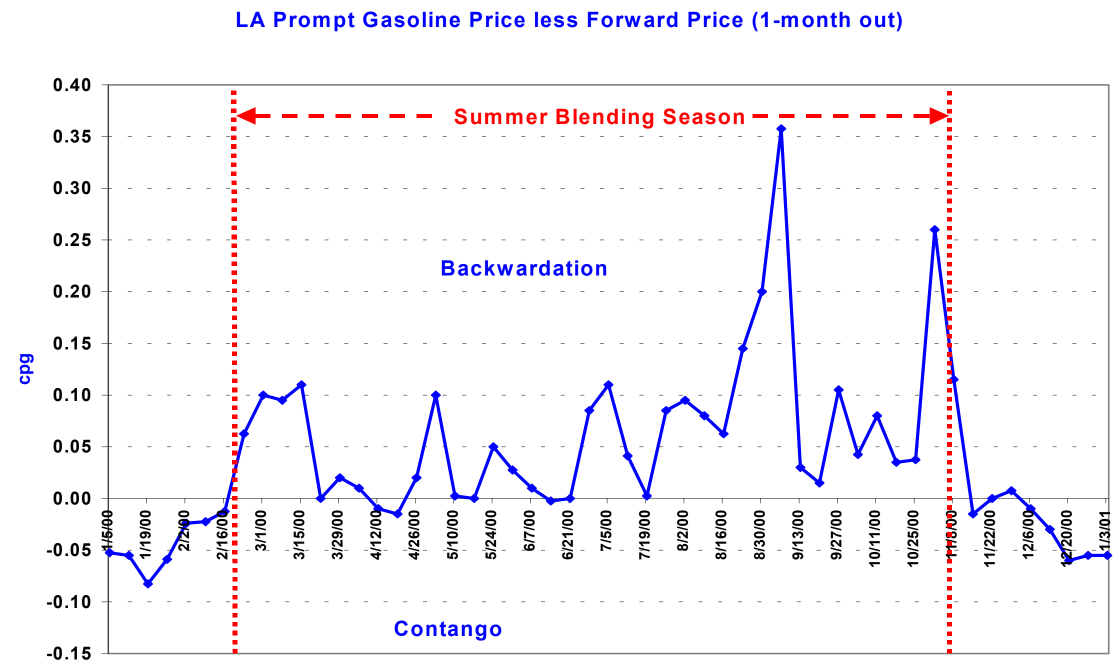


Instantaneous pass-through of the price effect. In Section 4 it was shown how spot price changes are not passed through to retail instantaneously or symmetrically. They pass through with a lag, rising faster than they fall. Since the model simulates a year's worth of disruptions, the lag is not critical to the calculations. The asymmetry, however, suggests that the economic benefits are slightly understated, perhaps as much as 10%.

Frequency of High Inventories. As shown in Section 4, price responses are muted whenever precautionary inventories are high relative to the size of the disruption. High inventories, occur usually, but not always in anticipation of a turn-around period or during the transition from winter to summer gasoline production which is roughly one-quarter of the time. The model explicitly accounts for this effect. According to the

Stillwater Associates plan, the SFR would only contain summer gasoline. Since the SFR will not likely be triggered during a period of high inventories, that is if there are available supply to ameliorate a disruption, an indication of the SFR non-use would be during contango[37] in the forward market. The gasoline market is most likely to be in contango during transition from winter to summer blending. A snapshot of 2000 in Figure 6-15 illustrates this effect. This effect is captured in the model.

Figure 6-15 – Seasonal Backwardation



6.6.4 *Sensitivity Analysis*

The analysis is performed for the following alternative scenarios:

1) *Alternative retail gasoline prices*. Base Assumptions, except that the average retail price is assumed to be $1.00 and $2.00.

2) *Alternative SFR auction differentials*. Base Assumptions, except that the SFR price differential is taken to be 5 cpg and 15 cpg. This explores the effect of not being able to truncate the price spikes at the 10 cpg level.

[37] Contango occurs when the forward price (one-month out) is higher than the prompt price.

3) *Exclusion of severe disruptions*. Base Assumptions, except the disruptions occur at the historical frequency, size, and duration excluding the year 1999. This explores the critique that analysts have raised that 1999 was a analogous to a "100 year flood" [38] and should be excluded from the analysis.

4) *Inclusion of "rumors*." Base Assumptions, except the disruptions identified as "rumors" are included at 1-week duration but no price impact. This explores the notion that the data sample excluded small, actual disruptions because they were not measurable.

A summary of the disruption input assumptions is given in Table 6.6.

Table 6.6 – Input Assumptions for Monte Carlo Analysis

Lognormal Distribution	Chance of Occurrence	Average Size MBD		Average Length Weeks	
Case	Probability	Mean	Std. Dev	Mean	Std. Dev
Base Assumptions Disruptions occur at historical frequency, size, duration	.017	21	15	2.7	3.9
Disruptions occur at historical frequency, size, duration excluding the year 1999	.014	19	14	1.8	1.9
Disruptions include rumored disruptions at 0 mbd impact and 1-week duration	.023	15	15	2.2	3.3

The SFR is not likely to be triggered for small disruptions (less than 10 mbd) of short duration (one week). The model handles this implicitly by not generating large enough price spikes to be ameliorated by the SFR. Thus, small disruptions such as those occurring in winter months are not counted in the economic benefits, since they do not produce a spike above the implied "refill" from the Gulf Coast.

[38] A "10 year flood" would be a more apt analogy. The base case includes 1999 data, in line with this being an "insurance policy."

6.7 Results

6.7.1 Economic Benefits of Reducing Price Spikes.

The Base Case and alternatives were analyzed using Crystal Ball, a Monte Carlo estimator add-in to Excel. Summary results are given in Table 6.7 and Table 6.8. Under repeated conditions that existed in the 1996 to 2001 time frame, the analysis suggests that additional consumer costs would be on the order of $400 million for base case conditions. The change in consumer surplus is close in size to the change in the consumer gasoline bill. The benefits can be reduced by over half this amount if the market does not experience refinery disruptions like those in 1999. In the Base Case, 4 of the 10 estimated refinery disruptions cause price spikes large enough to be truncated by use of the SFR. In all the sensitivities run, the consumer benefits, as measured by the reduction in the consumer gasoline bill or the net increase in consumer surplus with the SFR, would be an order of magnitude above the costs calculated by Stillwater Associates.

Table 6.7 – Net Economic Benefits – Lower Consumer Gasoline Bill

Lower Consumer Gasoline Bill with SFR versus Without SFR			
Assumed Combined Elasticity:	- 0.10	- 0.15 (Best Estimate)	- 0.20
Base Case Assumptions Historical disruption frequency, size, duration $1.50 retail price before disruptions 10 cpg incremental spot price to replenish SFR No price rise during period of high inventories	$687 MM/yr	$398 MM/yr	$261 MM/yr
Sensitivities - Base Case Assumptions Except:			
$1.00 retail price		$220 MM/yr	
$2.00 retail price		$607 MM/yr	
15 cpg incremental spot price		$339 MM/yr	
5 cpg incremental spot price		$498 MM/yr	
Disruptions excluding the year 1999		$169 MM/yr	
Rumored disruptions included		$255 MM/yr	

Even under the most conservative combination of alternative assumptions, for example, that disruptions have a lower chance of occurrence (excluding 1999) and that the SFR mechanism can only offset spikes in excess of 15 cpg, the economic benefits still exceed $ 140 million.

Note that the economic benefits are not symmetric with respect to elasticities, retail gasoline prices, and auction differentials. Using a different analytical approach, Stillwater Associates (2002) estimate that an SFR could have saved the consumer $.5 billion in a ninety-day period in 1999 and $4.7 billion over the 1999-2001 timeframe. These estimates are consistent with the ones provided here. The Stillwater study concludes that the SFR would cost $20 million annually. The benefits calculated in this report exceed the costs by an order of magnitude.

Table 6.8 – Net Economic Benefits – Consumer Surplus

Increase in Consumer Surplus with SFR versus Without SFR			
Assumed Elasticity:	- 0.10	- 0.15 (Best Estimate)	- 0.20
Base Case Assumptions Historical disruption frequency, size, duration $1.50 retail price before disruptions 10 cpg incremental spot price to replenish SFR No price rise during period of high inventories	$745 MM/yr	$401 MM/yr	$269 MM/yr
Sensitivities - Base Case Assumptions Except:			
$1.00 retail price		$200 MM/yr	
$2.00 retail price		$632 MM/yr	
15 cpg incremental spot price		$310 MM/yr	
5 cpg incremental spot price		$535 MM/yr	
Disruptions excluding the year 1999		$166 MM/yr	
Rumored disruptions included		$250 MM/yr	

6.7.2 Economic Benefits of Lowering the Average Gasoline Price.

One consequence of instituting the SFR is that gasoline prices will be on average lower than before the SFR. The estimated equation introduced suggests that prices will be lower by 3-5 cpg on average, translating into the consumer savings in Table 6.9.

Table 6.9 – Lower Average Gasoline Prices.

Days Applicable	3 cpg Lower Average	5 cpg Lower Average
175 Non-disruption days	$210 MM/yr	$350 MM/yr
125 Non-disruption days during the Summer Blending Season	$150 MM/yr	$250 MM/yr

7 OPTIMAL SIZE OF THE STRATEGIC FUEL RESERVE

A number of proposals have been made as to the "optimal" size of the SFR. A sample is given in Table 7.1. The legislative proposal for a reserve equal to two weeks' capacity of the largest refinery translates into 2.3 millions barrels.[39] An SFR sized to cover the average refinery disruption over the sample is 380 mb. To cover the maximum disruption in 1999 without imports contributing to the shortfall would require 6.3 million barrels.

Table 7.1 – Alternative Size Assumptions for the SFR

	MB
Legislative Prescription	2300
Cover average disruption: one refinery suffering a 20 mbd disruption for 2.7 weeks (19 days)	380
Cover Maximum Disruption in 1999	6300

We can use the same analytical approach as used in Section 6 to address the "optimal" size of the SFR (without reference to any offsets). Here, the desired size of a reserve would be one that would be sufficient to offset a disruption given that it occurs. Since the reserve would be replenished in a prescribed manner after the disruption, we need only have sufficient reserves to handle a typical disruption. Since the intent of the legislative inquiry is clearly to have a sufficient supply available, this can be interpreted to mean a sufficient supply to handle, say, the rare disruption. This can be translated statistically to mean the disruption that occurs in the, say, 90th percentile.

Using average parameters for 1996-2001, the Monte Carlo results indicate that the expected size of a disruption is 405 mb with the relevant distribution of results given in Table 7.2. Attachment E shows the full distribution of the size of a typical disruption.

[39] See Stillwater (2002).

Table 7.2 – Distribution of Disruptions under Average Parameter Assumptions

Percentile	Total Disrupted Barrels During a Typical Disruption
Mean (Expected Value)	405
80th	529
90th	865

Alternatively, the estimate of the required size was examined in another manner. A random six-week period, roughly the time of re-supply from imports or the Gulf, was simulated using the model. The resulting distribution of "disrupted barrels" approximates the distribution above.

Table 7.3 – Distribution of Disrupted Barrels during a 6-Week Period

Percentile	Total Disrupted Barrels During a Six-Week Period
Mean (Expected Value)	406
80th	700
90th	1,114

The implication of this analysis is that the size prescribed by the Legislature is significantly more than is necessary to offset a disruption of the type we have experienced in the 1996-2001 period. In order to have sufficient gasoline available to offset the 90th percentile of disruptions (a one-in-ten chance of occurring), the size of the SFR would need to be about 900 mb. Since Northern California and Southern California are not fully connected, one might need to have this available this amount allocated to two locations, one in the North and one in the South[40]. The split would need to be determined by a study of transportation logistics.

Since the SFR is sized for the large disruption episodes, the possible non-usage during the winter does not materially alter the conclusions about the optimal size.

[40] There may be the claim that we need this amount in both locations because of the lack of North-South connection. Since there is waterborne movement of gasoline from North to South, the shifting of barrels might be optimized, so that we do not need to "double" the size of the SFR. Even so, perhaps an amount of additional storage would be needed in addition to the amount calculated herein.

8 CONCLUSIONS

The conclusions from this study are that in California:

- Gasoline prices are higher and more volatile than in the rest of the country (including the Gulf Coast, an important petroleum refining center, and New York, site of the NYMEX).
- Gasoline price volatility has increased since the introduction of CARB II.
- Gasoline price volatility, while increasing generally over time, has been relatively unchanged since 1999.
- Gasoline price volatility is significantly higher than for jet fuel and diesel fuel, which are approximately equal in volatility.
- Refinery disruptions have occurred once a month on average since 1996.
- Production losses due to refinery disruptions average 21 MBD with several larger disruptions.
- Disruption effect is generally short-lived; average 2.7 weeks, but some last 6-8 weeks.
- In most cases, refinery disruptions have an immediate impact on spot prices.
- Planned turnarounds do not affect prices unless coinciding with a disruption.
- A refinery disruption in Northern or Southern California affects prices in the whole State.
- Price spikes are not transmitted to the Gulf Coast, but may be transmitted to neighboring states.
- Refinery disruptions occur in both summer and winter blending seasons in rough proportion to the time in those seasons, but have a more pronounced effect during the summer blending period.
- Refiners respond immediately to try to offset disruptions by drawing down inventories and increased sourcing of gasoline from other areas.The rise and fall of prices during a disruption is asymmetric.
- Retail price effects linger longer than other prices.
- Price spikes are more pronounced during periods of below normal inventories.

- Prices at the various market stages are highly correlated.
- The wholesale to retail pass-through, which is also asymmetric, is virtually complete within 4-8 weeks.
- For measuring short-term price impacts, a reasonable range of price elasticities (combining both demand and supply effects) is – 0.10 to – 0.20 with the best estimate at – 0.15.
- The potential economic benefit of the SFR reducing price spikes, if measured by the avoidance of increased consumer costs or increased consumer surplus, is about an average of $400 million per year under average disruption conditions. The benefits range from $200 to $700 million under various alternative assumptions considered. Benefits could be greater if future refinery disruptions are larger and the duration significantly longer than specified in this analysis.
- The additional potential economic benefit of the SFR in lowering the average price of gasoline (including spurious price spikes) is in the range of $150 – 350 million per year.
- The economic benefits are an order of magnitude larger than the costs determined in the Stillwater report.
- The “optimal” size of the SFR, given the average disruption conditions that existing in the 1996-2001 period, is significantly less that that prescribed by the Legislature.

9 RECOMMENDATIONS

1. Analyze alternatives to the SFR envisioned by Stillwater on a common Cost-Benefit framework similar to that outlined in Section 5. All economic comparisons should be done with the same rigorous analysis.

2. Since the economic benefits of the SFR proposal envisioned by Stillwater Associates appears to offer benefits of an order of magnitude above the estimated costs, the California Energy Commission should proceed to go beyond the scooping study and:

Design the detailed operational features of the SFR,

Examine the auction design to ensure that the mechanism is non-collusive and does not deter entry,

Simulate the SFR under "real" world conditions,

Perform an intense analysis of private versus public storage to ascertain the possibility of "crowding out,"

and

Examine the issues related to development of a forward market for gasoline in more detail.

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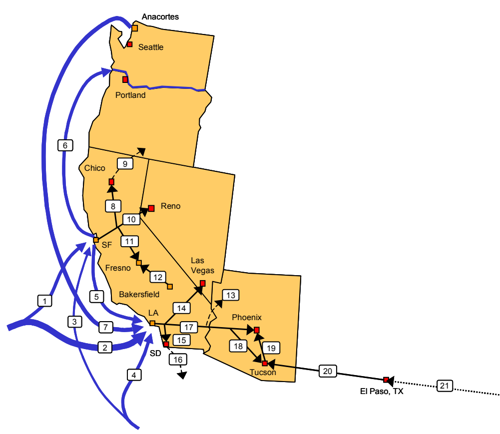
"California is an Island",

Peter Heylen, Cartographer, 1703



"California is an Island",

Gregg Haggquist, Stillwater Associates, 2002

Attachment A – DOE Data on California Refinery Disruptions

				Gasoline Impact	
	Week Ending Friday	Facility	Brief Description	Amount of Decrease	Maximum Duration
				mbd	weeks
1	3/22/1996	Mobil-Torrance	alky unit & coker	35	1
2	4/5/1996	Arco-Carson	HC & H2 plant at reduced rates	17	1
3	4/5/1996	Chev-Richmond	H2 plant reduced rates	3	1
4	4/12/1996	Shell Martinez	explosion	67	9
5	11/29/1996	Mobil Torrance		27	1
6	12/20/1996	Unocal Wilmington	FCC	1	2
7	12/20/1996	Chevron- Richmond	problems w/ FCC	38	1
8	12/20/1996	Ultramar Wilmington	unplanned prod losses	19	1
9	1/24/1997	Tosco Avon	HC fire	23	6
10	1/24/1997	Texaco-Wilmington	fire alky unit	25	1
11	8/8/1997	Chevron-Richmond	reformer down	21	1
12	8/15/1997	Exxon Benecia	HC & HT problems	20	1
13	4/17/1998	Exxon Benecia	reformer	25	2
14	5/1/1998	Ultramar Wilmington	shut down during outage	36	1
15	5/8/1998	Texaco-Wilmington	shut down during outage	21	1
16	5/8/1998	Tosco Wilmington	shut down during outage	6	1
17	1/22/1999	Exxon Benecia	FCC down for another month	55	12
18	3/5/1999	Tosco Avon	fire in crude unit	40	22
19	3/26/1999	Arco Carson	FCC	55	6
20	4/2/1999	Chevron Richmond	explosion	5	1
21	5/28/1999	Chevron Richmond	HC down	20	8
22	6/25/1999	Equilon Martinez	elec problems w/ FCC	20	2
23	7/23/1999	Chevron Richmond	FCC & alky unit unplanned maint	31	3
24	7/30/1999	Mobil Torrance	fire in H2 plant	20	1
25	8/6/1999	Arco Carson	unspecified	18	1
26	11/2/1999	Tosco Wilmington		8	1
27	2/18/2000	Mobil Torrance	alky problem	10	7
28	4/21/2000	Arco Carson	reformer	50	3
29	5/12/2000	Chevron El Segundo		10	1
30	6/30/2000	Chevron El Segundo	H2 plant problems	17	2
31	7/7/2000	Chevron Richmond	HC problem	10	1
32	7/7/2000	Equiva LA	coker down	12	1
33	7/7/2000	Tosco SF	coker at reduced rates	10	1
34	8/4/2000	Arco Carson	coker down	5	1
35	9/1/2000	Arco Carson	HC & coker down	13	1
36	9/1/2000	Equiva LA	reformer down	13	1
37	9/1/2000	Tosco SF	HC down for unplanned maint	15	1
38	10/6/2000	Mobil Torrance	planned maintenance	45	6
39	10/27/2000	Arco Carson	blending problem	5	1
40	11/3/2000	Arco Carson	HT down	27	1
41	11/17/2000	Mobil Torrance	problems restarting	25	1
42	11/24/2000	Chevron Richmond	crude unit maint	19	1
43	1/19/2001	Arco Carson	VGO HT in planned turnaround	24	1
44	1/26/2001	Valero Benecia	power outages	3	1
45	2/2/2001	Texaco	cut runs due to power costs	5	1
46	2/9/2001	Tosco LA	FCC problem	4	1
47	2/9/2001	Valero Benecia	HC due to restart	14	1
48	2/16/2001	Equilon LA	trouble coming back from turnaround	6	1
49	3/2/2001	Valero Benicia		14	3

DOE defined Refinery Disruptions excluded from sample.

				Gasoline Impact			Reason For Exclusion		
	Monday After Incident	Facility	Brief Description	Amount of Decrease	Maximum Duration	No Impact Given	No Duration Given	Event Had No Impact	Unproved Rumor
				mbd	weeks				
1	4/1/1996	Texaco-Wilmington	HC down			X	X		
2	4/1/1996	Unocal- Wilmington	HC & reformer down			X	X		
3	4/22/1996	Tosco Avon	FCC			X	X		
4	5/17/1996	Unocal Rodeo	fire			X	X		
5	11/18/1996	Texaco-Wilmington	fire levelled a cat feed HT		4	X			
6	3/17/1997	Chevron-Richmond	problems with isomax unit	0			X		
7	4/27/1998	Arco Carson	FCC unplanned maint	170	2				X
8	7/19/1999	Exxon-Benecia	HC running at reduced rate	20			X		
9	7/27/1999	Arco Carson			1	X			
10	2/18/2000	Exxon Benecia	FCC down	0	2			X	
11	6/26/2000	Equilon Wilmington	coker	0				X	
12	7/24/2000	Equiva SF	coker down			X	X		
13	8/7/2000	Equiva SF	HT problem			X	X		
14	10/11/2000	Equilon Martinez	HC	0				X	
15	10/11/2000	Chevron Richmond	crude & HC & cat	0	6			X	
16	11/13/2000	Valero Benecia	H2 plant problems	0				X	
17	4/2/2001	Chevron El Segundo	crude unit sched maint	27			X		

Attachment B – Alternative Volatility Analysis

As an alternative measure of volatility, some analysts use the moving average of the standard deviation of price movements, a useful measure of volatility[41]. It is also expressed in the same units of measure, e.g. cpg, as the underlying data. Figure B.1 displays the 90-day moving average of the standard deviation of prices and a trend line fitted to the data. The standard deviation (volatility) shows an upward trend since 1995. This increase in volatility is also evident in Gulf Coast prices, although not as pronounced. (Figure B.2.)

Figure B.1. LA Spot RFG Gasoline Price

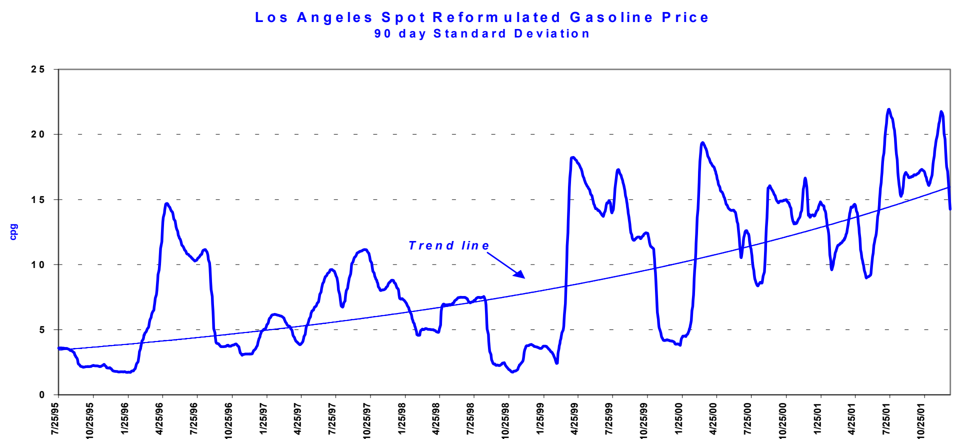
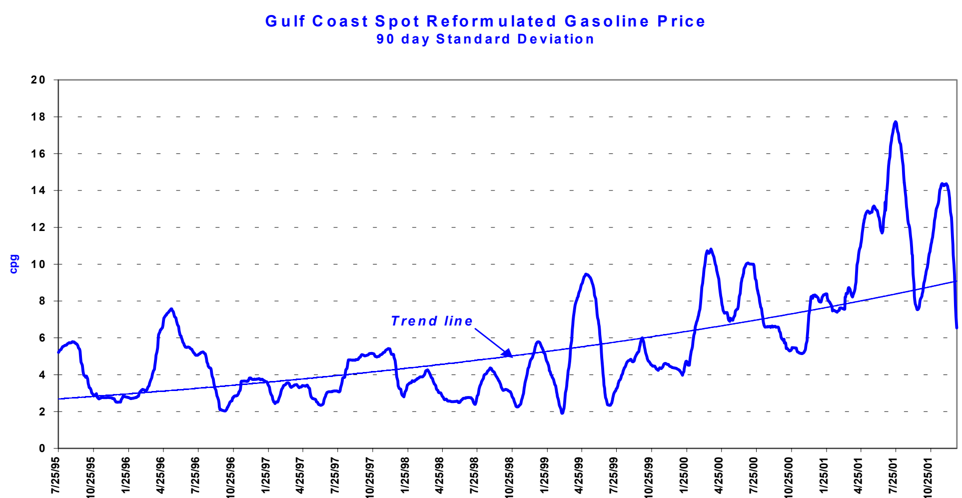


Figure B.2 Gulf Coast Spot RFG Gasoline Price



[41] Many analysts use the standard deviation of adjusted daily log changes in prices as the measure of volatility. See the main text for details.

We can test the statistical significance of the change in volatility as measured by the variance (the square of the standard deviation) in prices over time. The test of significance for the difference between variances of two samples is the F-test, as discussed in the main text. Notice in Table B.1 that the variance increases each year except for the move from 1996 to 1997. As Table B.1 Illustrates, one can reject the hypothesis that the variance in adjoining years is the same in all but the change from 1996 to 1997.

Table B.1. F-values To Test Difference Between Variance In Gasoline Prices Over Time.

Year	Variance	$F=\sigma_1^2/\sigma_2^2$ (Year vs. Prior Year)	Difference in Variance Significant?
1995	9.76		
1996	89.18	9.76	Yes
1997	81.33	1.10	No
1998	44.48	1.83	Yes
1999	248.69	5.59	Yes
2000	336.45	1.35	Yes
2001	547.50	1.63	Yes

Note: F is always calculated with the larger number of the pair in the numerator.

We conclude that gasoline price volatility:

- Has generally increased over time
- Has not changed since 1999

Attachment C – Empirical Results from Selected Elasticity Studies

Table C.1. Short-term Gasoline Price Elasticity Estimates From Dahl (1995)

Study (Year) **	Short-term Elasticity	Short-term Elasticity Chosen*
Hsing (1990)	-.20	-.20
Koshal (1991)	-.17	-.17
Sterner (1990)	-.13/-.29	-.19
	-.19	
Franzen (1991)	-2.13	-2.13
Gately (1992b)	-.10	-.095
	-.13	
	-.06	
	-.09	
Gately (1991)	-.00	-.00
	+.03	
	-.07	
Rao (1993)	-.14	-.14
Uri (1989)	-.31/-.36	-.335
Gately (1988)	-.10/-.15	-.125
Hogan (1989)	-.14	-.14
Gately (1992a)	-.01	-.01
	-.00	
	.00	
	-.02	
	-.00	
	-.01	
Mean	-.191	-.32
Standard Deviation	.42	.61
Median	-.10	-.155
Mean, excluding High and Low	-.116	-.156

* If the study had more than one estimate, this author took the median of the estimates. (For even number of entries, by convention, the median was chosen as the mean of the two middle entries.)

** These are citations in Dahl (1995) and do not correspond to this report's bibliography.

Table C.2. Short-term Gasoline Price Elasticity Estimates From Dahl & Sterner (1991)

Equation Category Cited	Short-term Elasticity	Number of Estimates
C3	-.24	38
C4	-.13	17
C5	-.14	10
C6	-.20	4
C7	-.19	5
C14	-.12	8
C15	-.17	4
C16	-.08	4
C17	-.22	13
C18	-.41	9
Mean	-.19*	
Mean (weighted by estimates)	-.20*	
Median of Estimates	-.18	
Mean with High/Low Categories Deleted	-.18	

Attachment D – Estimate of Retail to Wholesale Price Effects

Figure D.1. Regression Results for Borenstein Model.

Dependent Variable: CR
Method: Least Squares
Date: 03/08/02 Time: 07:55
Sample(adjusted): 4/02/1997 1/23/2002
Included observations: 252 after adjusting endpoints

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.929517	0.352372	2.637885	0.0089
CS1P	0.289667	0.043108	6.719546	0.0000
CS1M	0.137204	0.049766	2.757003	0.0063
CS2P	-0.025771	0.044611	-0.577679	0.5641
CS2MM	0.126943	0.049360	2.571793	0.0108
CS3P	0.089213	0.048706	1.831670	0.0683
CS3M	0.127520	0.049008	2.602009	0.0099
CS4P	0.065058	0.049665	1.309927	0.1916
CS4M	0.107355	0.048497	2.213633	0.0279
CS5P	0.016918	0.050114	0.337583	0.7360
CS5M	0.163118	0.048052	3.394636	0.0008
CS6P	0.043919	0.050567	0.868539	0.3860
CS6M	0.078970	0.047105	1.676447	0.0950
CS7P	0.065538	0.050872	1.288291	0.1990
CS7M	0.042266	0.046723	0.904616	0.3666
CS8P	0.084853	0.050981	1.664403	0.0974
CS8M	0.027038	0.046436	0.582275	0.5610
CS9P	-0.017664	0.051449	-0.343321	0.7317
CS9M	0.027211	0.046346	0.587120	0.5577
CS10P	-0.012268	0.051163	-0.239783	0.8107
CS10M	0.067694	0.045566	1.485635	0.1388
CS11P	-0.053295	0.051452	-1.035821	0.3014
CS11M	0.059142	0.040684	1.453702	0.1474
CS12P	0.029284	0.050693	0.577665	0.5641
CS12M	-0.012748	0.040460	-0.315070	0.7530
RESIDESTLAG	-0.029007	0.018655	-1.554895	0.1214

R-squared	0.536736	Mean dependent var	-0.050397
Adjusted R-squared	0.485490	S.D. dependent var	3.297850
S.E. of regression	2.365528	Akaike info criterion	4.657334
Sum squared resid	1264.633	Schwarz criterion	5.021482
Log likelihood	-560.8241	F-statistic	10.47369
Durbin-Watson stat	1.457423	Prob(F-statistic)	0.000000

Where:

CSxy = Change in Spot Price with lag x

Y=P if positive, M if negative

Table D.1 Weights For Borenstein Asymmetry Model.

Weekly lag	Positive Price Changes	Negative Price Changes
0	.37	.03
1	.55	.13
2	.61	.22
3	.67	.35
4	.70	.50
5	.74	.64
6	.79	.77
7	.85	.88
8	.88	.94
9	.90	1.00
10	.94	1.05

Attachment E – Monte Carlo Results

Figure E.1. Change in Consumer Bill – Base Case Assumptions.

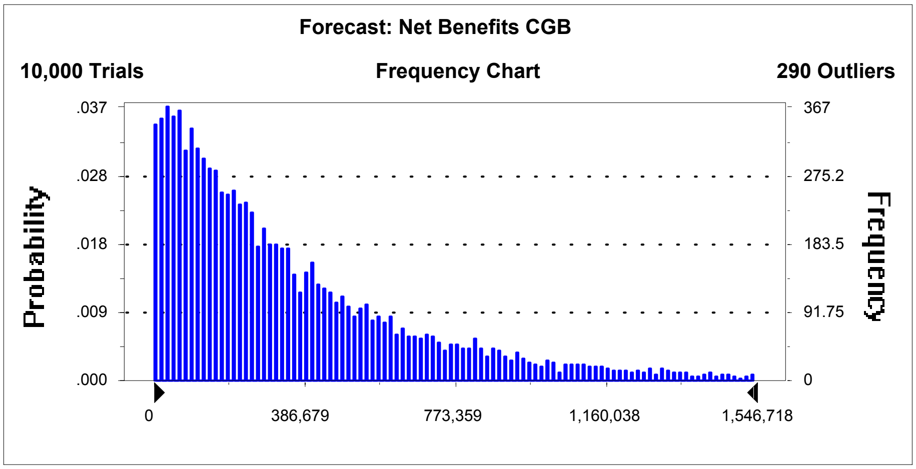


Figure E.2. Change in Consumer Surplus – Base Case Assumptions

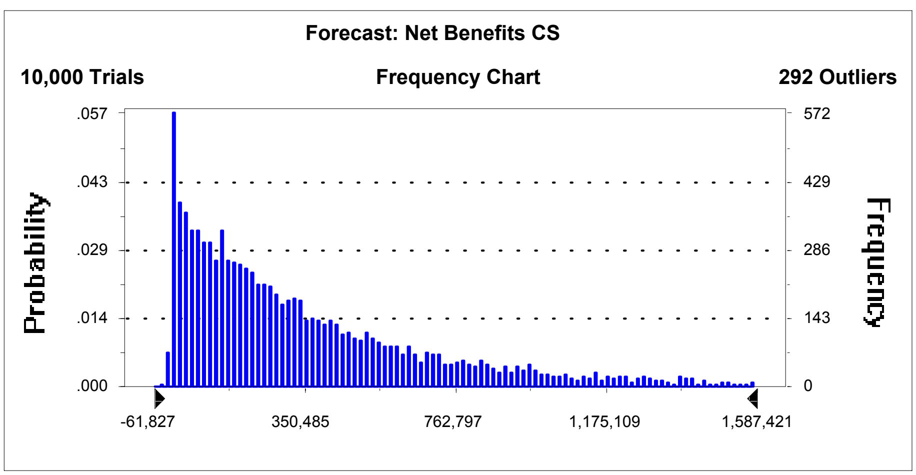


Figure E.3. Distribution of Total Disrupted Barrels Per Year – Base Case Assumptions.

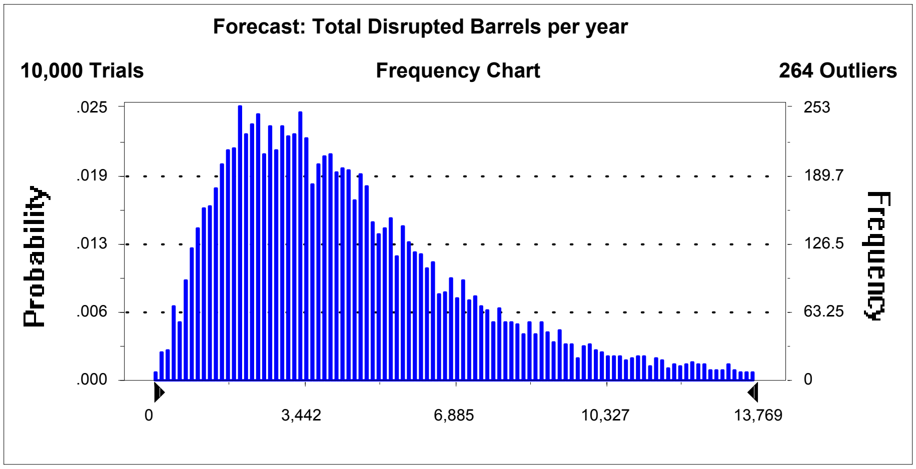
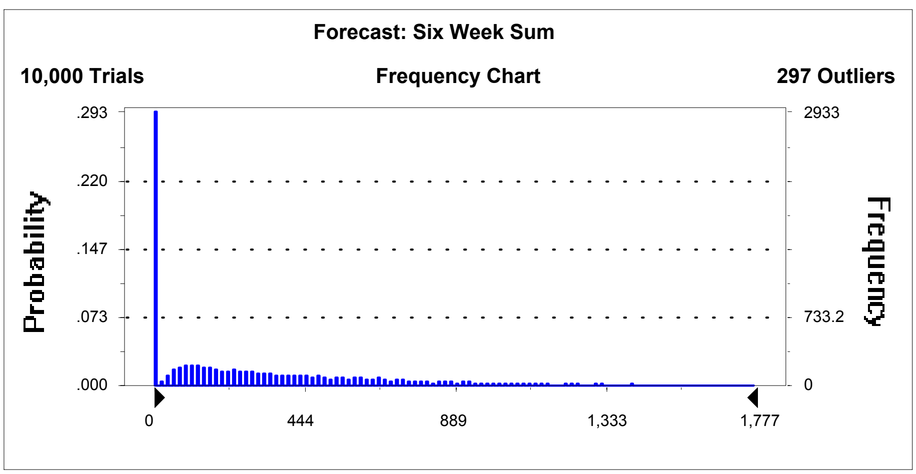


Figure E.5. Total Disrupted Barrels during a 6 Week Period – Base Case Assumptions



Attachment F – Economic Results of Supply Equation

Dependent Variable: SPOT_PRICE01
Method: Two-Stage Least Squares
Date: 05/30/02 Time: 10:09
Sample(adjusted): 1996:03 2001:12
Included observations: 70 after adjusting endpoints
Convergence achieved after 11 iterations
Instrument list: C JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV TIME C_SA_PD01 SIG TB3M TB3M(-1) TB3M(-2)
Lagged dependent variable & regressors added to instrument list

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	92.63351	39.78789	2.328184	0.0238
JAN	-3.231172	4.143809	-0.779759	0.4390
FEB	9.235601	5.583530	1.654079	0.1040
MAR	8.432972	6.092859	1.384075	0.1721
APR	10.88239	6.429755	1.692504	0.0964
MAY	6.478727	6.538065	0.990924	0.3262
JUN	8.179420	6.517032	1.255084	0.2150
JUL	2.230689	6.516596	0.342309	0.7335
AUG	4.115427	6.411578	0.641874	0.5237
SEP	-2.572314	6.343493	-0.405504	0.6867
OCT	-7.418770	5.784844	-1.282449	0.2053
NOV	-8.431357	4.397338	-1.917377	0.0606
ANS_PRICE01	2.054524	0.369190	5.564951	0.0000
CA_INV01(-1)	-0.008364	0.002782	-3.006465	0.0040
SIG	13.46495	7.438943	1.810062	0.0760
TB3M	-6.186311	3.807908	-1.624596	0.1102
AR(1)	0.778636	0.103374	7.532248	0.0000

R-squared	0.884893	Mean dependent var	77.72928
Adjusted R-squared	0.850143	S.D. dependent var	22.54294
S.E. of regression	8.726670	Sum squared resid	4036.203
F-statistic	28.13518	Durbin-Watson stat	2.172229
Prob(F-statistic)	0.000000		

Inverted AR Roots .78

Where:

Jan – Nov are monthly dummy variables (seasonal effects)

ANS_PRICE01 is the price of Alaskan oil (main raw material for gasoline in California)

CA_INV01(-1) is the level of inventories

SIG is a measure of volatility

TB3M is the Three-month T-bill (measures opportunity cost of holding gasoline inventories)

AR (1) First-order autoregressive correction term