Boutique Fuels and Market Power

by

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Abstract

The US Clean Air Act allows individual states to implement their own clean fuel programs to address local or regional air quality concerns. These regulations have led to a proliferation of fuel blends known as "boutique fuels." For each of the three grades of gasoline, more than 15 types of boutique fuels are currently in use, leading to about 45 different fuel blends in use nationally. These fuels are costly to produce, but they also segment the market and increase the market power of refiners. Using measures that differentiate gasoline regulation in a given state from those in neighboring states, we find that both cost and market segmentation significantly affect wholesale gasoline prices. In particular, the greater the regulatory "distance" between a state and its neighboring states, the higher the wholesale price in that state. Simulations suggest that for some states regulating a single boutique fuel nationally may lead to a counter-intuitive outcome: gasoline prices may decline, even though a larger share of their market will be under regulation.

Key Words: Clean Air Act, Environmental Regulation, Gasoline Prices, Market Structure, Product Differentiation

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1. Introduction

In order to improve public health in areas with air quality problems, the U.S. Clean Air Act of 1990 led to a variety of federal environmental regulations that aim to reduce emissions from motor vehicles. The Act also allows individual states to implement their own clean fuel programs for gasoline to address local or regional air quality concerns. These federal and state regulations have not only led to a significant improvement in air quality but also to a proliferation of fuel blends.[2] At least 15 different types of fuel specifications are currently in use. Combined with the three (octane) grades of gasoline available at pumps - regular, mid-grade and premium,[3] this implies that over 45 different blends are in use nationwide (Ryan, 2003).[4] These fuels are often called "boutique fuels."[5]

"The mix of state and federal standards in effect today has resulted in a situation where adjacent areas may be using gasoline with significantly different properties" (US Senate, 2002, p.74). Figure 1 shows the variety of gasoline blends that are in use by state. Because requirements vary from state to state and often within a state, refiners find it difficult to move product quickly from one area to another. Critics have suggested that the variety of fuels in use have caused price volatility especially during periods of supply disruption, such as winter-summer transitions, periods of high demand, refinery fires and pipeline breakdowns, since refiners mostly specialize in producing certain fuel specifications and cannot switch immediately. They have also resulted

[2] Differential gasoline standards include the Reformulated Gasoline (RFG) program, the Oxygenated Gasoline (OXY) program, and state programs that impose lower volatility requirements, caps on sulfur content, limits on the use of fuel additives such as MTBE (methyl tertiary butyl ether) and ethanol, and requirements for minimum oxygen content.

[3] Price levels vary by grade, but the price differential between grades is generally constant (EIA, 2003).

[4] To make matters worse, a new ozone rule proposed by the Environmental Protection Agency (EPA) is expected to add another 24 new blends into the mix by the year 2007.

[5] There has been some confusion whether boutique fuels are those arising from local and state fuel control programs. We use the broadly accepted definition that the EPA uses, to mean local, state and federal fuel programs (EPA, 2001). The term state and local "'boutique fuel'" was originally used in the President's Energy Report to describe state and local fuel control programs that are different from federal fuel control programs. However, certain federal requirements are targeted to specific regions. For instance, Reformulated Gasoline (RFG) is blended with ethanol for use in Chicago and Milwaukee. This special blend can not be mixed with other RFG formulations and must be segregated throughout the distribution and storage system (EPA, 2001).

in supply bottlenecks and pipeline congestion since various types of fuels must often use the same pipeline system.[6]

[Figure 1 here]

A recent EPA report suggested that state boutique fuel programs have "fewer fuel producers, are less fungible and have fewer distribution system supply options" (EPA, 2001). The magnitude of the problem varies with volumes, distance from supply sources, and the number of supply sources, which in turn depend on the degree of product differentiation. For example, in the summer, fuel produced for the Charlotte, North Carolina area cannot be used in Norfolk, Virginia (which must use Reformulated Gasoline) or Atlanta, Georgia (lower Reid Vapor Pressure and Sulfur cap). However, Atlanta and Norfolk fuels can be moved to Charlotte (Yacobucci, 2004).

Legislation to prevent further proliferation of boutique fuel "islands" has been recently introduced in the United States Congress through the Boutique Fuels Reduction Act of 2004 (Petri, 2004). The bill also calls for a study on creating a new fuels system that, among other things, maintains high air quality standards, improves fungibility and lowers overall prices. However actual trends suggest that the number of fuels may actually increase in the future because of a ban on MTBE use by some states, new EPA regulations on an eight-hour (replacing a one-hour) standard for measuring ozone, introduction of a renewable fuel standard and use of low sulfur fuels (EIA, 2002).

In this paper we examine the effect of differential environmental regulation on the wholesale price of gasoline. Boutique fuels are not only more costly to produce, they effectively segment the market and increase the cost of arbitrage between adjacent areas. Compared to an unregulated market, the number of firms supplying a particular boutique fuel may decline, leading to a potential increase in the market power of refineries that supply the regulated market. The empirical analysis uses data on the average wholesale price of gasoline in each state during the time period 1995 to 2002. We consider two major types of gasoline regulation, namely the

[6] Several pipelines put refiners into an allocation system during peak periods that delays fuel transportation and increases costs (EPA, 2001). Often the same pipeline needs to be washed before carrying a different fuel blend.

reformulated gasoline (RFG) and oxygenated gasoline (OXY) programs. These programs aim to reduce local ozone and carbon monoxide pollution, respectively. We assume that wholesale prices in each state are determined by the price of crude oil, refinery capacity per capita in the state, and the market concentration in the refinery sector in the state. These variables enable us to measure market power within the state.[7] Environmental regulation in a state increases the cost of refining, which is measured by the size of the market under regulation in each state. The proliferation of fuel blends across states leads to market segmentation, which increases the market power of refiners in a state. We use the regulatory distance between a state and its neighboring states as a proxy for measuring market power that arises from product differentiation.

The empirical results suggest that average wholesale prices are not only determined by the area of the state under regulation but by the absolute and differential size of the market between each state and its neighbors. In particular, the greater the difference in the size of the regulated market between a state and its neighboring states, the higher the wholesale price in a given state. We also test whether transportation and other arbitrage costs associated with gasoline imports from other regions may explain these wholesale price differences.

Through policy simulations we can estimate the effect of regulating a common national boutique fuel standard on wholesale prices. We find that in several states, such harmonization may lead to a reduction in wholesale gasoline prices. This net decline comes from a positive effect on prices because of increased regulation, and a negative effect due to the same fuel being used in all states, which causes a decline in market power of firms. We decompose these effects for each state.

Little research has been done on the issue of boutique fuels.[8] Chouinard and Perloff (2002) use a reduced form model of gasoline price differences across states and over time, using monthly

[7] Measuring market power through concentration is common in empirical studies. Kim and Singhal (1993) use the Herfindahl index to measure the degree of concentration within the airline industry. Evans and Kessides (1993), Berger and Hannan (1989), and Cotterill (1986) also use similar approaches.

[8] The dynamics of gasoline prices as well as the transmission of price changes from crude to wholesale and from wholesale to retail markets has been studied by Borenstein and Shephard (1996a) and Borenstein, Cameron and

panel data (1989-97) for the 48 contiguous states. They estimate a two-equation model to explain the variation in retail and wholesale gasoline prices. They control for the implementation of RFG and OXY gasoline in each state by using dummy variables that equal 1 when the program is run in a state, and 0 otherwise. These variables allow the measurement of the direct cost effect of these clean fuel programs but the authors do not control for the effect of pollution regulation on the market power of refiners.[9] Coloma (1999), using data for the period 1983-89 from the state of California, shows that there is considerable degree of product differentiation among major brands, allowing these brands to exercise market power. However, the analysis did not focus on environmental regulation.

Section 2 provides background information on the U.S. gasoline market and the environmental regulation of gasoline following the U.S. Clean Air Act. Section 3 describes the empirical model, the data used and provides estimation results and simulations. Section 4 concludes the paper.

2. Characteristics of the U.S. Gasoline Market

The U.S. gasoline market is the largest in the world, using about a quarter of the world's crude oil and producing about 40% of the world's gasoline. Retail gasoline prices have been especially volatile in recent years, as shown in Figure 2 which graphs the monthly wholesale price of gasoline and the price of crude oil between 1995 and 2002. This may be due to the volatility in the price of crude oil, which in turn is significantly affected by the output decisions of OPEC (the Organization of Petroleum Exporting Countries). OPEC accounts for nearly 40% of the world's crude oil supply.

[Figure 2 here]

Gilbert (1997). Borenstein and Shepard (1996b) examine market power in wholesale gasoline markets through the concentration of refiners supplying products at gasoline terminals.

[9] Chouinard and Perloff control for market power by introducing dummies for mergers and by computing the number of retail stations per square mile – their analysis focuses on the retail market. They do not explicitly model the effect of boutique fuels on market power but they recognize the importance of this issue: "the requirement that stations sell only specially formulated pollution-reducing gasoline increases refining costs and may create market power for wholesalers within a state. To produce reformulated gasoline, refiners must make several costly modifications to their production equipment. If producers in surrounding states avoid incurring these large capital costs, producers in states mandating the use of reformulated or oxygenated gas do not face competition from these out-of-state suppliers" (Chouinard and Perloff, 2002).

Imported and domestically produced crude oil is distilled by refiners and converted into gasoline, kerosene (jet fuel), heating oil and several other petroleum products. Approximately 50% of all crude oil in the U.S. is imported but 96% of the gasoline consumed is refined domestically (Energy Information Administration (EIA), 2000). Crude oil is transported in tankers from Europe, Asia and the Middle East (and through pipelines from Mexico and Canada) into major ports located in the New York Harbor, the Gulf Coast and on the West Coast. It is then moved by barge or pipelines to refineries. Refined petroleum products are mostly carried by pipelines into wholesale terminals, and from there through trucks to retail outlets.

The U.S. refining industry has gone through a substantial restructuring in recent years. In 1981, a total of 189 firms owned 324 refineries; by 2001 the number of firms in the industry had reduced to 65 which together owned a total of 155 refineries, a decrease of about 65 percent in the number of firms and 52 percent in the number of refineries. During this period the market share of the ten largest refiners increased from 55 percent to 62 percent. This consolidation happened while gasoline demand continued to increase and the consumption of gasoline went up by around 30 percent (U.S. Senate, 2002). Several important mergers occurred in the 1998-2001 time frame beginning with Marathon with Ashland Oil, followed by British Petroleum and Amoco, then Arco, and Exxon-Mobil and Chevron-Texaco.[10]

There are several reasons why the number of refineries has declined. Price controls on imported oil during the era of high world oil prices enabled many small refiners to operate profitably on domestically produced crude oil. The end of the Crude Oil Entitlements Program led to the shut down of some of these inefficient units. Conservation programs of the 1970s took effect in the 1980s, reducing demand and hence refining margins. In 1981, only about two-thirds of the refinery capacity was being utilized. In addition, the Clean Air Act of 1990 mandated higher gasoline standards, such as oxygenated and reformulated gasoline, forcing many refiners to upgrade their refineries and add to capacity. Many refiners that did not make the necessary investments exited the industry. Recent capacity utilization rates are routinely more than 90 percent. Increased concentration and capacity utilization has also meant reduced inventories.

[10] Other mergers include Philips with Tosco and Conoco and Valero with Ultramar Diamond Shamrock.

Average gasoline storage in 1981 was equal to 40 days consumption. In 2001, it declined to 25 days consumption.

This restructuring has resulted in a tight gasoline market characterized by frequent price spikes, even when the acquisition costs of crude oil did not increase significantly. For example, from March through May 2001, both gasoline prices and refining margins jumped by about 20 cents, yet refinery acquisition costs of crude oil changed little over this period (Greenspan, 2001). The price of crude oil accounts on average, for about two-thirds of the wholesale price of a gallon of regular grade gasoline.[11]

As a consequence, crude oil supply disruptions stemming from world events or domestic problems, such as refinery or pipeline outages, have had a significant impact on wholesale (and retail) gasoline prices. Even when crude oil prices are stable, gasoline prices normally fluctuate due to factors such as seasonality: prices tend to rise gradually before and during the summer driving season, and decline in the fall and winter, when people drive less. Gasoline prices also vary across regions. In general, areas farthest from the Gulf Coast, which is the source of nearly half of the gasoline produced in the U.S. and is a major supplier to the rest of the country, tend to have higher prices.

Table 1(a) shows state level data on population, wholesale price of gasoline (in real 1995 dollars), total number of refineries, total refinery capacity, the refinery capacity per capita, and the 4-firm concentration index for the refinery industry. All these figures are averaged over the 1995-2002 period.[12] Historically, crude oil allocation has been divided into five Petroleum Administration for Defense Districts (PADD).[13] The PADD identification of each state is reported in the table, and corresponding statistics for each PADD are presented in Table 1(b). Figure 3 provides a map of the PADD regions.

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[11] During the 1995-2002 period, the average wholesale price of gasoline per gallon in nominal terms was 73.9 cents, the retail price was 86.4 cents, and federal and state taxes were 41.3 cents. Thus the nominal retail price inclusive of taxes was $1.28.

[12] See Appendix for the definition and data sources for these variables.

[13] These districts were originally classified during World War II for purposes of administering an oil allocation program.

[Tables 1(a) and 1(b) here]

[Figure 3 here]

The states in Table 1(a) have been sorted by increasing average wholesale prices. Those states that have large refining capacities have, in general low gasoline prices. The lowest prices are observed in Texas (PADD 3) with 23 refineries out of a national total of 140, Mississippi (PADD 3) with 3 refineries, Louisiana (PADD 3) with 17 refineries, and Oklahoma (PADD 2) with 6 refineries. The East Coast states (PADD 1) are also an illustration of that rule: Connecticut, Massachusetts, and Maryland with no refinery capacity, have prices that are about 5 cents per gallon higher than the states of Pennsylvania, New Jersey, and Virginia where some crude oil is refined. California (PADD 5) is an exception to this rule since gasoline prices there are among the highest in the country despite the presence of 17 refineries in the state. This price premium is due to the state requiring the use of a unique, cleaner (and thus costlier) gasoline. The 4-firm concentration index, which is computed as the sum of the largest four market shares for those states that have a positive number of refineries, is lower than 0.60 in only two states: Texas (0.40) and Louisiana (0.54).[14] All states belonging to PADD 4 and 5 (the Rockies and West Coast, respectively) have higher gasoline prices and therefore are located in the bottom half of the table. The states of Alaska and Hawaii, which have to incur high costs of transportation when gasoline is imported, have the highest wholesale prices. As seen in Table 1(b), the Gulf Coast (PADD 3) has the highest number of refineries and the lowest wholesale prices. The Midwest (PADD 2) also has a significant number of refineries and relatively low gasoline prices. Because of California, Alaska and Hawaii, PADD 5 is an exception – large number of refineries and high wholesale prices.

Environmental Regulation in the US Gasoline Market

The Clean Air Act Amendments of 1990 established a clean fuels program to reduce harmful emissions from motor vehicles. Under this Act, the Environmental Protection Agency (EPA) is responsible for establishing minimum national standards for air quality. Areas that do not meet EPA's national ambient air quality standards[15] are required to implement clean gasoline

[14] Shepherd (1999) defines a market as a "tight oligopoly"' when this index is above 0.60.

[15] for ozone, carbon monoxide, particulate matter, sulfur dioxide, nitrogen dioxide and lead.

programs. The most important among them are the “Reformulated” and “Oxygenated” fuel programs.

The Reformulated Gasoline Program (RFG) was implemented beginning January 1995 in areas with major ozone problems. RFG is a gasoline blend that contains lower levels of benzene, sulfur and aromatic compounds. Areas with less severe pollution were given the option of using RFG, although it was not required (US Senate, 2002). RFG is now used in 17 states and the District of Columbia. It accounts for nearly 30 percent of the gasoline sold in the US.[16] The RFG program runs for the whole year (EIA, 1999a). RFG fuels must contain 2% oxygen by weight, since oxygen aids combustion and thus reduces emissions of certain harmful compounds. But how it is done is entirely at the discretion of the refiner. About 87% of RFG fuels contain the chemical MTBE as an oxygenate (since oxygen cannot be added directly), but in Chicago and Milwaukee, which are closer to ethanol production centers of the Midwest, ethanol is the preferred oxygenate. California requires a stricter blend of reformulated gasoline, which is not sold in any other state.

The Oxygenated Gasoline Program was launched in November 1992 and was mandatory in carbon monoxide non-attainment areas in order to reduce its production from gasoline in the winter months. Federal standards require oxygen additives to gasoline of at least 2.7 percent by weight. Oxygenated gasoline (OXY) accounts for about 5 percent of the gasoline sold during the winter months (November through February) and averages about 1.3 percent over the full year (EIA, 1999a). Originally 39 areas qualified for this program, but only 16 use OXY at present, the rest having already achieved target Clean Air regulatory standards. This program, which runs over the winter months, is administered by individual states.

There are a range of other less important state fuel programs that impose lower gasoline volatility requirements, caps on sulfur content, limits on the use of MTBE (which has been found to pollute water supplies) and minimum oxygen or ethanol content. We do not consider these programs in our analysis, and focus only on the RFG and OXY programs. Because of the chemical

[16] RFG provides the same vehicle performance as conventional gasoline but has lower levels of compounds such as benzene, sulfur and aromatics, and does not evaporate as easily as conventional gasoline, especially in the summer. It significantly reduces volatile organic compounds and toxic emissions relative to conventional gasoline.

characteristics of the pollutants, these two programs are mutually exclusive, i.e., with the exception of the Los Angeles region, all other areas are either ozone non-attainment areas (under RFG) or carbon monoxide non-attainment areas (under OXY).

The wholesale price of reformulated gasoline is higher than the price of conventional gasoline. On average over the 1995-2002 period, the observed price difference between RFG and conventional gasoline was around 5 cents, varying from 2.63 cents in PADD 3 to 8.23 cents in PADD 2 (Petroleum Marketing Annual, 1995-2002).[17] The first explanation for this price difference is that RFG and OXY blends are more costly to produce than conventional gasoline as refiners have to make adjustments in their production technology. It is estimated that it costs an additional two to four cents per gallon to produce RFG or OXY relative to conventional gasoline (EIA, 1999a). This "cost" effect is not sufficient to explain the observed difference between the price of RFG and the price of conventional gasoline.[18] Another possible explanation is that boutique fuels effectively segment the market, leading some refiners to produce these special fuels while others produce the standard gasoline blends. Yet other refiners may produce multiple blends and vary their output mix over time. Product differentiation may lead to a smaller number of firms selling in each wholesale gasoline market, reducing competition, and increasing prices. Our empirical analysis below aims to measure both of these "cost" and "segmentation"effects.

Table 2(a) (2(b)) reports the average wholesale price of gasoline along with the average shares of population in each state (PADD) under the RFG and OXY programs over the 1995-2002 period. As in Table 1(a), states in Table 2(a) are sorted by increasing average price. Note that most states in which none of the two programs are implemented have among the lowest wholesale gasoline prices (Mississippi, Louisiana, Oklahoma, South and North Carolina, Tennessee, Georgia, Alabama, Arkansas, Florida and Kansas). On the other hand, those states where both RFG and OXY gasoline are sold tend to have higher prices (Connecticut, Massachusetts, Maryland, Arizona, California and the District of Columbia).

[17] Information on the price of oxygenated gasoline was not available.
[18] Although these numbers may seem small, an industry rule of thumb is that a 10 cent/gallon gasoline price increase translates into additional industry revenues of 10 billion dollars (US Senate, 2002, p.20).

[Tables 2(a) and 2(b) here]

Table 3 shows descriptive statistics by year averaged over all the states. Average refinery capacity per state increased over the period from 302,649 to 329,125 barrels per day. The index measuring concentration in the refinery sector remained fairly stable at about 0.60 over the period. The share of population under RFG remained almost constant over the period (around 0.25) while we observe a decrease in the case of OXY, from 0.09 in 1995 to 0.05 in 2002. Some areas which were under the OXY program at the beginning of the period achieved their mandated standards and went out of the program during the study period.

[Table 3 here]

3. The Empirical Model

The empirical model for the wholesale price of gasoline denoted by *P* can be specified as follows:

$$P_{it} = X'_{it}\beta + Z'_{it}\gamma + \delta_m + \lambda_t + \alpha_i + v_{it} \qquad (1)$$

where the subscript i $(i=1,\ldots,N)$ denotes state, t $(t=1,\ldots,T)$ denotes the time period, and m $(m=1,\ldots,12)$ the month, respectively. The vector X_{it} represents the characteristics of the gasoline market in state i that may affect the wholesale price of gasoline. A distinctive feature of this model is the introduction of the vector of variables Z_{it} which includes the characteristics of the gasoline market in the region adjoining state i, defined as the set of states which share a common border with state i. A similar specification has been used by Baltagi and Levin (1986) and Baltagi and Li (1999) for estimating cigarette consumption. The vector of variables Z will be used to test for the effect of market segmentation on wholesale prices. The δ_m 's are monthly dummies introduced to control for seasonal effects in the price of gasoline. They are assumed to be the same across states. The λ_t*'s* are dummies that capture any specific time effects that would have affected all the states simultaneously. Examples may include the terrorist attack of September 11, 2001 or output decisions by OPEC. To control for unobserved state heterogeneity, we specify time-invariant, state-specific effects denoted by α_i. We assume that the α_i*'s* in equation (1) are fixed parameters to be estimated.[19] We include the usual idiosyncratic error term, v_{it}, assumed to be of mean 0. We assume that the vectors X_{it} and Z_{it} are uncorrelated with the idiosyncratic error term, v_{it} and also with the time effects, λ_t, but may be correlated with the state-specific effects, α_i.

The variables chosen to describe the structure of the gasoline market in state *i* (denoted by the *X* vector) are the following: the price of crude oil, the refinery capacity per capita in state *i*,[20] and the concentration index in the refinery sector of state *i*. We expect a positive relationship between the price of crude oil and the wholesale price. A state with a greater refinery capacity per capita is expected to have a lower wholesale gasoline price, all other things being equal. Finally, wholesale gasoline prices are expected to be positively correlated with the concentration index, the latter being interpreted as a measure of market power in the refinery sector. The greater the market concentration, the greater the potential for firms to exercise market power.

Environmental programs may affect the price of gasoline directly by increasing the cost of refining and distribution since RFG and OXY are more costly to produce than conventional gasoline (the "cost" effect). They may also affect the gasoline price indirectly through market segmentation, reducing competition among refineries (the "segmentation" effect). We propose to measure the cost effect by introducing the relative size of the RFG and OXY markets in each state as explanatory variables. These are defined as follows:

$$RFG_{it} = \frac{POP_{RFG,it}}{POP_{it}} \text{ and } OXY_{it} = \frac{POP_{OXY,it}}{POP_{it}}, \tag{2}$$

where $POP_{k,it}$ is the size of the market (population) for regulated gasoline of type *k* *(k=RFG, OXY)* in state *i* at time *t,* i.e., the total population in the area covered by the environmental program *k*, and POP_{it} is total population in state *i* at time *t.* The ratio of these two variables measures the relative size of the market (taking values from 0 to 1) covered by the environmental program. A higher relative size of the regulated market leads to production of a larger share of the cleaner and costlier gasoline and hence a higher wholesale price, all other things equal.

[19] The fixed-effects specification is preferred to the random-effects specification when one studies an exhaustive population (here the population of states), see Arellano (2003).
[20] A better fit was obtained with refinery capacity per capita, instead of total refinery capacity in the state.

To test for the effect of segmentation on wholesale price, we introduce variables that describe the gasoline market in the states adjoining state i (the Z vector).[21] We define two indices, $NRFG_{it}$ and $NOXY_{it}$ as follows:

$$NRFG_{it} = \frac{NPOP_{RFG,it}}{NPOP_{it}} \text{ and } NOXY_{it} = \frac{NPOP_{OXY,it}}{NPOP_{it}}, \tag{3}$$

where $NPOP_{k,it}$ is the size of the market (population) under regulated gasoline of type k $(k=RFG, OXY)$ in the states neighboring state i at time t, and $NPOP_{it}$ is total population in the states neighboring state i at time t. Further, we adopt the following two indices from the international trade literature (Helpman and Krugman, 1985) in which trade flows between countries is written as a function of GDP per capita and population:

$$I_{1k,it} = \log\left(\frac{POP_{k,it} + NPOP_{k,it}}{POP_{it} + NPOP_{it}}\right) \text{ and } I_{2k,it} = \left|\log\left(\frac{POP_{k,it}}{POP_{it}}\right) - \log\left(\frac{NPOP_{k,it}}{NPOP_{it}}\right)\right|, \ (k=RFG,\ OXY). \tag{4}$$

The index $I_{1k,it}$ measures the *overall* relative size of the regulated gasoline market in state i and its adjoining states at time t. The index $I_{2k,it}$ measures the *difference* in the relative market size for regulated gasoline in state i and its adjoining states at time t.[22] Over the 1995-2002 period the index I_1 varies from -9.21 to -0.02 for the RFG market (from -9.21 to -0.20 for OXY). A higher value for the I_1 index indicates a greater relative size of the regulated gasoline market in the overall region of state i (i.e., state i and its adjoining states). The index I_2 varies from 0 to 9.21 for the RFG market (from 0 to 8.82 for OXY). When the I_2 index equals 0 it indicates that the relative size of the regulated market in state i and its neighboring states is the same. When it

[21] We assume that refineries in state i compete only with refineries in states adjoining state i. Ideally, one would employ refinery data from states located further away, suitably weighted by distance. Moreover, there is heterogeneity both in the types of crude oil used for refining and in the refinery product mix. Not all refineries produce the same type of gasoline, leading to greater transportation of gasoline than if all refined product was homogenous. This issue is partly addressed later when we test for differences across PADDs that use domestically produced gasoline and those that rely on imports.

[22] When the share of population under the RFG or OXY program is zero, we use log(0.0001) ≈ -9.21 instead of log(0) which is undefined.

equals 9.21, we have complete differentiation between regulation in state *i* and in states adjoining *i*.

To avoid multicollinearity, all the above variables measuring market segmentation cannot be introduced simultaneously in the wholesale price model. We thus try alternative model specifications that use different combinations of them.

Our data are monthly observations for the 48 contiguous states and the District of Columbia over the 1995 – 2002 period (see Appendix).[23,24] We use the first 7 years for estimation and reserve the last 12 months (year 2002) for out of sample forecasts that will be used to choose the best specification for our model. We only consider the regular grade of gasoline. The average wholesale price of gasoline and the price of crude oil, expressed in logarithms, are measured in 1995 dollars.

To prevent endogeneity bias from the correlation of unobservable state-specific effects and model regressors, we estimate equation (1) with all variables deviated from their time means. Within estimation is demanding of the data, since estimates are based on time variation in the data for each state and not on cross-sectional variation across states. The effect of environmental regulation can be identified in our data because the size of the markets for regulated gasoline varies across time periods. Some areas entered or exited the program during the period covered by our data for both RFG and OXY. For OXY, there is also a variation across months of each year as OXY blends are normally sold during winter months only.

The Newey-West (1987) method is used to obtain robust standard errors.[25] This method allows for the correction of any form of heteroskedasticity or serial correlation in the error term. In particular, it will correct for any unobserved spatial auto-correlation that could enter the error term (see Anselin, 1988, p. 152).

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[23] The latest year is 2002 because RFG and OXY program data for later years was not yet available.
[24] We do not consider the states of Alaska and Hawaii as they do not share a border with any other state. In their case, the variables $NRFG_{it}$, $NOXY_{it}$, I_{1it} and I_{2it} are undefined.

Data and Estimation Results

We estimate six models. All of them include the following variables to describe the gasoline market in state *i*: the (log) price of crude oil, the (log) refinery capacity per capita, the (log) concentration index, and a dummy variable to account for California's unique reformulated gasoline program.[26] This dummy variable has a value of 1 beginning from March 1996, when California legislated use of its own RFG blend, and 0 otherwise.

The regressors used to describe environmental programs and market segmentation vary from one model to another. Table 4 details the set of additional variables included in each of the six models as well as the selected econometric technique.

[Table 4 here]

Model (A) assumes that only the characteristics of the gasoline market in state *i* matter. It does not account for any regional effects. The Ordinary Least Squares (OLS) method is used. Only if the state-specific effects are uncorrelated with the explanatory variables will OLS provide consistent estimates. The regressors in Model (B) are the same as in Model (A) but the Within estimation procedure is used instead. From Model (C) to Model (F) the characteristics of the gasoline market in the entire region (i.e. the states neighboring state *i*) are included as additional explanatory variables. From one model to another the variables capturing market segmentation due to environmental regulation differ. In Model (C) we use as separate exogenous regressors the relative size of RFG and OXY markets in state *i* and the relative size of RFG and OXY markets in the states adjoining *i*. In Model (D) we use the relative size of RFG and OXY markets in state *i* as well as the I_2 index for both markets. In Model (E) we combine all the variables from Model (C) and Model (D). In Model (F) we use the I_1 and I_2 indices for both markets as measures of market size and segmentation. Each of the last four models is estimated using the Within estimation technique.

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[25] The method for computing robust standard errors in the case of a panel with a large number of periods is described in Arellano (2003, p. 19).

All models are estimated under the assumption that the observable explanatory variables have the same effect on the wholesale price over the entire country. Allowing for state or PADD-specific parameters did not permit identification of the parameters in most cases, especially those associated with the variables measuring environmental regulation.

The performance of the six models is compared in terms of their ability to forecast wholesale prices for gasoline in the year 2002. We follow Baltagi and Li (1999) in computing the predicted wholesale price $\hat{P}_{im}$ in state *i* for month *m* in year 2002:

$$\hat{P}_{im} = X'_{im}\hat{\beta} + Z'_{im}\hat{\gamma} + \hat{\delta}_m + \hat{\alpha}_i \qquad (5)$$

where $\hat{\beta}$ and $\hat{\gamma}$ are the estimated parameters, and $\hat{\delta}_m$ and $\hat{\alpha}_i$ are the estimated month and state-specific effects.[27] The Mean Sum of Square Errors (MSSE) is computed as

$$MSSE = \frac{1}{N \times 12} \sum_{i=1}^{N} \sum_{m=1}^{12} \left(\hat{P}_{im} - P_{im} \right)^2 \qquad (6)$$

where P_{im} is the corresponding observed wholesale gasoline price for year 2002. The MSSE is computed for all six models and reported in the bottom line of Table 4. They suggest that using an inconsistent method (OLS) significantly increases the forecast error - the MSSE for model (A) is the largest of all six models. Second, incorporating the characteristics of the gasoline market in adjacent states improves the model fit significantly – the MSSE of models (C) to (F) are lower than the MSSE of model (B). These results suggest that markets in neighboring states have a significant role to play in determining wholesale prices in any given state. Finally, models (C) to (F) provide quite similar predictions but the best appears to be model (D). These figures show

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[26] Several forms (linear-linear, log-linear and log-log) were tested. The log-log equation yields the best fit to the data. The log of the variables which take on values of zero (refinery capacity per capita and concentration index) is set at 0.

[27] The state-specific effects $\hat{\alpha}_i$ correspond to the average residual for each state from the Within estimation of equation (1).

that our best model is able to forecast the wholesale gasoline price for 2002 with an error of about 6 cents per gallon.[28]

Estimation results for model (D) are reported in Table 5,[29] except for the estimated coefficients of the 84 time dummies. There are a total of 84 time periods for the 48 states and the District of Columbia, which correspond to a monthly series for seven years (1995-2001). Because of two missing observations for wholesale prices in New Hampshire and Nevada, the total number of observations used in the estimation is (84)(49)-2=4,114.

[Table 5 here]

We find strong evidence of serial correlation (up to the sixth order) of the error terms in the model, which we correct using the method of Newey and West (1987). Our results confirm the finding of Chouinard and Perloff (2002) that the price of crude oil is a major determinant of gasoline prices. The estimated parameter associated with the price of crude oil (in log) measures the elasticity of the wholesale price to the price of crude oil. We estimate this elasticity at 0.77, which means that a 10% increase in the price of crude oil leads to a 7.7% increase in the wholesale price. As expected, states with a larger refinery capacity per capita have a lower wholesale price of gasoline, all other things equal. The small variation in refinery capacity over time in each state may explain why the coefficient for this variable is not significant. The refinery concentration index has a significant positive coefficient, emphasizing the link between concentration and the wholesale price of gasoline. The estimated elasticity is equal to 0.17. We find that the requirement of using a special gasoline blend in California adds a premium equal to 2.8 cents to the price of a gallon of gasoline.[30]

All the four variables used to measure the impact of environmental regulation, through the implementation of the RFG and OXY programs have positive signs. Three of them are

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[28] The MSSE of model (D) equals 37.35 so that the average prediction error is $\sqrt{37.35} \approx 6$ cents per gallon.

[29] Results for the other five models are not displayed here but can be made available upon request.

[30] The parameter associated with the indicator for California's unique gasoline blend (which is estimated at 0.036) measures the effect of selling this boutique fuel on the log of wholesale price. Equivalently, it implies that gasoline

significant. The larger the relative size of the market for regulated gasoline in a state, the higher the average wholesale price. This result illustrates the cost effect described earlier: RFG and OXY are more costly to produce than conventional gasoline and those states where a larger segment of the market uses RFG or OXY fuels exhibit a higher average price for gasoline. All other things equal, the implementation of RFG (OXY) gasoline in a state where no special gasoline is sold would increase the wholesale price by 4.6% (2.3%), which corresponds to a premium of 3.4 (1.7) cents per gallon. The "cost effect" as predicted by our model is within the two to four cent interval estimated by the EIA (1999a).

The difference in the relative sizes of the regulated market between a state and its neighbors is also found to be positively related to the average wholesale price in the state. It is highly significant in the case of OXY. In other words, the greater the difference in the market size of an environmental program between a state and its neighbors, the higher the average wholesale price in the state. This result suggests that market segmentation has a positive effect on the wholesale price of gasoline.

This segmentation effect is found to be stronger in the OXY market than in the RFG market. This may be because the supply of OXY gasoline varies from season to season. OXY is mainly sold during winter months while RFG is normally sold all through the year. The lower variation in the variables related to the RFG program during the year could make it difficult for the Within estimator to identify the associated effect, which could also explain the non-significance of the variable measuring segmentation in the RFG market.

The model was also estimated using Instrumental Variables (IV) techniques for panel data (see Baltagi, 2001), controlling for the possible endogeneity of refinery capacity and the refinery concentration index. Contrary to the Within estimation technique which relies on variation across time for each state, the data in the IV approach are defined as levels, and thus do not involve any transformation of the variables. Qualitatively, we get the same results using the IV approach and

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regulation has increased the wholesale price in California by $1-e^{-0.036} \approx 3.5\%$, which corresponds to roughly 2.8 cents per gallon.

more importantly, the refinery capacity and the index measuring the difference in the relative sizes of the RFG market between a state and its neighbors are still found to be insignificant.

Month dummies are all significant. January is chosen as the reference. Larger coefficients are obtained from May to September when demand increases because of driving activity.
Time dummies are also found to be highly significant in the model, suggesting that some purely temporal effects had a common impact on all states. In particular, we observe strong positive effects in the spring of each year. There is often a tight balance between supply and demand in spring because this is the period of conversion from the production of winter-grade to summer-grade gasoline - the oxygenated gasoline program is implemented in winter months only.

One could argue that the index of differentiation (I_2) does not measure market power but is picking up the increased "cost" of gasoline transportation to any given state. These "transportation" costs may be broadly defined as the cost of arbitrage if product of a certain quality has to be imported from distant sources, the cost of fewer distribution system options, time delays and a generally lower degree of fungibility. Gasoline prices in a state may be higher if the difference in regulation between it and its adjoining states is large, since supplies must then come from more distant sources, at a higher cost. We test this hypothesis by considering the states in PADDs 1 and 2 (East Coast and Midwest) that mostly import gasoline from outside the region relative to PADDs 3, 4 and 5 that are mainly self-reliant. Figure 2 provides a graphical representation of the flow of petroleum products into each PADD.[31] The parameter associated with the differentiation index should not be the same for these two groups of PADDs. If the transportation cost argument was true, we should observe that the coefficient associated with the differentiation index is significant and positive only for PADDs 1 and 2 which are major importers of gasoline. For the other PADDs which mainly use their own gasoline, the index should not be significant. A simple test involves estimating separate coefficients of the differentiation index for these two groups of PADDs. The wholesale price model is thus re-estimated, assuming four differentiation indices: the differentiation index in the RFG market for

[31] See EIA (2002, Figure 5) for precise import data by PADD. The East Coast (PADD 1) is most dependent on distant production – mainly from the Gulf Coast and foreign imports. The Midwest (PADD 2) is also heavily import dependent. The Gulf Coast (PADD 3) is totally self-reliant, while the Rocky Mountain states (PADD 4) and the West Coast (PADD 5) import a small amount of gasoline from outside the region.

PADDs 1 and 2 grouped together, and for PADDs 3, 4, and 5 also taken together. This is repeated for the OXY market. The estimated model (except for month and time dummies) is reported in Table 6.

[Table 6 here]

The estimated coefficients in Table 6 are quite similar to the coefficients reported in Table 5. The differentiation index is significant only in the OXY market. Simple Fisher tests show that the null hypothesis of equal effects of the differentiation indices between PADDs 1 and 2, and PADDs 3, 4, and 5 cannot be rejected in both cases. In other words, the impact of the differentiation in regulation on the wholesale price of gasoline is the same across both groups of PADDs. Equivalently, the differentiation index has a significant effect on price even in the states that do not import gasoline. This result reinforces the interpretation of this index as a measure of market power instead of increased transportation costs.[32]

Policy Simulations

The above results can be used to simulate policy scenarios, and examine the effect of extending the use of RFG or OXY gasoline to the whole country.[33] Consider scenario 1 in which RFG is the only gasoline sold in all the states (minus Hawaii and Alaska, of course) and the District of Columbia, and oxygenated gasoline is no longer produced. The overall effect on wholesale gasoline prices is indeterminate since extending the use of RFG would require that all the refineries make the costly investments necessary to produce RFG. So prices may rise. But at the same time, prices may fall from increased competition between the refineries as they would all

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[32] The above test with PADDs may not capture transportation and other frictional costs between states if "generic" gasoline is imported into a PADD and then mixed in storage terminals with additives tailored to specific regulated markets. This is not a major problem for PADDs 3,4 and 5 where gasoline is mainly stored in refineries (US Senate, 2002, p.52). In general, a better approach may be to repeat this test at the level of individual states. This will require state level RFG and OXY gasoline import data or refinery production data by type of boutique fuels, which may be difficult to obtain. The variable refinery capacity per capita (which we control) compensates to some degree, since given high utilization rates, refinery capacity is a good proxy for domestic production for states with a low level of imports.

[33] See EPA (2001) for a discussion of this issue. We only consider two polar cases, RFG or OXY fuels use in the entire country. Other intermediate cases could be modelled, e.g., RFG in some states and OXY in others, but the results may be some combination of those given here.

produce the same blend of gasoline. The simulated wholesale price is computed as follows (see Baltagi and Li, 1999):

$$\hat{P}_{it} = X'_{it}\hat{\beta} + Z'_{it}\hat{\gamma} + \hat{\delta}_m + \hat{\alpha}_i \qquad (7)$$

where the *X*-vector represents the price of crude oil, refinery capacity per capita, refinery concentration index, and the relative size of the RFG and OXY markets in state *i*. The *Z*-vector includes the I_2 indices for both RFG and OXY markets. The estimated parameters $\hat{\beta}$, $\hat{\gamma}$, and $\hat{\delta}_m$ are taken from Table 5 and $\hat{\alpha}_i$ is the estimated state-specific effect. For each state *i*, we compute twelve simulated prices, one for each month. The price of crude oil, refinery capacity per capita and refinery concentration index take their 2002 values and we assume that

$$RFG_{im} = 1,\ OXY_{im} = 0,\ I_{2,RFG,im} = 0, \text{ and } I_{2,OXY,im} = 0,\ i=1,..,49;\ m=1,..,12.$$

Under this scenario the relative size of the market for RFG now equals 1 in all states, while the relative size of the market for OXY is 0 as OXY gasoline is no longer in use. The indices measuring the difference in the size of regulated markets equal 0 as all states produce the same gasoline.

The impact of this policy is computed in terms of a price premium. Table 7(a) (7(b)) shows, for each state (PADD), the average price premium (over the twelve months) following the extension of RFG to the whole country. This price premium is decomposed into a "cost" effect and a "segmentation" effect. We further decompose these effects by RFG and OXY.

[Tables 7(a) and 7(b) here]

For each state, the cost effect is the added cost of extending RFG regulation to the entire state net the removal of OXY regulation. The segmentation effect is from the decline in market power from implementing a uniform RFG program and removal of the OXY program.[34] As a result of

[34] We assume that this policy would not induce any price adjustment in California as this state would still be producing a unique gasoline blend.

uniform RFG regulation, several states, all from PADD 1, experience a net decline in wholesale prices. These are New Jersey, Massachusetts, Rhode Island, Connecticut, and Delaware. In these states, a large segment of the population already buys regulated gasoline, so the (negative) market power effect dominates the (positive) cost effect from marginally increased coverage.

The price differential varies from –0.36 cents per gallon to +4.13 cents per gallon, with a national average of +2.52 cents. The average country-wide “cost” effect, which represents an increase in the wholesale price of 2.96 cents, is partially offset by the “segmentation” effect which lowers the price by 0.44 cents. In Table 7(b), we observe the lowest cost effect in PADD 1 (an average of +2.04 cents per gallon).

States in which no special gasoline is currently sold (Georgia, Alabama, Mississippi, South Carolina, Florida) would bear the biggest increase in wholesale gasoline prices, as the cost effect would dominate the market power effect. The largest cost effect would be observed in PADD 4 (+3.98 cents per gallon). The (negative) segmentation effect is smaller than the (positive) cost effect, the former varying from –0.23 cents per gallon in PADD 1 to –0.70 cents per gallon in PADD 2.

These results are more pronounced in Scenario 2 which assumes that OXY is sold all over the country and RFG is no longer produced. We use the same procedure as for RFG except that we now assume

$$RFG_{im} = 0,\ OXY_{im} = 1,\ I_{2,RFG,im} = 0,\ \text{and}\ I_{2,OXY,im} = 0.$$

The simulated price differential under this scenario is displayed in Tables 8(a) and 8(b).

[Tables 8(a) and 8(b) here]

Fifteen states see a net price decline. Wholesale prices in states which are under significant RFG or OXY regulation - Connecticut, Delaware, Massachusetts, New Jersey and Rhode Island - fall by more than 2 cents per gallon. The price premium varies from –2.41 cents per gallon to +1.96

cents per gallon, with a national average of +0.43 cents (+ 0.89 cents for the "cost" effect and – 0.44 cents for the "segmentation" effect). On average the price increase under scenario 2 (extending OXY to the whole country) is lower than the price increase under scenario 1 (extending RFG to the whole country). The "segmentation" effect is similar under the two scenarios but the "cost" effect is higher under RFG than for OXY.

While the harmonization of RFG blends increases prices in all the PADDs (Table 7(b)), in the case of OXY, PADD 1 (East Coast) registers an average price decline of 0.28 cents (Table 8(b)). In this PADD, 49% of the population is in a RFG zone, so the price declines when the RFG program is abolished, and increases by a smaller amount when a uniform OXY program is established. Thus the net cost effect is negative and so is the segmentation effect.

The above results provide some general insights into the likely impact of regulating uniform fuel standards in the entire country. However we have to remain cautious about the results as these simulations are run under the assumption that all other things (number of refineries, refinery capacity, etc.) remain unchanged.

4. Concluding Remarks

This paper examines the effect of state level environmental regulation on wholesale gasoline prices. We consider two major boutique fuels – reformulated gasoline and oxygenated fuels which aim to reduce ozone and carbon monoxide from automobile emissions. Using measures that include the relative size of the regulated market in the state as well as the difference in relative sizes between a state and its adjoining states, we find that boutique fuels cause an increase in wholesale gasoline prices in two ways – by increasing the cost of refining and by segmenting the market and increasing the market power of firms. While the refinery concentration in the regulated market within a state leads to an increase in the price of gasoline, the price is also affected by the regulatory distance between a state and its neighbors. This suggests that heterogeneity in environmental regulation following from the Clean Air Act may be an important factor in the increase in gasoline prices in recent years, as suggested by many analysts (Fesharaki, 2004).

Estimates derived in this analysis are useful in particular to simulate the impact on wholesale gasoline prices of a homogenization of regulatory standards. We show that selling a unique blend (reformulated or oxygenated gasoline) is likely to raise prices in those states which currently have a relatively low degree of regulation, i.e., boutique fuels are required in a relatively small geographical area. This is because in such states, a larger area must now sell the higher cost gasoline, and thus the cost effect will dominate the benefits from reduced market power. However, in those states with an already high degree of regulation, the cost effect will be small but the market power effects are likely to be large, especially if their current regulation is sufficiently distant from their neighboring states. Overall, they may see a decline in the wholesale price of gasoline from adoption of a common fuel program. Of course, such predictions may be somewhat simplistic, since they do not consider the effect of altered prices on consumer demand for gasoline and on refiner's profit margins and resulting entry-exit decisions.

We have only considered the cost and market power effects of multiple gasoline blends. Fuel harmonization may need to weigh the added costs of regulation to the benefits from a lower degree of market power as well as improved environmental benefits. Future research could also focus on the effects of MTBE regulation on the gasoline market, as well as conducting analysis at the state or PADD levels with disaggregated price data. One could test for price volatility and examine whether gasoline prices are more volatile in states where there is stronger environmental regulation or in those which are at a greater regulatory distance relative to their neighbors.

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Appendix

Data description and sources

Wholesale gasoline prices are obtained from the Petroleum Marketing Annual reports (1995-2002) prepared by the Energy Information Administration (EIA). The price of crude oil is the monthly national average price of the composite (domestic and imported) refiner acquisition cost, which is the average price of crude oil purchased by refiners (in cents per gallon). The wholesale price is the monthly average price of regular motor gasoline wholesale sales (in cents per gallon excluding taxes) within the state. We deflate prices using the Consumer Price Index (CPI) provided by the Bureau of Labor Statistics.

Refinery capacity (in million barrels per calendar day) is the aggregated capacity of all refineries operating in the state (source: EIA). Information on refineries was missing for the years 1996 and 1998, so 1995 and 1997 figures were used as substitutes. Total capacity is a good proxy for crude oil production since the annual average refinery utilization rate regularly exceeds 90 percent of installed capacity (US Senate, 2002, p. 5). These figures are annual and therefore exhibit no month-to-month variation. They are used to compute the market share (based on capacity) of each firm owning a refinery in any given state and the firm concentration index is defined as the sum of the largest four market shares.[35] These indices are also computed on an annual basis.

Information on control areas under reformulated gasoline (RFG) and oxygenated gasoline (OXY) programs was obtained from the Environmental Protection Agency (EPA). EPA provides the population of the mandated and opt-in RFG control areas and the population of OXY control areas, both estimated on July 1, 1996. The duration of the oxygenated fuel programs is for at least four months, and typically runs from November 1 to February 29, although it sometimes varies by state. We control for the period of implementation (number of days per month) for the OXY program (source: EIA, 1999b).

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[35] Different concentration measures have been proposed in the literature. We follow Dansby and Willig (1979) who advocate the use of a *m*-firm concentration ratio when the largest *m* firms collude and the remaining firms are price-takers. We choose $m=4$. The US Senate report (2002, p.4) also uses the four-firm concentration ratio in its analysis of mergers in the gasoline industry.

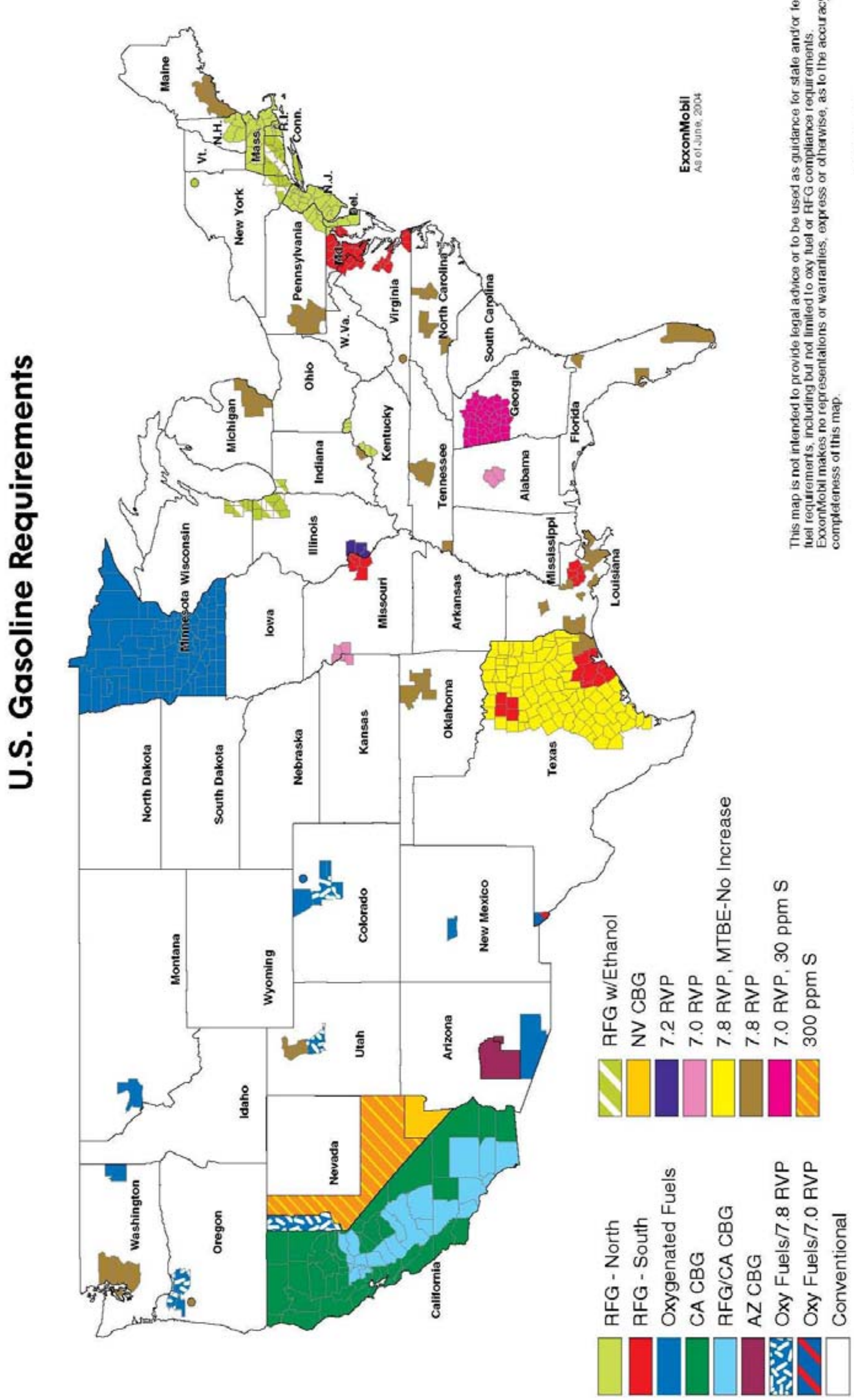

Figure 1. Areas (Islands) under Gasoline Regulation (Source: ExxonMobil)

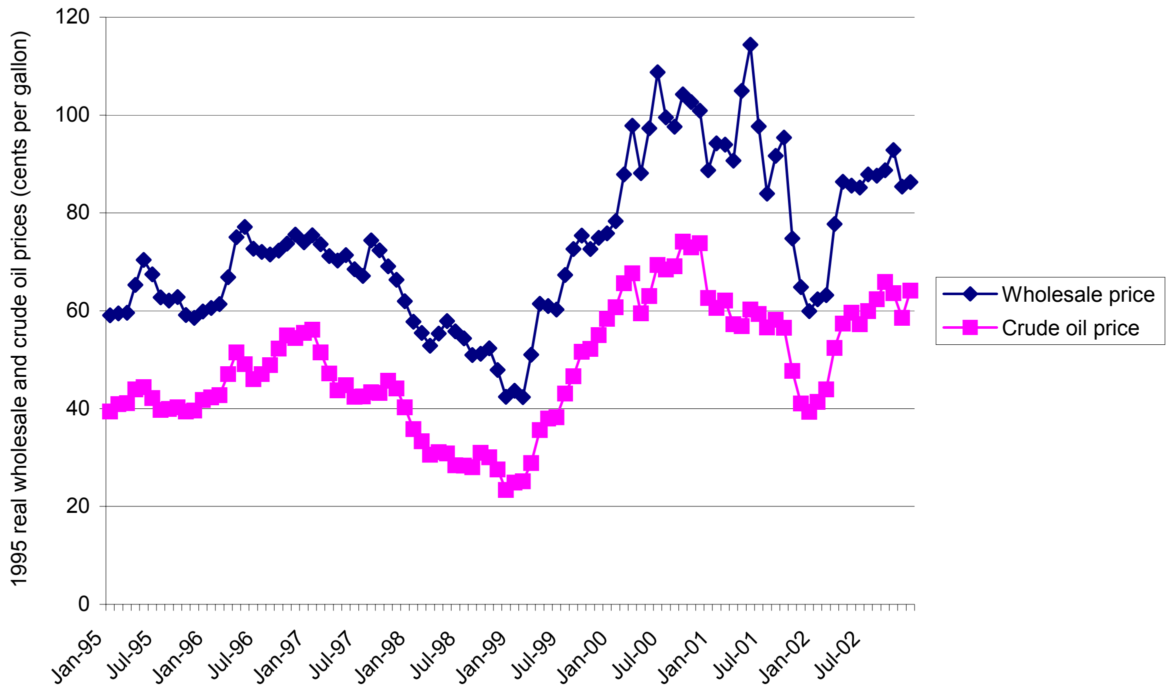

Figure 2. Monthly wholesale price and crude oil price over the 1995-2002 period

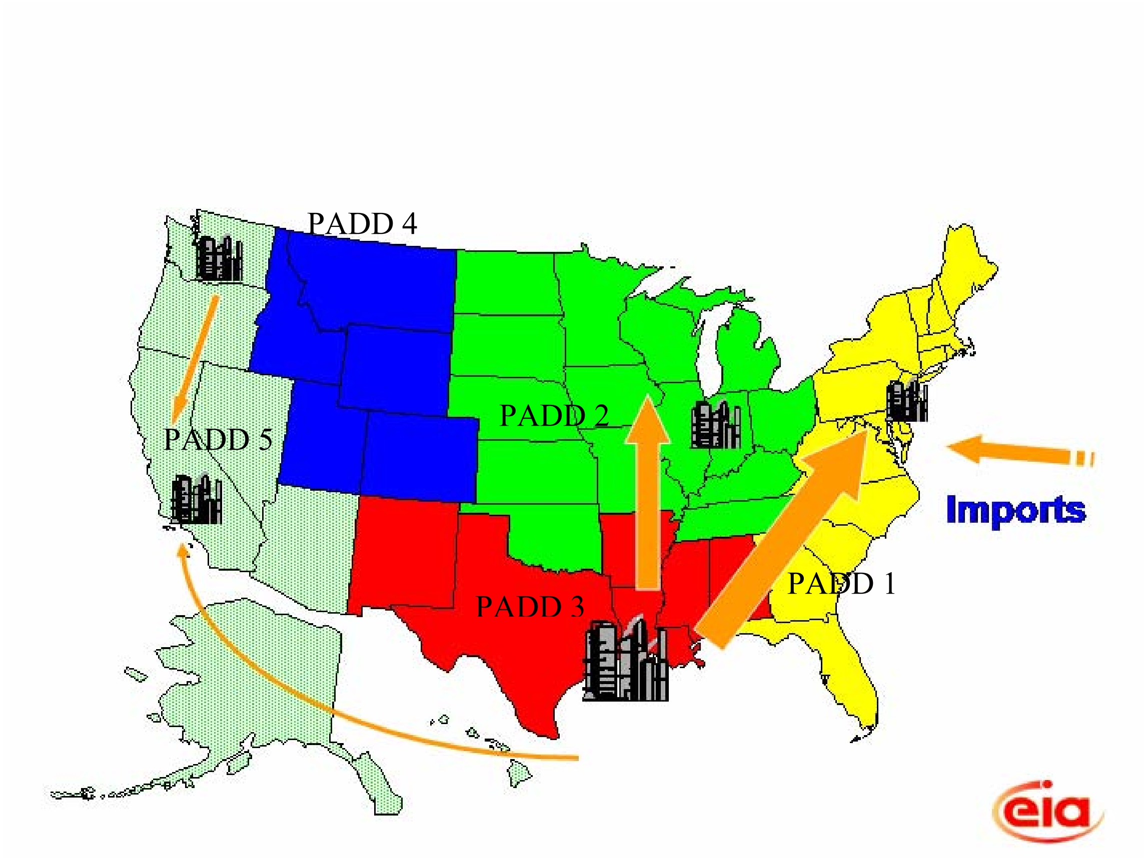

Figure 3. The Five PADD Regions (Source: EIA (2002))

Note: Arrows show flow of petroleum products. Their thickness shows approximate volumes. The East Coast and Midwest (PADDs 1 & 2) are primarily dependent on imports, mainly from refineries in the Gulf Coast (PADD 3) and abroad. The Gulf, Rockies and the West Coast (PADDs 3, 4 & 5) are largely self-reliant.

Table 1(a). Gasoline Market Statistics by State (1995-2002 averages)

State	PADD	Population	Wholesale price (cents / gallon)	Number of refineries	Refinery capacity (barrels / day)	Capacity per capita	Concentration index
Texas	3	20,357,661	65.36	23	4,154,651	0.204	0.40
Mississippi	3	2,807,667	65.63	3	337,050	0.120	1.00
Louisiana	3	4,440,333	65.78	17	2,539,488	0.572	0.54
Oklahoma	2	3,410,162	66.71	6	434,455	0.127	0.88
South Carolina	1	3,936,429	66.99	0	0	0.000	0.00
Tennessee	2	5,587,687	67.20	1	129,750	0.023	1.00
Georgia	1	7,953,055	67.31	2	33,470	0.004	1.00
North Carolina	1	7,858,645	67.36	0	0	0.000	0.00
Alabama	3	4,404,759	67.84	3	126,500	0.029	1.00
Arkansas	3	2,633,774	67.93	3	64,458	0.024	1.00
Florida	1	15,620,174	68.17	0	0	0.000	0.00
Kansas	2	2,662,544	69.04	3	291,694	0.110	1.00
Pennsylvania	1	12,260,058	69.48	5	713,425	0.058	0.98
New Jersey	1	8,329,169	69.59	5	641,000	0.077	0.94
Virginia	1	6,968,506	70.24	1	56,975	0.008	1.00
Indiana	2	6,016,794	70.42	2	435,275	0.072	1.00
Kentucky	2	3,996,711	70.81	2	224,875	0.056	1.00
Nebraska	2	1,697,541	70.83	0	0	0.000	0.00
Iowa	2	2,907,058	70.90	0	0	0.000	0.00
Missouri	2	5,536,208	71.03	0	0	0.000	0.00
Ohio	2	11,318,068	71.08	4	511,250	0.045	1.00
Michigan	2	9,875,224	71.50	2	102,650	0.010	1.00
Maine	1	1,266,183	71.58	0	0	0.000	0.00
Delaware	1	768,877	72.13	1	151,375	0.197	1.00
Wisconsin	2	5,316,610	72.18	1	33,800	0.006	1.00
West Virginia	1	1,812,900	72.19	1	13,188	0.007	1.00
New York	1	18,831,173	72.81	0	0	0.000	0.00
North Dakota	2	643,939	72.83	1	58,000	0.090	1.00
Illinois	2	12,311,089	72.96	5	989,443	0.080	0.84
South Dakota	2	749,500	73.02	0	0	0.000	0.00
Colorado	4	4,171,483	73.36	2	85,688	0.021	1.00
Rhode Island	1	1,039,361	73.42	0	0	0.000	0.00
New Mexico	3	1,794,611	73.67	3	94,975	0.053	1.00
Connecticut	1	3,383,624	74.33	0	0	0.000	0.00
Massachusetts	1	6,290,891	74.36	0	0	0.000	0.00
Maryland	1	5,244,375	74.43	0	0	0.000	0.00
Minnesota	2	4,845,224	75.19	2	320,900	0.066	1.00
Wyoming	4	491,486	75.35	5	133,099	0.271	0.99
New Hampshire	1	1,215,568	75.87	0	0	0.000	0.00
Vermont	1	603,070	77.13	0	0	0.000	0.00
Utah	4	2,176,219	77.21	5	157,963	0.073	0.93
Oregon	5	3,363,534	77.44	0	0	0.000	0.00
Montana	4	895,108	77.68	4	154,679	0.173	1.00
Washington	5	5,788,980	78.38	6	587,869	0.102	0.92
Idaho	4	1,262,296	78.48	0	0	0.000	0.00
Arizona	5	4,949,269	79.21	0	475[a]	0.000	0.13
Nevada	5	1,886,244	79.41	1	6250	0.003	1.00
California	5	33,301,897	80.58	17	1,944,123	0.058	0.64
District of Columbia	1	571,554	82.81	0	0	0.000	0.00
Alaska	5	621,972	92.19	4	314,816	0.505	1.00
Hawaii	5	1,215,297	100.72	2	147,500	0.121	1.00
U.S. Average		277,390,562	73.37	140	15,991,107	0.07	0.59

Note: Only one refinery was operational in Arizona for only one year over this period.

Table 1(b). Gasoline Market Statistics by PADD (1995-2002 averages)

PADD	Population	Wholesale price (cents / gallon)	Number of refineries	Refinery capacity (barrels / day)	Capacity per capita	Concentration index
1 – East Coast	103,953,613	72.23	15	1,609,433	0.020	0.33
2 – Midwest	76,874,359	71.05	28	3,532,092	0.046	0.72
3 – Gulf Coast	36,438,805	67.69	51	7,317,122	0.167	0.82
4 – Rockies	8,996,592	76.41	16	531,428	0.107	0.78
5 – West Coast	51,127,193	83.91	29	3,001,033	0.113	0.67

Table 2(a). Implementation of RFG and OXY programs in each state, 1995-2002 averages

State	PADD	Wholesale price (cents/gallon)	Share of population under RFG program	Share of population under OXY program
Texas	3	65.36	0.43	0.02
Mississippi	3	65.63	0.00	0.00
Louisiana	3	65.78	0.00	0.00
Oklahoma	2	66.71	0.00	0.00
South Carolina	1	66.99	0.00	0.00
Tennessee	2	67.20	0.00	0.00
Georgia	1	67.31	0.00	0.00
North Carolina	1	67.36	0.00	0.00
Alabama	3	67.84	0.00	0.00
Arkansas	3	67.93	0.00	0.00
Florida	1	68.17	0.00	0.00
Kansas	2	69.04	0.00	0.00
Pennsylvania	1	69.48	0.41	0.02
New Jersey	1	69.59	0.98	0.28
Virginia	1	70.24	0.59	0.01
Indiana	2	70.42	0.11	0.00
Kentucky	2	70.81	0.26	0.00
Nebraska	2	70.83	0.00	0.00
Iowa	2	70.90	0.00	0.00
Missouri	2	71.03	0.16	0.00
Ohio	2	71.08	0.00	0.00
Michigan	2	71.50	0.00	0.00
Maine	1	71.58	0.32	0.00
Delaware	1	72.13	0.98	0.00
Wisconsin	2	72.18	0.34	0.00
West Virginia	1	72.19	0.00	0.00
New York	1	72.81	0.66	0.24
North Dakota	2	72.83	0.00	0.00
Illinois	2	72.96	0.63	0.00
South Dakota	2	73.02	0.00	0.00
Colorado	4	73.36	0.00	0.22
Rhode Island	1	73.42	0.97	0.00
New Mexico	3	73.67	0.00	0.10
Connecticut	1	74.33	0.98	0.13
Massachusetts	1	74.36	0.99	0.04
Maryland	1	74.43	0.88	0.03
Minnesota	2	75.19	0.00	0.51
Wyoming	4	75.35	0.00	0.00
New Hampshire	1	75.87	0.59	0.00
Vermont	1	77.13	0.00	0.00
Utah	4	77.21	0.00	0.17
Oregon	5	77.44	0.00	0.17
Montana	4	77.68	0.00	0.03
Washington	5	78.38	0.00	0.07
Idaho	4	78.48	0.00	0.00
Arizona	5	79.21	0.39	0.24
Nevada	5	79.41	0.00	0.35
California	5	80.58	0.92	0.26
District of Columbia	1	82.81	0.95	0.06
Alaska	5	92.19	0.00	0.18
Hawaii	5	100.72	0.00	0.00
U.S. Average		73.35	0.25	0.06

Table 2(b). Implementation of the RFG and OXY programs in each PADD, 1995-2002 averages

State	Wholesale price (cents/gallon)	Share of population under RFG program	Share of population under OXY program
1 – East Coast	72.23	0.52	0.05
2 – Midwest	71.05	0.10	0.03
3 – Gulf Coast	67.69	0.07	0.02
4 – Rockies	76.41	0.00	0.09
5 – West Coast	83.91	0.19	0.18

Table 3. Descriptive statistics by year (averaged over states)

	1995	1996	1997	1998	1999	2000	2001	2002
Refinery capacity (barrels per day)								
Mean	302,649	302,574	302,976	302,976	318,849	323,860	325,399	329,125
Std. Dev.	694,213	694,246	698,933	698,933	728,748	743,027	747,921	764,002
Min	0	0	0	0	0	0	0	0
Max	4,004,050	4,004,050	4,043,450	4,043,450	4,185,350	4,246,050	4,292,430	4,418,380
Refinery concentration index								
Mean	0.604	0.584	0.588	0.588	0.592	0.594	0.592	0.593
Std. Dev.	0.468	0.472	0.473	0.473	0.473	0.473	0.473	0.473
Min	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Max	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Share of population under RFG								
Mean	0.245	0.244	0.245	0.251	0.245	0.246	0.246	0.246
Std. Dev.	0.372	0.370	0.369	0.372	0.368	0.369	0.369	0.369
Min	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Max	0.986	0.986	0.996	0.996	0.996	0.996	0.996	0.996
Share of population under OXY								
Mean	0.086	0.076	0.060	0.057	0.055	0.054	0.054	0.051
Std. Dev.	0.131	0.130	0.119	0.114	0.113	0.113	0.113	0.110
Min	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Max	0.510	0.556	0.556	0.556	0.556	0.556	0.556	0.556

Table 4. Additional regressors included in the six models and MSSE for year 2002 forecasts

	Model (A)	Model (B)	Model (C)	Model (D)	Model (E)	Model (F)
Relative size of regulated market in state *i* (RFG_{it}, OXY_{it})	X[(a)]	X	X	X	X	.
Relative size of regulated market in region *i* ($NRFG_{it}$, $NOXY_{it}$)	.	.	X	.	X	.
Overall (relative) size of the regulated market ($I_{1,RFG,it}$, $I_{1,OXY,it}$)	.	.	.	.	.	X
Difference in the relative size of regulated markets ($I_{2,RFG,it}$, $I_{2,OXY,it}$)	.	.	.	X	X	X
Unobserved state specific effects (α_i)	.	X	X	X	X	X
Econometric technique[(b)]	OLS	W	W	W	W	W
Mean Sum of Square Errors (MSSE)	56.73	46.98	37.70	37.35	37.79	38.67

(a) The symbol 'X' indicates that this variable is included in the model.
(b) OLS and W represent Ordinary Least Squares and Within estimation procedures, respectively.

Table 5. Estimation results for Model (D)

	Estimated coefficient	Corrected Standard Error	p-value
Crude oil price (log)	0.7717***	0.0121	0.000
Refinery capacity per capita in the state (log)	-0.0038	0.0025	0.125
Measure of concentration in the refinery sector in the state (log)	0.1718**	0.0859	0.046
Relative size of RFG market in the state	0.0476**	0.0194	0.014
Relative size of OXY market in the state	0.0231**	0.0111	0.037
Index measuring the absolute difference in relative RFG market sizes ($I_{2,RFG,it}$)	0.0007	0.0011	0.495
Index measuring the absolute difference in relative OXY market sizes ($I_{2,OXY,it}$)	0.0017***	0.0005	0.000
California dummy variable	0.0360	0.0222	0.106
January (reference case)	-	-	-
February	0.0221**	0.0098	0.024
March	0.0937***	0.0105	0.000
April	0.0985***	0.0086	0.000
May	0.1586***	0.0086	0.000
June	0.1981***	0.0161	0.000
July	0.1140***	0.0099	0.000
August	0.1161***	0.0107	0.000
September	0.1027***	0.0109	0.000
October	0.0894***	0.0104	0.000
November	0.0537***	0.0103	0.000
December	0.0524***	0.0089	0.000
Number of observations			4,114
Overall R-squared			0.91
F-test that $\alpha_i = 0 \forall i$		F(48, 3975) = 112.25	
		Prob>F = 0.000	

Note: *, ** and *** denote significance at 10, 5 and 1% levels, respectively.

Table 6. Testing for Differences in Transportation Costs between PADDs

	Estimated coefficient	Corrected Standard Error	p-value
Crude oil price (log)	0.7716***	0.0121	0.000
Refinery capacity per capita in the state (log)	-0.0041	0.0028	0.148
Measure of concentration in the refinery sector in the state (log)	0.1706**	0.0845	0.044
Relative size of RFG market in the state	0.0490**	0.0199	0.014
Relative size of OXY market in the state	0.0230**	0.0111	0.039
Index measuring the absolute difference in relative RFG market sizes ($I_{2,RFG,it}$) – PADDs 1 and 2	0.0010	0.0010	0.335
Index measuring the absolute difference in relative RFG market sizes ($I_{2,RFG,it}$) – PADDs 3, 4 and 5	0.0005	0.0017	0.774
Index measuring the absolute difference in relative OXY market sizes ($I_{2,OXY,it}$) – PADDs 1 and 2	0.0019***	0.0005	0.000
Index measuring the absolute difference in relative OXY market sizes ($I_{2,OXY,it}$) – PADDs 3, 4 and 5	0.0015*	0.0009	0.080
California dummy variable	0.0342	0.0253	0.175
Test of parameter equality for $I_{2,RFG,it}$ and $I_{2,OXY,it}$:			
$I_{2,RFG,it}$: Fisher statistic = 0.24 (Prob > F = 0.6244)			
$I_{2,OXY,it}$: Fisher statistic = 0.25 (Prob > F = 0.6199).			

Note: *, ** and *** denote significance at 10, 5 and 1% levels, respectively.

Table 7(a). Simulation results for each state. Scenario 1. Base year: 2002

					Decomposition of the price differential (¢/gallon)			
State	PADD	Share of population under RFG	Share of population under OXY	Price differential (¢/gallon)	Cost effect – RFG production	Cost effect – no OXY production	Segmenta-tion effect – RFG production	Segmenta-tion effect – no OXY production
Alabama	3	0.00	0.00	4.10	4.10	0.00	0.00	0.00
Alaska	5	0.00	0.18					
Arizona	5	0.57	0.24	1.26	1.78	-0.43	-0.02	-0.07
Arkansas	3	0.00	0.00	3.32	4.14	0.00	-0.48	-0.35
California	5	1.00	0.20	0.00	0.00	0.00	0.00	0.00
Colorado	4	0.00	0.20	3.20	4.15	-0.36	-0.45	-0.14
Connecticut	1	0.98	0.10	-0.13	0.08	-0.17	-0.02	-0.02
Delaware	1	0.98	0.00	-0.08	0.09	0.00	-0.03	-0.14
District of Col.	1	0.95	0.00	0.19	0.21	0.00	-0.02	0.00
Florida	1	0.00	0.00	4.05	4.05	0.00	0.00	0.00
Georgia	1	0.00	0.00	4.13	4.13	0.00	0.00	0.00
Hawaii	5	0.00	0.00					
Idaho	4	0.00	0.00	3.50	4.07	0.00	0.00	-0.58
Illinois	2	0.63	0.00	1.46	1.53	0.00	-0.06	0.00
Indiana	2	0.11	0.00	3.62	3.67	0.00	-0.05	0.00
Iowa	2	0.00	0.00	2.65	4.12	0.00	-0.49	-0.98
Kansas	2	0.00	0.00	3.37	4.12	0.00	-0.44	-0.31
Kentucky	2	0.26	0.00	3.03	3.04	0.00	-0.01	0.00
Louisiana	3	0.00	0.00	2.92	3.70	0.00	-0.44	-0.34
Maine	1	0.00	0.00	3.55	4.07	0.00	-0.52	0.00
Maryland	1	0.88	0.00	0.43	0.48	0.00	-0.05	0.00
Mass.	1	0.99	0.00	-0.34	0.06	0.00	-0.02	-0.38
Michigan	2	0.00	0.00	3.78	4.14	0.00	-0.36	0.00
Minnesota	2	0.00	0.56	1.37	4.22	-1.10	-0.47	-1.29
Mississippi	3	0.00	0.00	4.08	4.08	0.00	0.00	0.00
Missouri	2	0.35	0.00	2.64	2.66	0.00	-0.02	0.00
Montana	4	0.00	0.03	3.74	4.09	-0.06	0.00	-0.29
Nebraska	2	0.00	0.00	3.35	4.08	0.00	-0.43	-0.30
Nevada	5	0.00	0.37	2.83	4.20	-0.68	-0.56	-0.13
N. Hampshire	1	0.59	0.00	1.66	1.68	0.00	-0.02	0.00
New Jersey	1	0.98	0.12	-0.36	0.08	-0.18	-0.04	-0.22
New Mexico	3	0.00	0.10	3.30	4.13	-0.17	-0.49	-0.17
New York	1	0.64	0.21	1.03	1.49	-0.36	0.00	-0.09
N. Carolina	1	0.00	0.00	3.60	4.07	0.00	-0.47	0.00
North Dakota	2	0.00	0.00	2.92	4.14	0.00	0.00	-1.22
Ohio	2	0.00	0.00	3.67	4.11	0.00	-0.45	0.00
Oklahoma	2	0.00	0.00	3.15	4.04	0.00	-0.47	-0.41
Oregon	5	0.00	0.17	3.03	4.10	-0.29	-0.54	-0.24
Pennsylvania	1	0.30	0.00	2.49	2.88	0.00	-0.04	-0.35
Rhode Island	1	0.97	0.00	-0.18	0.12	0.00	0.00	-0.30
S. Carolina	1	0.00	0.00	4.05	4.05	0.00	0.00	0.00
South Dakota	2	0.00	0.00	2.98	4.10	0.00	0.00	-1.12
Tennessee	2	0.00	0.00	3.67	4.12	0.00	-0.45	0.00
Texas	3	0.43	0.02	1.46	2.08	-0.03	-0.45	-0.14
Utah	4	0.00	0.08	3.28	4.07	-0.13	-0.45	-0.21
Vermont	1	0.00	0.00	3.20	4.09	0.00	-0.54	-0.36
Virginia	1	0.59	0.00	1.66	1.72	0.00	-0.06	0.00
Washington	5	0.00	0.04	3.74	4.04	-0.07	0.00	-0.24
West Virginia	1	0.00	0.00	3.64	4.14	0.00	-0.50	0.00
Wisconsin	2	0.34	0.00	1.69	2.77	0.00	-0.01	-1.08
Wyoming	4	0.00	0.00	3.73	4.07	0.00	0.00	-0.33
Average		0.25	0.06	2.52	3.04	-0.08	-0.20	-0.24

Table 7(b). Simulation results for each PADD. Scenario 1. Base year: 2002

				Decomposition of the price differential (¢/gallon)			
PADD	Share of population under RFG program	Share of population under OXY program	Price differential (¢/gallon)	Cost effect – RFG production	Cost effect – no OXY production	Segmentation effect – RFG production	Segmentation effect – no OXY production
1	0.49	0.02	1.81	2.08	-0.04	-0.13	-0.10
2	0.11	0.04	2.89	3.66	-0.07	-0.25	-0.45
3	0.07	0.02	3.20	3.71	-0.03	-0.31	-0.17
4	0.00	0.06	3.49	4.09	-0.11	-0.18	-0.31
5	0.22	0.17	2.17	2.82	-0.29	-0.22	-0.14

Table 8(a). Simulation results for each state. Scenario 2. Base year: 2002

					Decomposition of the price differential (¢/gallon)			
State	PADD	Share of population under RFG	Share of population under OXY	Price differential (¢/gallon)	Cost effect – no RFG production	Cost effect – OXY production	Segmentation effect – no RFG production	Segmentation effect – OXY production
Alabama	3	0.00	0.00	1.95	0.00	1.95	0.00	0.00
Alaska	5	0.00	0.18	0.00				
Arizona	5	0.57	0.24	-0.83	-2.29	1.55	-0.02	-0.07
Arkansas	3	0.00	0.00	1.15	0.00	1.97	-0.48	-0.35
California	5	1.00	0.20	0.00	0.00	0.00	0.00	0.00
Colorado	4	0.00	0.20	1.01	0.00	1.61	-0.45	-0.14
Connecticut	1	0.98	0.10	-2.17	-3.98	1.85	-0.02	-0.02
Delaware	1	0.98	0.00	-2.12	-3.99	2.03	-0.03	-0.14
District of Col.	1	0.95	0.00	-1.84	-3.84	2.01	-0.02	0.00
Florida	1	0.00	0.00	1.92	0.00	1.92	0.00	0.00
Georgia	1	0.00	0.00	1.96	0.00	1.96	0.00	0.00
Hawaii	5	0.00	0.00	0.00				
Idaho	4	0.00	0.00	1.36	0.00	1.94	0.00	-0.58
Illinois	2	0.63	0.00	-0.60	-2.51	1.98	-0.06	0.00
Indiana	2	0.11	0.00	1.48	-0.42	1.95	-0.05	0.00
Iowa	2	0.00	0.00	0.49	0.00	1.96	-0.49	-0.98
Kansas	2	0.00	0.00	1.21	0.00	1.96	-0.44	-0.31
Kentucky	2	0.26	0.00	0.91	-1.05	1.97	-0.01	0.00
Louisiana	3	0.00	0.00	0.98	0.00	1.76	-0.44	-0.34
Maine	1	0.00	0.00	1.42	0.00	1.94	-0.52	0.00
Maryland	1	0.88	0.00	-1.61	-3.57	2.01	-0.05	0.00
Massachusetts	1	0.99	0.00	-2.38	-4.01	2.03	-0.02	-0.38
Michigan	2	0.00	0.00	1.61	0.00	1.97	-0.36	0.00
Minnesota	2	0.00	0.56	-0.87	0.00	0.89	-0.47	-1.29
Mississippi	3	0.00	0.00	1.94	0.00	1.94	0.00	0.00
Missouri	2	0.35	0.00	0.55	-1.39	1.96	-0.02	0.00
Montana	4	0.00	0.03	1.59	0.00	1.89	0.00	-0.29
Nebraska	2	0.00	0.00	1.21	0.00	1.94	-0.43	-0.30
Nevada	5	0.00	0.37	0.61	0.00	1.30	-0.56	-0.13
N. Hampshire	1	0.59	0.00	-0.41	-2.37	1.98	-0.02	0.00
New Jersey	1	0.98	0.12	-2.41	-3.99	1.85	-0.04	-0.22
New Mexico	3	0.00	0.10	1.13	0.00	1.79	-0.49	-0.17
New York	1	0.64	0.21	-1.05	-2.58	1.63	0.00	-0.09
North Carolina	1	0.00	0.00	1.47	0.00	1.94	-0.47	0.00
North Dakota	2	0.00	0.00	0.75	0.00	1.97	0.00	-1.22
Ohio	2	0.00	0.00	1.51	0.00	1.96	-0.45	0.00
Oklahoma	2	0.00	0.00	1.03	0.00	1.92	-0.47	-0.41
Oregon	5	0.00	0.17	0.87	0.00	1.66	-0.54	-0.24
Pennsylvania	1	0.30	0.00	0.37	-1.23	1.98	-0.04	-0.35
Rhode Island	1	0.97	0.00	-2.22	-3.94	2.02	0.00	-0.30
South Carolina	1	0.00	0.00	1.92	0.00	1.92	0.00	0.00
South Dakota	2	0.00	0.00	0.83	0.00	1.95	0.00	-1.12
Tennessee	2	0.00	0.00	1.51	0.00	1.96	-0.45	0.00
Texas	3	0.43	0.02	-0.39	-1.52	1.72	-0.45	-0.14
Utah	4	0.00	0.08	1.14	0.00	1.80	-0.45	-0.21
Vermont	1	0.00	0.00	1.05	0.00	1.95	-0.54	-0.36
Virginia	1	0.59	0.00	-0.44	-2.40	2.02	-0.06	0.00
Washington	5	0.00	0.04	1.61	0.00	1.86	0.00	-0.24
West Virginia	1	0.00	0.00	1.47	0.00	1.97	-0.50	0.00
Wisconsin	2	0.34	0.00	-0.47	-1.40	2.02	-0.01	-1.08
Wyoming	4	0.00	0.00	1.60	0.00	1.93	0.00	-0.33
Average		0.25	0.06	0.43	-0.95	1.84	-0.20	-0.24

Table 8(b). Simulation results for each PADD. Scenario 2. Base year: 2002

				Decomposition of the price premium (¢/gallon)			
PADD	Share of population under RFG program	Share of population under OXY program	Price difference (¢/gallon)	Cost effect – no RFG production	Cost effect – OXY production	Segmentation effect – no RFG production	Segmentation effect – OXY production
1	0.49	0.02	-0.28	-1.99	1.94	-0.13	-0.10
2	0.11	0.04	0.74	-0.45	1.89	-0.25	-0.45
3	0.07	0.02	1.13	-0.25	1.86	-0.31	-0.17
4	0.00	0.06	1.34	0.00	1.83	-0.18	-0.31
5	0.22	0.17	0.32	-0.46	1.27	-0.22	-0.14