Price Effects of Boutique Motor Fuels: Federal Environmental Standards, Regional Fuel Choices, and Local Gasoline Prices

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Federal clean air regulations have spawned a proliferation of motor fuel types that have created differentiated markets for motor fuels, increased the cost of supplying these fuels, and reduced the capacity of the supply infrastructure. In this paper we examine wholesale gasoline prices in 99 US cities over a time horizon of 204 weeks using a panel data regression model to explain fuel prices as a function of fuel attributes, the price of crude oil, and seasonal and city-market-specific effects. Our results show that fuel prices are related to the use of a special blend not widely available in the region and more costly to make, and the situation of the particular city market in relation to major refining centers or other sources of supply.

1. INTRODUCTION

High and continuing levels of air pollution in major urban centers and more stringent air quality standards have led the US federal government and some states to implement strategies to reduce emissions of pollutants. In particular ground-level ozone has been identified as a pollutant having negative health impacts and, because vehicles are important emitters of the chemical precursors to the formation of ground-level ozone, federal and state efforts to reduce pollution have included reductions in vehicular emissions. In addition to federally mandat-

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ed reductions in the allowable emissions from newer vehicles, which have led to changes in engine technology and the design of vehicles, the federal government has mandated the use of a particularly stringent blend of gasoline—known as federal reformulated gasoline or RFG—in areas that are in extreme non-attainment of the National Air Quality Standards.

Due to the high cost of producing RFG, in many instances the states and localities, in collaboration with refiners, have adopted unique fuels—sometimes referred to as boutique fuels—not widely used in adjacent markets; these boutique fuels address pollution concerns in the local market while being less costly to produce than federal RFG. In effect this has created differentiated markets for motor fuels and this, in turn, has increased the cost of supplying these fuels while at the same time reducing the capacity of the supply infrastructure. More highly differentiated markets, higher refining costs and reduced capacity in the supply infrastructure might all be expected to cause gasoline prices to rise, perhaps differentially so for areas that use more costly or more unique motor fuels.

In this paper we examine wholesale gasoline prices in 99 US cities using a panel data regression model to explain fuel prices as a function of fuel attributes, the price of crude oil, and seasonal and city-market-specific effects.[1] The specific contribution of our paper is to disentangle city-market-specific effects from fuel attributes in the determination of wholesale gasoline prices; the statistical model accounts for the variation across cities as well as the variation in a city in response to changes in fuel attributes through time and across cities.[2] Our results show that fuel prices are related to the use of special blends that are not widely available within a region and are more costly to make, and the proximity of the particular city market to major refining centers and alternative sources of supply.

2. ENVIRONMENTAL STANDARDS AND FUEL-TYPE PROLIFERATION

The Clean Air Act as amended authorizes the EPA to set National Ambient Air Quality Standards (NAAQS) and to enforce these standards to reduce negative health effects of air pollution. EPA has set NAAQS for six pollutants; namely ozone, particulate matter, carbon monoxide, nitrogen dioxide, sulfur di-

1. The energy literature is replete with papers that have quantified the demand for gasoline, gasoline demand in response to price spikes, and the asymmetric response of gasoline prices to changes in crude oil prices (see, for example, the summary of gasoline demand provided in the survey articles of Dahl (1986) and Dahl and Sterner (1991) and the papers on asymmetric price response by Bacon (1991), Galeotti (2003), and Radchenko (2005)). The published literature on gasoline demand does not go far in relating the price of gasoline to the particular attributes of fuels and the markets in which they are sold. In one of the few published papers that does touch on this point, Taylor and Fischer (2003) find that higher prices are related to the higher refining costs in their study of wholesale gasoline prices on the West Coast of the U.S.

2. Our research complements a number of other concurrent working papers, namely Muehlegger's (2004), Chakravorty and Nauges (2005), and Brown, Hastings, Mansur, and Villas-Boas (2006). We discuss our paper's model and results in relation to the other papers below.

oxide, and lead. However, because ozone is not directly emitted but is formed in a chemical reaction when volatile organic compounds (VOCs) and nitrogen oxides (NO_x) mix in the presence of heat and sunlight, emissions of VOCs and NO_x are also considered by EPA as primary targets for reductions.

Every state that has areas that are in nonattainment with NAAQS is required under the Clean Air Act to develop a state implementation plan (SIP) to identify how the state intends to bring these areas into attainment. States have wide discretion in how they plan to reduce pollution in nonattainment areas. For example, they can reduce emissions from stationary sources such as power plants or nonstationary sources such as automobiles. Because many stationary sources of pollution had been targeted in the past, and automobiles emit significant proportions of ambient VOCS, NO_x and carbon monoxide, the EPA and states have focused a lot of attention on vehicle emissions in the past 15 years.

States' adoption and EPA approval of cleaner-burning motor fuel blends has largely occurred without consideration of the effects on regional or national motor fuels markets. In discussions with state and federal regulators and with refiners and industry consultants, the authors confirmed the details of the decentralized process through which special fuels are introduced: States considering adoption of a cleaner-burning motor fuel typically approached a refiner in their region or an industry consultant to determine what it would cost to refine a special fuel blend. Based on the differential costs of refining cleaner-burning fuels and on models that predicted the emissions reductions the targeted areas would achieve if such fuels were used, states then included the most "cost effective" special fuel blend in their SIP. EPA approved these plans without considering the impacts of the proliferation of such fuel blends on overall fuel prices and price volatility.[3]

The result of this process has been a proliferation of special motor fuel blends that conform to state and local boundaries as opposed to regional or market boundaries.[4] The primary ways in which gasoline blends vary are described in Table 1 and a list of the various gasoline blends currently used including, conventional gasolines, reformulated gasoline, and California Air Resources Board (CARB) gasoline, can be found in Table 2.

It is typical for areas using special gasoline blends to be surrounded by regions that use conventional gasoline (see Figure 1). In some cases, these areas are relatively large, as is the case for the state of California, where nearly all of the state uses one of two fuels. In other cases, "islands" of special gasoline use can divide otherwise regional gasoline markets. For example, in the St. Louis metropolitan area—which includes parts of the states of Missouri and Illinois—three different fuels are used: one special gasoline blend required on the Missouri side, a different special gasoline blend required on the Illinois side, and conventional gas-

3. According to the EPA, it is currently authorized to approve state applications to use cleaner-burning motor fuels but does not have authority to condition its approval on the basis of any adverse impacts such fuels may have on the overall market. For more details on this point, see GAO (2005).

4. See Muehlegger (2002) for a detailed summary of gasoline content regulation.

Table 1. Fuel Attributes and Additives

Term	Description
Oxygenate	One or more combustible liquids which contain oxygen. Emissions regulations require gasoline to be oxygenated during the winter in areas that have a carbon monoxide pollution problem (cold weather and atmospheric inversions). Oxygenates help engines run leaner so they emit less carbon monoxide.
RVP	Reid vaporization pressure. Pressure of confined vapor in equilibrium with its liquid at a specified temperature; a measure of a liquid's volatility; used to quantify seasonal performance (e.g., higher volatility is needed in cold weather, and lower volatility in hot weather) and evaporative loss.
MTBE	Methyl tertiary-butyl ether; originally used to raise the octane of gasoline; now primarily used to raise the oxygen content of gasoline, i.e. it is an oxygenate.
Ethanol	Also known as ethyl alcohol (C_2H_5OH); used as an oxygenate.

Table 2. Primary Types of Gasoline

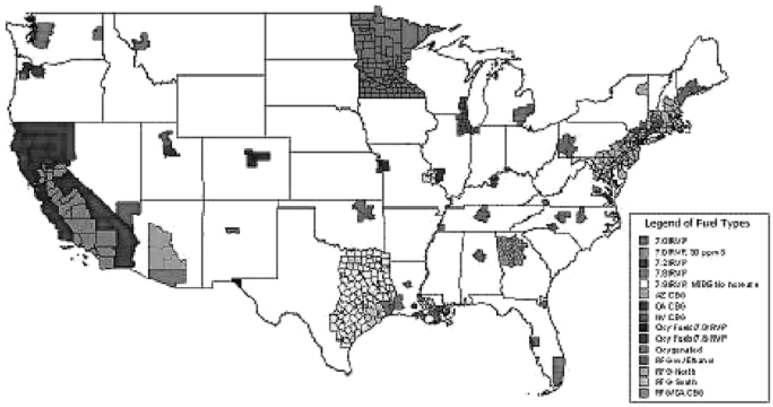
Fuel Type	Description
Conventional	The most widely available gasoline; used where air quality is satisfactory; formulated to evaporate more slowly in hot weather with RVP limits; contains detergent additives to reduce engine deposits.
RFG	Reformulate gasoline; mandated in areas where air quality is persistently unsatisfactory; contains oxygenates.
CARB	California Air Resources Board RFG; a different formulation of RFG that burns cleaner than regular RFG. After 2002 MTBE no longer used as oxygenate in CARB RFG due to concerns over MTBE contaminating ground water.
Low Sulfur	Gasoline with a low sulfur content and low RVP. Originally mandated for Atlanta and now used in many Georgia counties.

oline is allowed in the surrounding areas.[5] In some cases, special gasoline blends are used in only one area of the country. For example, variants of CARB gasoline used in California and Arizona and the special blend used in the Atlanta area are not used anywhere else in the United States. Even relatively common special gasoline blends can create isolated markets if they are not used in nearby areas. For example, although 7.8 RVP is the most widely used special blend of gasoline, Pittsburgh, Pennsylvania, is the only city in its region that uses it. Similarly, the Chicago/Milwaukee area uses RFG North with ethanol, a gasoline blend used in the Northeast, but not used elsewhere in the Midwest.

Special gasoline blends accounted for more than half the gasoline consumed in the United States during the summer of 2001—the last year for which complete data are publicly available. Of the special fuel blends, RFG and 7.8 RVP blends together accounted for about 33 percent of the national gasoline market. California and Arizona gasoline blends accounted for roughly 13 percent of total

5. Each state is overseen by a separate EPA regional office; Missouri is overseen by EPA region 7 and Illinois is overseen by EPA region 5.

Figure 1. Map of Special Fuel Use



U.S. gasoline consumption. The remaining 6 percent of gasoline use was divided among four separate blends.

While there were 11 special blends of gasoline during the summer of 2004, more than 45 gasoline blends were sold in the United States throughout the year. Special winter-only gasoline blends are required to be used in areas of 8 states; these blends contain an oxygenate to address winter carbon monoxide pollution. And because many gasoline stations sell gasoline in three octane grades there is also a doubling of fuels.[6] Thus, pipelines, terminals, and retailers carry multiple variations of the gasoline blends. Gasoline blends also differ regionally and seasonally and this is independent of fuel content regulation: Differences in outside temperature require different blends to maintain vehicle performance. The primary difference among these blends is RVP. Refiners produce gasoline with higher RVP in cold conditions to allow cars to start, and gasoline with lower RVP during warm conditions to improve vehicle operation, even in areas that use conventional gasoline. As a result of these differences, refiners routinely ship different fuels to different regions and also ship different gasoline blends seasonally. Special blends of cleaner burning fuels compound these variations.

Prior to 1990, the refining industry in the United States was asked to produce a largely fungible type of gasoline. While the Reid vaporization pressure varied regionally and seasonally to accommodate vehicle engine performance, these changes were fairly simple to make from a refining perspective and had only minor implications for distribution and storage. For example, if two batches of gasoline that differ by several pounds RVP interfaced in a pipeline during shipping, the resulting blended fuel at the interface could simply be mixed with the higher RVP fuel—a process called "downgrading." Because mixing this small interface had little effect on engine performance, it created no major problems for shippers. Similarly, when

6. Both premium and regular grades are refined and shipped to terminals, where they are blended together to make mid-grade gasoline.

Table 3. Emissions Reductions Estimates for Special Gasoline Blends

	Pollutant[a]		
Gasoline Blend	**VOC**	**NO_x**	**CO**
Conv. RVP 7.8	12 to 16%	0.7%	none
Conv. RVP 7.2	19 to 23%	0.7%	none
Conv. RVP 7.0	21 to 25%	0.7%	none
Federal RFG	25 to 29%	0.7%	10 to 20%
CARB RFG	25 to 29%	5.7%	no estimate[b]

Notes:

a. Emissions reductions are based on reductions from conventional 9.0 RVP gasoline projected to be in use in calendar year 2006. VOC—volatile organic compounds. NO_x—oxides of nitrogen. CO—carbon monoxide.

b. EPA estimated VOC and NO_x emissions reductions for California CBG and RFG CA/CBG (which includes an oxygenate) were the same for these pollutants, however RFG CA/CBG would likely provide some reduction of CO, in addition.

RVP changed to match seasonal temperature variations, the new gasoline could simply be pumped into the same storage tanks as the old gasoline without thoroughly clearing the system of the old. The resulting blend simply acted as a transitional fuel until the mixed blend was used up and the new fuel completely replaced it.

Since 1990, the proliferation of new fuel blends and the legal requirements to use fuels within strict specifications in some areas has required large investments in refinery upgrades, caused or sped up the closing of many small refineries that could not make the switch to producing more stringent gasoline blends, and reduced the capacity of the nation's shipping and storage infrastructure. With regard to the refining industry, producing many of the gasoline blends—as well as removing increasing amounts of sulfur from diesel and gasoline—has required large new investments in refinery upgrades. For example, the Energy Information Administration estimates that the costs of refining California's CARB gasoline costs between 5–15 cents per gallon more than conventional gasoline. A by-product of this investment has been the closure of many small, less complex, refineries that could not economically make the switch to producing cleaner burning fuels.[7] While many of these closures may have occurred eventually due to their higher incremental costs of production, the introduction of cleaner burning fuels clearly accelerated this disinvestment and reduced total refining capacity in the process.[8]

7. Chakravorty and Nauges (2005) and Brown, Hastings, Mansur, and Villas-Boas (2005) argue that the decrease in the number of suppliers has increased their market power, partially explaining the increase in prices in the markets using boutique fuels.

8. It is important to note that many of the refineries that invested in new processes to produce cleaner burning fuels also took advantage of this build-up to install additional capacity on their existing refining sites. This has been called capacity creep by the industry to distinguish it from investment in an entirely new "grassroots" refinery, something that has not happened since the 1970s in the United States. Also, there is evidence in the literature that refinery investments made to meet stringent environmental regulations have actually enhanced productivity (Berman and Bui, 2001). We are indebted to a referee for this point.

The shipping and storage capacity for fuels has also been reduced by the proliferation of fuels and because the different specifications are now a matter of legal requirement rather than simply to optimize engine performance. For example, the shipping of smaller, incompatible blends of gasoline have increased the numbers of interfaces of fuels in the pipeline system. In addition, because in many cases the fuel specifications for different special blends of gasoline do not allow simply downgrading the more stringent fuel into the less stringent fuel, more of the interfaces create "transmix" that must be pulled out of the system and reprocessed before sale. Another effect of shipping larger numbers of smaller batches of fuel has been to reduce the speed of the pipeline. This slower speed is the result of pipelines having to keep more types of fuel segregated in storage terminals that were designed and built to accommodate a more fungible product. During shipping, tank terminals are routinely used to segregate fuels during shipping and to consolidate fungible batches as specific batches are pulled off for delivery to specific locations.

Most of the terminal storage was built when gasoline was largely fungible and it was routine to be pumping gasoline into and out of a single large-capacity tank to optimize the operation of the pipeline while simultaneously removing product for delivery. Now, smaller batches of fuel that must be segregated from all other fuels in the pipeline must be pulled off into tanks designed to handle an order of magnitude larger batch and held there until it can be delivered to retail outlets. The pipeline must also be operated at a slower speed to facilitate pulling off these smaller batches at precisely the correct destination. In some cases, missing a batch at its destination requires pulling the product off the system at the next terminal and trucking it back to a location that can use it. This is the case for gasoline with MTBE additive used in Texas and Oklahoma but not allowed in markets north of Tulsa.[9] Reduced storage capacity and slower pipeline speeds directly raise the per-unit shipping and delivery costs and the increase in transmix raises refining costs per unit and further stresses the storage capacity.

3. STATISTICAL ANALYSIS OF FUEL PRICES

3.1 Data Description

Wholesale gasoline prices were obtained from the Oil Price Information Service (OPIS) for ninety-nine cities in the United States; in industry parlance these are referred to as *rack prices*. The price data are weekly observations on each type of fuel sold at each city over the interval from 7th December 2000 to 28th October 2004. The sample of data includes cites that use conventional gasoline as well as those that use special fuels. In our empirical analysis, we also control for

9. Pipeline operators told the authors of an instance of a batch of MTBE oxygenated fuel destined for Tulsa that could not be offloaded in Tulsa because sufficient storage capacity was not available. The pipeline had to be shut down while tanks were emptied before the fuel could be offloaded and the pipeline restarted.

the weekly price of West Texas Intermediate (WTI) crude oil—the material primary input in refining gasoline; the WTI price series was obtained from Platts.

Using the OPIS data, we constructed a single price series for each city that represents the price of the fuel actually used in that city in a particular week. For example, the OPIS data lists numerous fuel prices for a city such as Houston, which is a major refining center at a major pipeline hub, but the city price we refer to in our analysis of Houston will be for the particular reformulated gasoline mandated for use in that city at that calendar date. Because the fuel required varies across summer and winter seasons—and because the fuel regulations are varying across years in some cities—the price series for each city will typically represent multiple fuels. This variation in fuels within city markets as well as across city markets provides the richness present in our data set and the opportunity to analyze it using statistical methods designed for analyzing time series of cross-sectional observations.

With regard to uncommon or unique special gasoline blends, the data show that cities using relatively less common or more stringent blends of gasoline typically have higher prices than do cities using more common or less stringent blends.[10] For example, the five California cities in the data set are all in the top 20 cities with respect to gasoline prices. California's fuel is the cleanest burning fuel and in order to make it, California's refineries have invested billions of dollars in new processes. Further, only a few refineries outside of California routinely make California gasoline, the closest being in Northern Washington. This uniqueness of California's gasoline has been noted by many sources as contributing to California's higher and more volatile gasoline prices relative to the rest of the country: The five California cities we examined had average prices that ranged from about 24 to 26 cents per gallon higher than the city with the lowest price, Beaumont, Texas, which uses conventional gasoline and is located near the large refining center in the Gulf Coast. Another factor that appears to affect gasoline price is distance from major refining centers. Many of the cities having the highest prices are far from refining centers or are served by few and/or small pipelines.

Adding ethanol to gasoline also appears to correspond with higher wholesale gasoline prices. For example, for the nation as a whole, average prices for conventional gasoline with ethanol were about 4 cents per gallon higher than conventional without ethanol over the time period we analyzed. The switch from using ethanol as opposed to MTBE was also associated with higher gasoline prices. For example, in the years 2001–2003, during which California phased out the use of MTBE and phased in the use of ethanol, the average summer price of gasoline with ethanol was between about 4 and 8 cents per gallon more than the price of gasoline with MTBE. Similarly, over the period 2001–2004, the average summer price for federal reformulated gasoline with ethanol was between about 6 and 13 cents per gallon more than for federal reformulated gasoline with MTBE.

In contrast to the high-price cities, cities having the lowest average wholesale gasoline prices over the period typically used common gasoline blends and/or

10. A more detailed description of the data, including many descriptive statistics on price levels and the dispersion of prices, is presented in Ludwigson, Rusco and Walls (2005).

were located near a major refining center-most often near the Gulf Coast, the largest refining center in the country in terms of both numbers of refineries and total refining capacity. For example, among the 20 cities with the lowest prices, 8 use conventional gasoline which is the most widely available gasoline blend. Conventional gasoline is used widely across the United States and most cities that use it are surrounded by other areas using the same fuel. Another 9 cities among those with the lowest prices use 7.8 RVP gasoline—7.8 RVP gasoline is the least stringent and most widely used of the special blends. Most of the 7.8 RVP gasoline is used in areas close to the Gulf Coast refining center. In addition, refiners told us that making 7.8 RVP gasoline is simpler and less costly than some of the more stringent blends, which may make it more available from refineries in the event there is a local supply shortfall. The other three cities use less common special blends but are all close to the largest refining center, the Gulf Coast, and therefore have many more potential supply options than do more isolated cities. Overall, the wide use, simplicity and lower cost of refining conventional and 7.8 RVP, and the proximity to major refining centers are factors that would reduce isolation of cities.

Similar results obtain with regard to the volatility of gasoline prices where we measured volatility for each city as the standard deviation across time of the city price minus the price of West Texas Intermediate crude oil.[11] In general, we found that prices tended to be more volatile in isolated cities. Specifically, 18 of the 20 cities with the most volatile prices use special blends of gasoline. In contrast to the cities with relatively high price volatility, 17 of 20 cities with the lowest volatility use either conventional or 7.8 RVP gasoline.

3.2 Econometric Modeling

The basic statistical model for the empirical analysis is a reduced-form specification that relates the price level for gasoline in each city *i* during a particular week *t* to the price of West Texas intermediate (WTI) crude oil, the distance measured in miles to the closest alternative supply location that uses the particular fuel in that week, the attributes of the particular fuel, a set of season-specific variables, and city-market-specific effects α_i.[12] Algebraically the regression model can be expressed as

$$\text{Price}_{it} = \alpha_i + \beta_1\ \text{WTI}_t + \beta_2\ \text{Distance-to-Substitute}_{it} + \theta'\ \text{Fuel Attributes}_{it} + \psi'\ \text{Seasonality}_t + \mu_{it} \quad (1)$$

11. For brevity we have not reproduced here these tables of descriptive statistics, each of which can take multiple pages to display. Because the focus of the econometric model is on price levels, the data description also focuses mostly on price levels. The interested reader is referred to the appendix of GAO (2005) for the tables corresponding to the narrative in the text.

12. We take the price of West Texas intermediate crude oil to be exogenously determined. Crude oil prices, up to quality and transportation differentials, are determined in the world oil market (Horsnell and Mabro, 1993). For this reason, we are not particularly concerned about city-specific shocks in gasoline prices affecting the world price of oil. In any case, estimates of the model are nearly the same when using WTI_{t-1} as an instrument for WTI_t.

where the Distance-to-Substitute variable is the distance measured in miles to the closest source of a substitutable fuel, and μ_{it} is the random disturbance for city *i* in week *t*.[13] The statistical model is a reduced-form specification that quantifies the joint distribution of equilibrium wholesale gasoline prices across cities; it is not a structural demand nor supply equation. The purpose of the present statistical analysis is to explain the equilibrium level of fuel prices in relation to city-market-specific effects and fuel-specific effects, and for this purpose a reduced-form model is appropriate.[14] We estimate several variations of this particular model in levels and we also estimate the model in logarithms.[15]

We first estimate the basic model in levels for a common intercept specification where $\alpha_i=\alpha$ for each city market *i*, a fixed-effects specification where each city market *i* has a fixed effect α_i, and as a variance components or random-effects model where the α_i are assumed to be drawn from a distribution; the estimates of these three specifications are displayed in the first three columns of Table 4.[16] We can reject the hypothesis of a common intercept term (*i.e.* no city-market-specific effects) at a marginal significance level of practically zero.[17]

The second and third columns of Table 4 display the estimates for the fixed-effects and random-effects (*aka* variance components) specifications. In each of these specifications a separate city-market-specific effect is estimated for each city, but the specifications differ in whether the city effect is modeled as being predetermined or random. In the random-effects formulation, we can make statistical inferences that are unconditional with respect to the population of all possible city-specific effects while in the fixed-effects formulation we can make

13. We allow the random disturbance to follow a first-order autoregressive process in our empirical implementation below. Also, we investigate the model when the city-market-specific effects ai are treated as predetermined as well as random in our empirical analysis below. All specifications are estimated in levels and in logarithms.

14. A structural model would be required to analyze consumer behavior (demand) or firm behavior (supply) in the gasoline market. Muehlegger (2004) provides an econometric analysis of firm-level behavior in the gasoline market and Chakravorty and Nauges (2005) examine the role of investigate the impact of gasoline content regulation on gasoline prices using OPIS data boutique fuels in creating market power. Brown, Hastings, Mansur, and Villas-Boas (2006) but using a treatment and control methodology to isolate the effect of content regulations on price levels as well as price volatility. Only Muehlegger (2004) develops a structural behavioral model.

15. Note that while we can control for city-market-specific effects, we can not include city-specific variables on demographics or other characteristics if those variables are constant within a city across the sample. Within the span of weekly observations in the data, city-specific demographics derived from census data do not vary, so they are perfectly collinear with the city-specific indicator already included in the analysis. Also, we cannot model weekly volatility since we observe the price level with weekly frequency. We can measure volatility over a period of many weeks, as we did in the data description section, but we can not use this as an input in the weekly panel data model; this type of volatility measure could be used in a cross-section regression and this is the approach taken by Brown, Hastings, Mansur, and Villas-Boas (2006) in one of their auxiliary regressions.

16. We also estimated White's (1980) heteroscedasticity-consistent standard errors in our analysis, but in the interest of making the tables of results more readable we have chosen not to reported them since they were nearly identical to the traditional standard error estimates.

17. The likelihood-ratio test statistic for excluding the city-specific constants, which is distributed Chi-squared with 98 degrees of freedom, is 4000.34.

statistical inferences that are conditional on the city-specific effects in the sample (Hsiao, 1986). In practice this can be a thorny issue because the estimates from fixed-effects and random-effects models can differ significantly in the commonly observed case where a large number of cross-sectional units are observed over a small number of time periods (Hausman, 1978). Given the context of our analysis, it is sensible for us to make statistical inferences conditional on the city-market-specific effects in the sample, as they are likely to remain fixed for the 99 cities and not be randomly reassigned; however, for completeness we investigate the random-effects formulation. Fortunately, in our data set we observe prices across 99 cities for 204 weeks, and the effect of having a large number of time observations for the cross-sectional units is that the fixed-effects and random-effects estimates are nearly identical.

A final refinement to the model is to correct for serial correlation. The Durbin-Watson test statistic indicates the presence of first-order serial correlation, which is to be expected in each city's time series of gasoline prices. The final column of Table 4 displays the estimates of the fixed-effects model with the inclusion of a first-order autoregressive random disturbance term.[18] We now examine the coefficient estimates in detail; we have estimated the model in levels as well as in logarithms, with the log-linear results displayed in Table 5. Because the model estimated in logarithms yields essentially the same results qualitatively, we will focus our discussion on the estimates obtained from the price-level model.

Our coefficient estimate on the price of West Texas intermediate crude oil indicates that a one cent per gallon increase in the price of WTI results in a 0.91 cent increase in the wholesale price of gasoline, holding constant all other correlates in the regression equation. The price of gasoline is also increasing in the distance to the nearest city with a substitute fuel, indicating that the price increases about 0.003 cents per mile, or about three miles per hundred miles of distance and this statistically differs from zero. The remaining variables in the regression are indicators for the particular special fuels, and those coefficients represent the change in the expected price of gasoline when the particular fuel is required.

The coefficient on low sulfur fuel is statistically no different from zero. Next, we examine the impact of increasingly stringent Reid vaporization pressure standards. The coefficients on RVP levels of 7.8 and 7.2 are about 0.48 and 4.25, respectively, with only the latter being statistically different from zero at conventional significance levels. It is interesting that the coefficient on RVP 7.8 is not statistically different from zero; this finding is consistent with the thickness of the market for that particular fuel. 7.8 RVP gasoline is the least stringent and most widely used of the special blends. Most of the 7.8 RVP gasoline is used in areas close to the Gulf Coast refining center. In addition, petroleum refiners report that

18. In the AR(1) model estimates reported in column 4 of Table 4 , a common autoregressive term is estimated for the 99 cities. Allowing the AR(1) term to vary across cities—so that we estimate 99 separate autoregressive coefficients—does not have any significant impact on the estimates coefficients and their standard errors. Also, a random-effects AR(1) model yields results almost identical to the fixed-effects AR(1) model.

Table 4. Regression Results: Price Level Model

	Estimated Model			
Variable	**Common Intercept**	**Fixed Effects**	**Random Effects**	**AR1 Fixed Effects**
WTI (¢ per gallon)	1.144763 (0.00426)	1.144920 (0.00379)	1.144695 (0.00381)	0.91288 (0.00877)
Distance to Substitute	0.020135 (0.00035)	0.003254 (0.00082)	0.002620 (0.00077)	0.002893 (0.00089)
Low Sulfur	-1.64788 (1.18618)	4.473293 (1.18181)	4.240553 (1.17752)	1.842931 (3.49516)
RVP 7.8	-6.067402 (0.286694)	0.086029 (0.33562)	0.539160 (0.33285)	0.485227 (0.40096)
RVP 7.2	2.863657 (1.08990)	5.408887 (0.54436)	5.191942 (1.20386)	4.246441 (1.49352)
Ethanol 5–5.7%	8.186236 (0.38914)	4.043033 (1.16014)	4.328534 (1.14976)	2.054036 (1.49294)
Ethanol 10%	11.98170 (0.89512)	5.45463 (0.54436)	5.647419 (0.53730)	5.713578 (0.681378)
RFG MTBE RVP 8.2	2.510608 (0.74198)	3.05819 (0.69184)	2.902271 (0.69327)	1.395519 (1.04477)
RFG MTBE RVP 7.2	6.229890 (0.83839)	4.408249 (0.79247)	4.756108 (0.79271)	1.054140 (1.04858)
RFG Ethanol RVP 8.2	19.21851 (1.20145)	12.32809 (1.2178)	12.43295 (1.12430)	6.569909 (1.69966)
CARB RFG Ethanol	23.97494 (0.40099)	7.72078 (0.89933)	8.416503 (0.85265)	3.866366 (1.23909)
Seasonal Dummy Variables	yes	yes	yes	yes
AR(1)				0.899959 (0.00322)
R^2	0.833	0.869	0.868	0.967
Durbin-Watson	0.245	0.301	0.297	1.967

Note: Estimated standard errors in parentheses.

making 7.8 RVP gasoline is simpler and less costly than some of the more stringent blends, which may make it more available from refineries in the event there is a local supply shortfall (GAO, 2005).

The coefficients on the required ethanol content are also positive and increasing in the percentage of ethanol, however only the coefficient on 10% ethanol content differs statistically from zero. The remaining fuel attribute variables are for various types of reformulated gasoline, first those that use MTBE as an oxygenate, where the effect on price is about 1.05 to about 1.40—but neither is significantly different from zero.

Table 5. Regression Results: Log-linear Model

	Estimated Model			
Variable	**Common Intercept**	**Fixed Effects**	**Random Effects**	**AR1 Fixed Effects**
log WTI (¢ per gallon)	0.897286 (0.00339)	0.896960 (0.00279)	0.896851 (0.00277)	0.698117 (0.00642)
log Distance to Substitute	0.001423 (0.00014)	0.004389 (0.00173)	0.002437 (0.00099)	0.003326 (0.00061)
Low Sulfur	-0.016898 (0.01086)	0.051517 (0.01132)	0.050424 (0.01129)	0.022116 (0.03462)
RVP 7.8	-0.039164 (0.00298)	0.005251 (0.00324)	0.005593 (0.00312)	0.007531 (0.00402)
RVP 7.2	0.009897 (0.01139)	0.058231 (0.01156)	0.057605 (0.01154)	0.038700 (0.01480)
Ethanol 5–5.7%	0.127137 (0.00400)	0.053640 (0.01110)	0.055387 (0.01106)	0.022148 (0.01479)
Ethanol 10%	0.132256 (0.00936)	0.069049 (0.00521)	0.070378 (0.00517)	0.051417 (0.00675)
RFG MTBE RVP 8.2	0.021350 (0.00776)	0.035425 (0.00662)	0.035315 (0.00662)	0.012663 (0.01035)
RFG MTBE RVP 7.2	0.072504 (0.00889)	0.049987 (0.00751)	0.049488 (0.00750)	0.008285 (0.01037)
RFG Ethanol RVP 8.2	0.167431 (0.01256)	0.113162 (0.01074)	0.113592 (0.01074)	0.042899 (0.01684)
CARB RFG Ethanol	0.216046 (0.00419)	0.057659 (0.00861)	0.059005 (0.00841)	0.037275 (0.01228)
Seasonal Dummy Variables	yes	yes	yes	yes
AR(1)				0.899783 (0.00323)
R^2	0.825	0.885	0.885	0.969
Durbin-Watson	0.221	0.328	0.328	1.953

Note: Estimated standard errors in parentheses.

Reformulated gasoline using ethanol increases the expected price by about 6.57 cents per gallon. California's CARB gas using ethanol as an oxygenate increases the expected price by about 3.87 cents per gallon. The coefficients on both of the reformulated gasolines that use ethanol as the oxygenate are statistically different from zero.

The results of the regression equation provide estimates of the reduced-form impact of changes in particular fuel specifications on expected wholesale fuel prices, and these are generally consistent with our expectations that requiring more stringent and costly fuels—those with lower Reid vaporization pressure, higher ethanol content, and the most stringent reformulated blends—will result in higher wholesale fuel prices.

The results also provide estimates of the city-market-specific effects for each of the 99 cities in our sample of data and these are listed in Table 6, along with their estimated standard errors, in the appendix. It is important to recall that the city-market-specific effects reflect the constant term α_i in our regression equation for each city *i* and that the regression model has explicitly accounted for all of the explanatory variables included in the estimation, such as the price of WTI, the attributes of the fuel used, and the distance to the nearest city with a substitute fuel. The city effects are highest for Anchorage followed by the California, Arizona, and Nevada cities. The city effects are lowest for Beaumont and Meridian, and also low for other cities that are in close proximity to the Gulf Coast refining centers and located along major pipelines.

The panel data model did not permit the inclusion of explanatory variables that remained constant through time for individual city markets.[19] However, we can perform an auxiliary cross-sectional regression analysis relating the estimated city-market-specific effects to factors that vary across cities, including population, income, and the number of commuters that use public transport.[20] The estimates of this regression are:

$$
\begin{array}{llll}
\multicolumn{4}{l}{\text{city-specific-effect} =} \\
20.627 & -\ 1.63\ \text{population} & +\ 2.82\ \text{income} & -\ 3.97\ \text{transit users} \\
(3.43) & (0.68) & (0.84) & (1.19) \\
[4.48] & [0.65] & [0.82] & [1.17]
\end{array}
\qquad (2)
$$

$$R^2 = 0.198$$

where the estimate standard errors are in parentheses and the White (1980) robust standard errors are in brackets.[21] Although this regression explains only about 20% of the variation in city-market-specific effects, the results do suggest that the city-

19. Variables that do not vary across time for individual city markets are perfectly collinear with the city-specific effects. It is for this reason that the panel data model can not accommodate these variables in the estimation.

20. The data on population, income, and commuters using public transport were obtained directly from the 2000 Census database.

21. The population and public transport users variables were in units of 10^6, while income was in units of 10^4. Scaling the regressors does not affect the substantive nature of the results, it simply makes the magnitude of the estimated coefficients more manageable.

market-specific effects are related to market size in addition to the market isolation which was already included in the panel regression through inclusion of the distance-to-substitute variable.

Our empirical analysis and results complement some other recent papers on the pricing of boutique motor fuels. Chakravorty and Nauges (2005) use state-level monthly average fuel prices to estimate a reduced-form panel data model. They find that boutique fuels are associated with higher fuel prices due to higher refining cost and through the creation of heterogeneous fuel markets. Brown, Hastings, Mansur, and Villa-Boas (2006) analyze city-level weekly prices using a treatment and control group approach that pairs cities that used special fuels with similar cities that did not. They find that geographic isolation is associated with higher prices of boutique fuels; additionally they find that the adoption of special fuels is associated with a reduction in the number of suppliers, and that this may also cause higher prices and price volatility.[22]

4. CONCLUSIONS

We have taken a first step to separate fuel-specific effects on prices from city-specific effects and to explain some of the variation in the level of gasoline prices across cities. Among other things, the results of this analysis suggest that the size of market for a particular blend of gasoline and the fungibility of the specific blend are influential factors in explaining differences in price. For example, average prices are higher in cities using gasoline blends unique to their region. The relatively low price of 7.8 RVP fuel also illustrates this point—it is the largest market among the special blends of gasoline and is widely available in many regions. From a policy perspective, the results of this analysis suggest that EPA should consider the impacts of additional uses of boutique fuels on gasoline prices as well as the air quality benefits before approving such uses. Further work is required to evaluate more completely the variation of gasoline prices over time, such as an examination of gasoline prices in individual cities in response to supply disruptions while controlling for different blends and different city-market-specific attributes. In addition, the impacts of the proliferation of special fuel blends on individual refiner's market power could be explored in a structural model, since suppliers may in fact have an incentive to facilitate the proliferation of special fuel blends. Given the role of refiners in advising states on the costs of various special blends, this avenue of research deserves more attention.

22. We cannot augment our panel data model to price volatility directly because we do not have a weekly city-specific measure of volatility that can account for changes in volatility within a city as the fuel changes across weeks. Measuring volatility over time and then running a cross-section regression across cities is inadequate in our application, because the fuel used in a given city is in fact changing over the year.

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APPENDIX

Table 6. City Names, Fuels, and Estimated City-Market-Specific Effects

City Name	State	Primary Summer Fuel[a]	Primary Winter Fuel[a]	City Effect[b]	Std Error[b]
Akron/Canton	OH	Conv. RVP 9.0	Conv.	30.86422	3.688726
Albuquerque	NM	Conv. RVP 9.0	Conv. ethanol	33.52739	3.691679
Anacortes	WA	Conv. RVP 9.0	Conv.	35.46052	3.688463
Anchorage	AK	Conv. RVP 9.0	Conv.	61.07981	3.898402
Artesia	NM	Conv. RVP 9.0	Conv.	34.68456	3.691329
Atlanta	GA	Low Sulphur RVP 7.0	Low Sulphur	29.12020	4.059081
Austin	TX	Conv. RVP 7.8	Conv.	26.83832	3.691344
Baltimore	MD	RFG North	RFG North	31.83637	3.689746
Baton Rouge	LA	Conv. RVP 7.8	Conv.	25.67419	3.690531
Beaumont	TX	Conv. RVP 7.8	Conv.	24.91367	3.691400
Billings	MT	Conv. RVP 9.0	Conv.	36.90646	3.695808
Birmingham	AL	Conv. RVP 7.0	Conv.	27.50289	3.691961
Bloomfi	NM	Conv. RVP 9.0	Conv.	35.92736	3.690440
Boise	ID	Conv. RVP 9.0	Conv.	38.35435	3.694567
Boston	MA	RFG North	RFG North	31.68515	3.689206
Buffalo	NY	Conv. RVP 9.0	Conv.	30.57098	3.688965
Charlest	WV	Conv. RVP 9.0	Conv.	30.88510	3.690224
Charlotte	NC	Conv. RVP 7.8	Conv.	26.15351	3.692058
Cheyenne	WY	Conv. RVP 9.0	Conv.	34.30719	3.689296
Chicago	IL	RFG North ethanol	RFG North ethanol	39.98790	3.692122
Cincinnati	OH	Conv. RVP 9.0	Conv.	29.62836	3.689304
Cleveland	OH	Conv. RVP 9.0	Conv.	31.34611	3.688747
Colorado	CO	Conv. RVP 9.0	Conv.	32.40542	3.688921
Columbus	OH	Conv. RVP 9.0	Conv.	32.14004	3.691620
Dallas Metro	TX	RFG South	RFG South	31.88379	3.689698
Dallas/Ft. Worth	TX	RFG South	RFG South	31.67002	3.689680
Denver	CO	Conv. ethanol RVP 7.8	Conv. ethanol	31.05188	3.753636
Des Moines	IA	Conv. RVP 9.0	Conv.	31.69604	3.690286
Detroit	MI	Conv. RVP 7.8	Conv.	31.81822	3.690398
El Paso	TX	Conv. RVP 7.0	Conv.	32.75489	3.719358
Eugene	OR	Conv. RVP 9.0	Conv.	35.88521	3.690256
Evansville	IN	Conv. RVP 9.0	Conv.	28.39824	3.689958
Fairfax	VA	RFG South	RFG South	31.45616	3.689697
Fargo	ND	Conv. RVP 9.0	Conv.	33.56092	3.693562
Fayetteville	NC	Conv. RVP 9.0	Conv.	33.56092	3.693562
Flint	MI	Conv. RVP 9.0	Conv.	33.07561	3.689161
Fresno	CA	CARB	CARB	50.70338	3.798061
Hammond	IN	RFG North ethanol	RFG North ethanol	39.53728	3.692123
Houston	TX	RFG South	RFG South	29.23848	3.694607
Huntington	IN	Conv. RVP 9.0	Conv.	39.64608	3.690170
Indianapolis	IN	Conv. RVP 9.0	Conv.	29.60794	3.689390
Kansas City	KS	Conv. RVP 7.0	Conv.	33.48274	3.688293
Knoxville	TN	Conv. RVP 9.0	Conv.	29.28049	3.689617
Las Vegas	NV	Conv. RVP 9.0	Conv.	44.74078	3.718921
Lexington	KY	Conv. RVP 9.0	Conv.	30.83338	3.689463

continued

Table 6. City Names, Fuels, and Estimated City-Market-Specific Effects (continued)

City Name	State	Primary Summer Fuel[a]	Primary Winter Fuel[a]	City Effect[b]	Std Error[b]
Lincoln	NE	Conv. RVP 9.0	Conv.	31.41956	3.688936
Little Rock	AR	Conv. RVP 9.0	Conv.	27.07303	3.690626
Los Angeles	CA	CARB	CARB	47.85877	3.801163
Louisville	KY	RFG North ethanol	RFG North ethanol	40.11959	3.695286
Lubbock	TX	Conv. RVP 9.0	Conv.	29.33920	3.691082
Madison	WI	Conv. RVP 9.0	Conv.	31.29277	3.689205
Memphis	TN	Conv. RVP 7.8	Conv.	29.24596	3.691691
Meridian	MS	Conv. RVP 9.0	Conv.	24.37990	3.690831
Miami	FL	Conv. RVP 7.8	Conv.	27.07421	3.701762
Milwaukee	WI	RFG North ethanol	RFG North ethanol	39.71838	3.692835
Minneapolis	MN	Conv. ethanol RVP 9.0	Conv. ethanol	36.37238	3.700807
Missoula	MT	Conv. RVP 9.0	Conv.	36.86590	3.694839
Montgomery	AL	Conv. RVP 9.0	Conv.	25.56144	3.689695
Nashville	TN	Conv. RVP 7.8	Conv.	28.61926	3.691826
New Haven	CT	RFG North	RFG North	31.24294	3.689319
New Orleans	LA	Conv. RVP 7.8	Conv.	25.22868	3.690542
New York	NY	RFG North ethanol	RFG North ethanol	33.51480	3.689489
Newark	NJ	RFG North	RFG North	30.18978	3.689124
Norfolk	VA	RFG South	RFG South	30.97596	3.691402
North Augusta	SC	Conv. RVP 9.0	Conv.	25.93635	3.690068
Oklahoma	OK	Conv. RVP 9.0	Conv.	29.22914	3.689740
Omaha	NE	Conv. RVP 9.0	Conv.	31.56773	3.688981
Orlando	FL	Conv. RVP 9.0	Conv.	28.14832	3.693556
Pasco	WA	Conv. RVP 9.0	Conv.	37.28324	3.689631
Philadelphia	PA	RFG North	RFG North	31.01617	3.689347
Phoenix	AZ	AZ CARB	AZ CARB	53.85600	3.798616
Pittsburgh	PA	Conv. RVP 7.8	Conv.	29.50344	3.691155
Portland	ME	Conv. RVP 7.8	Conv.	26.85419	3.703291
Portland	OR	Conv. RVP 7.8	Conv. ethanol	33.37213	3.699885
Providence	RI	RFG North	RFG North	32.28699	3.689083
Riverside	MO	Conv. RVP 7.0	Conv.	33.61251	3.688237
Roanoke	VA	Conv. RVP 9.0	Conv.	25.62796	3.690297
Rochester	NY	Conv. RVP 9.0	Conv.	28.89017	3.689039
Rockford	IL	Conv. RVP 9.0	Conv.	30.89413	3.689146
Salt Lake City	UT	Conv. RVP 7.8	Conv.	37.04247	3.699518
San Antonio	TX	Conv. RVP 7.8	Conv.	25.82356	3.691277
San Diego	CA	CARB	CARB	50.39795	3.838725
San Francisco	CA	CARB	CARB	49.20970	3.797125
San Jose	CA	CARB	CARB	50.81953	3.797156
Scranton	PA	Conv. RVP 9.0	Conv.	28.52587	3.690374
Seattle	WA	Conv. RVP 7.8	Conv.	34.78187	3.688025
Sioux Falls	SD	Conv. RVP 9.0	Conv.	31.91153	3.691620
Sparks/Reno	NV	Conv. RVP 7.8	Conv. ethanol	40.67793	3.712230
Spartanburg	SC	Conv. RVP 9.0	Conv.	25.56206	3.689418
Spokane	WA	Conv. RVP 9.0	Conv. ethanol	38.06399	3.690806
Sprinfield	MO	Conv. RVP 9.0	Conv.	30.41258	3.691067

continued

Table 6. City Names, Fuels, and Estimated City-Market-Specific Effects (continued)

City Name	State	Primary Summer Fuel[a]	Primary Winter Fuel[a]	City Effect[b]	Std Error[b]
St. Louis	MO	RFG South ethanol	RFG South ethanol	38.68564	3.688648
Toledo	OH	Conv. RVP 9.0	Conv.	30.50785	3.689026
Topeka	KS	Conv. RVP 9.0	Conv.	30.68880	3.689062
Tucson	AZ	Conv. RVP 9.0	Conv.	41.09841	3.778352
Tulsa	OK	Conv. RVP 7.8	Conv.	29.64752	3.691295
Wichita	KS	Conv. RVP 9.0	Conv.	30.18902	3.690517
Wilmington	DE	RFG North	RFG North	30.34541	3.689332
Wood River	IL	Conv. RVP 7.2	Conv.	29.39655	3.728039

Notes:

a. Representative summer and winter fuels. Actual specification of fuel used may vary over the sample within a given city.

b. City-specific effects and standard errors correspond to the fixed-effects regression reported in the final column of Table 4.