Simulated Ethanol Transportation Patterns and Costs

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Ethanol production booms in the Midwest in 2007. Regulations require ethanol be included as a fuel additive in many areas as of 2006, though consumer willingness to adopt ethanol blends voluntarily is uncertain and benchmark ethanol and oil prices fluctuate. In this context, we jointly simulate consumer demand for ethanol and ethanol transportation costs. Results demonstrate a non-linear relationship between benchmark prices and transportation costs that depends critically on (1) the prevalence of additive ethanol use in a state and (2) the proximity of local prices to parity in energy equivalent terms.

INTRODUCTION

The ethanol market is developing, as quantities bought and sold rose rapidly in recent years and may continue to rise at least as fast as mandated by the U.S. Energy Independence and Security Act (EISA) of 2007, which outlined levels of biofuel use. As for supply, most ethanol used in the U.S. now is made in the Midwest from corn, although there is potential for greater imports or new technologies in the future. Developments in supply and demand are accompanied by questions about how distribution patterns will develop. Some questions relate to U.S. ethanol transported from the Midwest, where the majority of production occurs, to population centers throughout the U.S. For example, costs associated with the movement of ethanol affects the price competitiveness of the product. Questions about the effects of petroleum fuel price variations on ethanol distribution lead quickly to complications because of the impacts both on transportation costs and on consumer willingness to buy ethanol.

Even near-term future predictions are uncertain, as the market structure has changed and historical data, where available, may not represent circumstances in the future (Westhoff et al. 2007). Regulatory changes brought about the virtually complete replacement of methyl tertiary butyl ether (MTBE) with ethanol as a fuel additive to change the properties of fuels (Gallagher et al. 2000; Hwang et al. 2003). Whereas this use of ethanol is largely related to the regulatory environment, consumers are choosing to use ethanol in blends with 10% (E10) or as much as 85% (E85) ethanol (Eidman 2006). But expanding regulatory and voluntary uses of ethanol requires that the product be distributed from Midwest production facilities to consumers. Consumer willingness to purchase ethanol depends on relative retail prices, which depends on benchmark prices of ethanol and oil, taxes, and the costs of getting the fuels to consumers.

For the next few years, it is reasonable to assume that Midwest-produced ethanol will continue to play a major role. From 2002 to 2006, imports were 6% as large as domestic production on average (EIA 2008a), and most ethanol production capacity is corn-based and located in the Midwest (RFA 2008). Infrastructure costs associated with rising use of ethanol produced in the Midwest and blended and sold throughout the United States are new and difficult to predict. The means of transportation may be truck, rail, or barge, but as yet ethanol shipments are not made via existing pipelines. The Energy Information Agency (EIA 2006) assessment of MTBE replacement in Northeastern states in 2006 indicated that the use of ethanol requires that the gasoline into which it is blended be high quality, at least at that time, and the ethanol additive must not be added into the petroleum until the final stages before sale. These constraints led to required changes in the handling equipment in many outlets and the development of a distribution system capable of keeping several varieties of mixed and unmixed products separate, as well as contracting arrangements among agents that reflect these complexities.

A critical uncertainty about ethanol distribution is the regional disposition of consumer demand for fuels containing ethanol. Thus, when considering the near-term evolution of infrastructure costs associated with shipping ethanol from Midwest production centers, it is critical to assess both the likely consumption patterns and the costs of ethanol blended fuels to consumers. This assessment is further complicated by the different components of ethanol demand, which may be partly compulsory or entirely voluntary, and the role of oil prices in determining quantities demanded, as well as in their capacity to affect transportation costs.

The objective of this paper is to show how ethanol demand and transportation costs change for different benchmark oil and ethanol prices in broad terms. Output is generated from a simulation model. The model is calibrated to recent data, but there is little scope to estimate key relationships. Thus, a stylized representation of demand and transportation costs is used. For a given constellation of initial conditions, simulation results illustrate the sort of ethanol consumption patterns that could evolve. Key results highlight the importance and inflexibility of transportation costs associated with compulsory uses and the contrasting flexibility of voluntary ethanol uses with respect to the relative local prices of ethanol and oil-based gasoline.

MODEL AND DATA

Historical data are limited. There are data relating to consumption of E10, as well as overall motor fuel use (FHWA 2006). There are newly available data relating to E85 use (EIA 2008b, Table c4), but these data are not sufficiently up to date to capture rapid market changes. The usefulness of estimates based on these data is uncertain. For example, many data pre-date the replacement of MTBE with ethanol as a key fuel additive. There are also only limited retail price data, and these naturally reflect the situation at centers of sales in the past, not the full scope that could develop if benchmark prices change dramatically. Relying on relationships and parameters that are typically assumed or calibrated, consumer substitution among fuels and benchmark-to-retail price links are represented.

The model of state-level consumer demand for ethanol is based on the stylized representation of Mussa and Rosen (1998), which has also been used in studies of consumer adoption of other goods, such as genetically modified goods (Moschini, Bulut, and Cembalo 2005; Sobolevsky, Moschini, and Lapan 2005). The key element is a consumer-specific parameter that governs the trade-off between two alternatives. In this case, the trade-off takes place in demand equations for two goods, gasoline and ethanol. The reasons for varying consumer perceptions of the values of these two goods are many, including (1) differing assessments of their fuel equivalence, (2) preferences for higher octane associated with ethanol blends, (3) concerns for the environment and expectations about these fuels' environmental affects, (4) desires for independence from foreign sources of oil and beliefs about how alternative fuel purchases achieve that objective, and (5) intentions to help farmers and understandings of the degree to which ethanol achieves that end. To this list, we add the potential that average prices will differ from local prices as another reason to expect consumers to react differently to a given set of average prices.

The basic representation with this stylized trade-off introduced in the aggregate demands is as follows. All quantities and prices are in energy equivalent terms, not in volume terms. First, motor fuel demand is

(1) $\ln(D_{MFL,s}) = \alpha_{0,s} + \alpha_P \ln(P_{MFL,s}) + \alpha_Y \ln(Y_s)$.

The demand of a given state, s, for motor fuel, $D_{MFL,s}$, reflects movements in the average motor fuel price, $P_{MFL,s}$, that are defined below. The other factor is state income, Y_s. The own-price elasticity is assumed to be -0.05 (EIA 2006), and the income elasticity is calibrated to projected fuel use and income growth. Based on an assumed uniform distribution of consumer willingness to switch from one fuel to another based on relative prices, aggregate motor fuel use is decomposed into its elements. State mandated rates of ethanol use, Mandates, are imposed as minimum levels, to the extent that E85 use does not meet them. The mandated percent use in motor fuel is converted into an amount of E10 that would satisfy this requirement, then the equivalent value of E85 used is removed.

E85 is perceived to be relatively less responsive to relative prices because consumers can use E85 only if they own a special (flex fuel) vehicle. In the past, we observe that some consumers exhibit a strong preference for this fuel irrespective of its ability to minimize the costs of fuel services. E85 purchases in the past may not represent the willingness of the broader population to use E85. Presumably, most consumers will decide to buy this fuel only when it is closer to being cost competitive for fuel services.

E85 demand is simulated in two stages, one for the atypical consumer, whose purchasing is less sensitive to prices, and one for the general population, as

(2A) $Ratio^{A}_{E85,s}=$

if $P_{E85,s} / P_{N85,s} \geq \theta H^{A}_{E85,s}$ then 0

if $\theta H^{A}_{E85,s} > P_{E85,s}/ P_{N85,s} > \theta L^{A}_{E85}$

then $((P_{E85,s}/ P_{N85,s})- \theta L^{A}_{E85})/ (\theta H^{A}_{E85,s} - \theta L^{A}_{E85})$

if $\theta L^{A}_{E85} \geq P_{E85,s} / P_{N85,s}$ then 1 ;

(2B) $Ratio^{B}_{E85,s}=$

if $P_{E85,s} / P_{N85,s} \geq \theta H^{B}_{E85}$ then 0

if $\theta H^{B}_{E85} > P_{E85,s} / P_{N85,s} > \theta L^{B}_{E85}$

then $((P_{E85,s}/ P_{N85,s})- \theta L^{B}_{E85})/ (\theta H^{B}_{E85} - \theta L^{B}_{E85})$

if $\theta L^{B}_{E85} \geq P_{E85,s} / P_{N85,s}$ then 1 ; and

(2C) $D_{E85,s} = (Ratio^{A}_{E85,s} Limit^{A}_{E85} + Ratio^{B}_{E85,s} (Limit^{B}_{E85} -Limit^{A}_{E85}))D_{MFL,s}$.

The demand for E85 in a state, $D_{E85,s}$, depends on the ratio of the price of E85 to the average price of other fuels in that state, $P_{E85,s}$ over $P_{N85,s}$, and where it sits relative to key switching parameters. One set of switching parameters reflects the adoption of E85 over a higher range of quantity for a smaller share of consumers, with adoption starting if the relative prices are below a threshold, $\theta H^{A}_{E85,s}$, and reaching a certain small share of the total market, $Limit^{A}_{E85}$, if the price ratio is at or below the lower threshold, θL^{A}_{E85}. Broader adoption starts from a lower upper-end threshold, θH^{B}_{E85}, stops expanding at a lower threshold, θH^{B}_{E85}, and reaches a greater upper limit, $Limit^{B}_{E85}$, at the lower threshold.

The trade-off between E85 and non-E85 fuels occurs in two phases based on consumer behavior as described above. The first consumer type is the very small number of total consumers who will tend to buy E85 at a high relative price. The second consumer type reflects the majority of consumers. For consumers of the first type, the lower bound, θL^{A}_{E85}, is assumed to be 1, and the corresponding share of E85 in motor fuel use if the retail prices are equal, $Limit^{A}_{E85}$, is assumed to be 1%. The upper bound for these consumers at which they would purchase no ethanol, $\theta H^{A}_{E85,s}$, is calibrated to historical data. In other words, the trade-off is extrapolated based on two points, the assumed price ratio and quantity at which these consumers would adopt E85 in full (parity retail price and a quantity equivalent to 11% of state motor fuel use) and the historical price ratio and quantity in base data. The extrapolation varies with historical state price ratios and E85 use. The simple average upper bound, $\theta H^{A}_{E85,s}$, is 1.28.

The usual consumer adopts E85 when it is competitive as a motor fuel. Historical data are unlikely to inform this representation, as noted above, so a range in price ratios and volumes are assumed. These consumers start to buy E85 when the retail price of E85 equals the price of alternative fuels, and they increase E85 use as long as the relative E85 prices fall. There are limits to the extent of E85 market penetration growth from an annual demand perspective. For example, the potential for a finite amount of flex fuel vehicles to be brought into use in a given year. This constraint is reflected in a maximum penetration, $Limit^{B}_{E85}$, that rises from 5% in 2007 to 10% in 2009. While by no means precise, the initial value is based loosely on data about the number of E85 cars in existence (EIA 2008b, Table v1, endnote c) relative to the total number of cars (FHWA 2008), and the increase in the flex fuel fleet (EIA 2008b, Table s7).

The substitution between E10 and other fuels is

(3A) $\text{Ratio}_{E10,s}=$

$$\begin{aligned}
&\text{if } P_{E10,s} / P_{E0a,s} \geq \theta H_{E10,s} \text{ then } 0\\
&\text{if } \theta H_{E10,s} > P_{E10,s} / P_{E0a,s} > \theta L_{E10,s} \text{ then } ((P_{E10,s}/ P_{E0a,s})- \theta L_{E10,s})/ (\theta H_{E10,s} - \theta L_{E10,s})\\
&\text{if } \theta L_{E10,s} \geq P_{E10,s} / P_{E0a,s} \text{ then } 1 \text{ ; and}
\end{aligned}$$

(3B) $$D_{E10,s}=\max[\text{Ratio}_{E10,s}, \; \text{Mandate}_s/(S_{E10,s}\gamma_{E10,s})-(S_{E85,s}D_{E85,s})/(S_{E10,s} D_{E10,s})] \; (D_{MFL,s} - D_{E85,s}) .$$

The ratio of E10 price, $P_{E10,s}$, to the average price of the remaining fuels such as gasoline, $P_{E0a,s}$, drives consumer choice. The upper threshold at which consumers begin to adopt E10, $\theta H_{E10,s}$, is calibrated, and the lower threshold at which adoption is complete, $\theta L_{E10,s}$, is assumed based on local labeling requirements, as described below. State level mandates, $Mandate_s$, as given by ACE (2006) and EERE (2008), are imposed here. The mandate, expressed as shares of fuel expressed in energy equivalent terms, must be reduced by the ethanol use used in E85 to determine the E10 required.

E10 adoption is assumed to be complete at the point, $\theta L_{E10,s}$, at which the relative price is 85% of the gasoline price in states where fuel is labeled as including ethanol and at 92.5% in states without labeling. The upper parameter at which consumers begin to buy E10, $\theta H_{E10,s}$, is calibrated based on historical use data, or assumed in those cases where there is no use historically, and averages 1.04 among all states.

The ranges of substitution appeal to intuition about consumer behavior and are aligned to historical data through calibration when possible. But these assumptions are not tested, and until enough historical data are available, may be un-testable. The results are likely to be quite sensitive to these parameters, but no sensitivity analysis is undertaken here.

Largely compulsory uses of ethanol must also be represented in order to assess the evolution of ethanol demand. These take two forms: additive and mandated. Additive use is required in some places or at certain times, so any decision by consumers not to buy E85, nor to use E10, voluntarily implies in these areas that the consumer chooses fuel with ethanol as an additive. Thus, in areas where additive use is present, all consumer fuel choices result in the purchase of some amount of ethanol. As for mandates, which exist at federal and state levels, several are ignored in this analysis. The federal mandate relating to corn-based ethanol, as established in the EISA, is 10.5 billion gallons in 2009 and is assumed not to be binding in the near term, given that corn-based ethanol production that year is projected to be about 12 billion gallons (FAPRI-MU 2008). Many state-level mandates are contingent on targets of ethanol production within the state that seem unlikely to be met. Mandates that may be binding in the near term are those of Hawaii, Minnesota, Missouri, and Washington, whose motor fuel comprises less than 10% of the national total (ACE 2006; EERE 2008). Representation is often not very clear cut, as demonstrated by the choice to assume that 2.5% (by volume) of fuel use in Oregon must be ethanol to represent the 10% ethanol required by the Portland Renewable Fuels Standard to be in all gasoline sold (EERE 2008). In those few cases, the demand relations are bound so that the quantity of fuel with ethanol will achieve the mandate.

The state-level demands for fuels other than E85 and E10, namely fuels in which ethanol is an additive, $D_{EAd,s}$, and gasoline with no ethanol at all, $D_{Gas,s}$, are

(4) $D_{EAd,s} = (D_{MFL,s} - D_{E85,s} - D_{E10,s})Share_{Add,s}$, and

(5) $D_{Gas,s} = (D_{MFL,s} - D_{E85,s} - D_{E10,s})(1\text{-}Share_{Add,s})$.

The share of fuel in which ethanol is used as an additive over the sum of additive fuels and gasoline without additive or ethanol, $Share_{Add,s}$, is assumed to be determined by regulatory requirements, not consumer choice. If local regulations required an additive, then MTBE would likely have been included before 2006, and ethanol is the likely fuel additive since MTBE replacement.

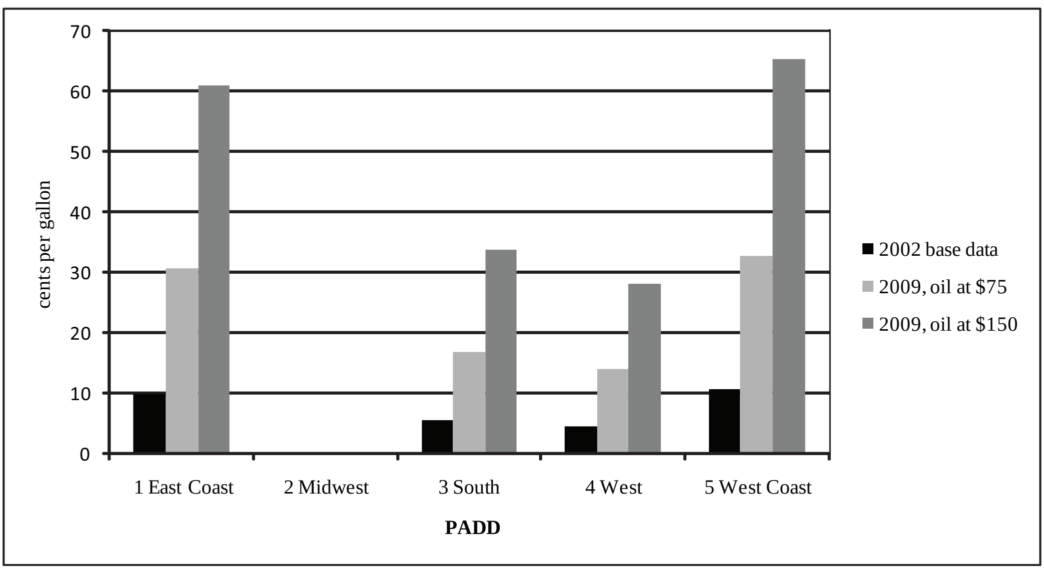
Total ethanol use of a state is

(6) $D_{Eth,s}{=}(D_{E85,s} / \gamma_{E85,s})\, S_{E85,s} + (D_{E10,s} / \gamma_{E10,s})\, S_{E10,s} +/(D_{Ead,s} / \gamma_{EAd,s})\, S_{EAd,s}$,

where the demands for each fuel type simulated above are converted into their volume equivalents by a conversion factor, γ_{is}, and then multiplied by the share of ethanol, S_{is}.

The local retail prices, including taxes and relative energy values, matter to consumers. For gasoline, historical data permit direct estimation of the local gasoline price before taxes as a function of a given benchmark oil price per barrel. This link implicitly includes any effect of higher oil prices on transportation costs. For ethanol, there are few historical data that can be used to tie a benchmark ethanol price to local prices, before taxes, and none at all for many states. Instead, there are historical data relating to ethanol shipments between regions (EIA 2002). Regions, in regard to these data, are defined as Petroleum Administration for Defense Districts (PADDs). These shipment data are adjusted by the ratio of the current or projected oil price to the price in 2002, when those data were collected, to capture changes in ethanol transportation costs from that base period (Figure 1). For example, the base data for 2002 indicate that the average cost of shipping ethanol from the Midwest to the West Coast was $0.105 per gallon, when petroleum was $24.10 per barrel. If the

Figure 1: Historical and Assumed Costs per Gallon of Transporting Ethanol from the Midwest



Note: 2002 base data as reproduced in EIA (2002) represent an average of all modes of transportation, with projections to 2009 based on the change in the petroleum price as discussed in the text.

petroleum price is $150, or 6.22 times higher, then the cost of shipping ethanol to the West Coast is assumed also to increase by 6.22 times, or to $0.654.

Using these values for the transportation costs per unit, the price of any fuel made available to consumers is expressed as a function of two benchmark prices. First, two retail prices are calculated, one for ethanol and one for oil-based fuel. Second, these retail prices are averaged with the weights determined by the shares of the two components in the fuel. Combining these two steps, retail prices, $PR_{i,s}$, are

$$(7)\ PR_{i,s}=[S_{O,i,s}\,(\alpha_{g0,s}+\alpha_{g1,s}\,PB_O)+S_{E,i,s}\,(PB_E+TC_{w,s}+TC_{ER}-C)+T_i+T_{i,s}]\,\gamma_{i,s}\,.$$

Each fuel *i* in state *s* has a retail price that is a function of the benchmark prices for oil and ethanol, PB_O and PB_E. The link from the oil price to oil-based fuel prices is based on estimated parameters, $\alpha_{g0,s}$ and $\alpha_{g1,s}$, using EIA data from 1985-2005 (2007). Thus, the retail gasoline prices are based on historical data, which are available. In contrast, there are few historical retail price data for some states, and no historical ethanol-blended fuel price data for states that have no experience retailing ethanol given the small quantities available in the past. So this equation generates a proxy measure of the retail price based on links to the underlying benchmark prices. The link between the benchmark ethanol price and ethanol prices in various regions, $TC_{W,s}$, is from EIA (2002) described above, and an assumed constant mark-up to retail, TC_{ER}, is added. While transportation costs and mark-up raise retail prices, the federal tax credit for ethanol blending, *C*, lowers retail ethanol prices relative to the wholesale price. Federal and state fuel taxes, T_i and $T_{i,s}$, are added to the price and may vary by fuel type. These fuel tax data are from FTA (2007), with additional information about differential ethanol tax treatment from ACE (2006) and EREE (2007). The shares of gasoline and ethanol in volume terms, $S_{O,i,s}$ and $S_{E,i,s}$ are used to weight these fuels. A fuel-specific conversion rate, $\gamma_{i,s}$, that is calculated based on the share that is ethanol and an assumed energy equivalence, 65.5%, converts each fuel into its energy equivalent. In the case of E85, an additional cost associated with constructing retail outlets is also added, but is endogenous such that there is no cost unless E85 use in a state expands and, even then, expands only slowly to a maximum level determined through interviews with industry experts (Friedrich 2007; Perkins 2007).

The benchmark petroleum and ethanol prices are used to calculate 2004 retail prices, for example. The petroleum price in 2004 was $0.88 per gallon, or $36.98 per barrel, and the ethanol price was $1.69 per gallon. For example, the link from petroleum price to the New York price of gasoline before taxes implies a price of $1.42 per gallon, before taxes. If sold as gasoline without ethanol, then the federal tax of $0.18 per gallon and state tax of $0.24 per gallon are added, giving a retail price of $1.84 per gallon. If ethanol is included in the fuel, such as in the case of E10, then the local ethanol price is calculated as well. The benchmark price $1.69 per gallon is the starting point. The cost of shipping ethanol from the Midwest was $0.098 in 2002, which is increased by 53% to $0.15 to take account of the increase in petroleum price from $24.10 per barrel in 2002 to $36.98 per barrel in 2004. The Midwest corresponds to PADD 2, which is comprised of Illinois, Indiana, Iowa, Kansas, Kentucky, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, Oklahoma, South Dakota, Tennessee, and Wisconsin.

The fixed wholesale-to-retail ethanol price wedge of $0.12 is also added to give $1.96, and the tax credit of $0.54 per gallon is subtracted to give $1.42 as implied local price of ethanol before blending. When blended to get E10, the shares of 90% gasoline and 10% ethanol are applied to give a weighed average of pre-tax prices that is equal to $1.42 per gallon. The price with taxes is $1.79, which is equal to the pretax price, $1.42, plus the sum of federal and average state taxes, $0.37. The conversion factor, 1.04, reflects the smaller energy content of E10 relative to gasoline, so the price of E10 in fuel equivalent terms, with taxes, is $1.85 per gallon. A similar procedure is followed to calculate other fuel prices in New York and in other states.

Total transportation costs of moving ethanol from the Midwest to a particular state depend on two variables given above, the quantity of ethanol consumed and the transportation cost per unit.

This product of quantity and transportation cost per unit is

(8) $Cost_s = D_{eth,s} TC_{w,s}$.

The total transportation cost of moving ethanol from the Midwest to all states is the sum of transportation costs of all states.

The base data set is initially constructed for 2004, then projected forward to 2009 so that results relate to the immediate future. The projection method is summarized below, but a key element is the replacement of MTBE with ethanol that was complete by year-end 2006. In projecting data, the use of ethanol in place of MTBE is based on historical shares of fuels with an additive, $Share_{Add,s}$ and the ethanol inclusion rate of ethanol when used as an additive, $S_{Ead,s}$. This inclusion rate is assumed to be 10% (EPA 2008). State-level policies, including tax breaks and mandates, are represented based on information from the American Ethanol Coalition (2006) and the Office of Energy Efficiency and Renewable Energy of the Department of Energy (2007).

Base data reveal a significant role for additive use. Almost a quarter of total ethanol consumption occurs as a fuel additive in California in order to meet regulatory requirements. The share of ethanol in total motor fuel use is highest in Minnesota, where state law mandates that 10% of motor fuel is ethanol. The share of ethanol tends to be higher in Midwestern states than in other regions, and voluntary. Illinois accounts for the second highest amount of ethanol motor fuel, at about half as much as California. E85 use is widely dispersed with some use in every state, but its share in motor fuel use in energy terms is not more than a quarter of a percent in any case.

To project forward, there are two steps required. First, exogenous data that represent the external conditions, including the benchmark price for petroleum, are taken from various sources, and second, the model is simulated. Projections are based on exogenous benchmark oil price, state-level economic growth, Y_s, and general price deflator data from Global Insight. Thus, instead of using base period data to reflect the conditions of 2004, data for 2009 can be used for these variables to reflect expected market conditions in 2009. By using 2009 data instead of base period data, the model simulation can take into account the change in the higher oil price, and income, as well as the increase in additive use of ethanol noted above. For 2009, as discussed below, two values for the oil price are considered to illustrate how alternative assumptions affect ethanol consumption patterns and measures of transportation costs.

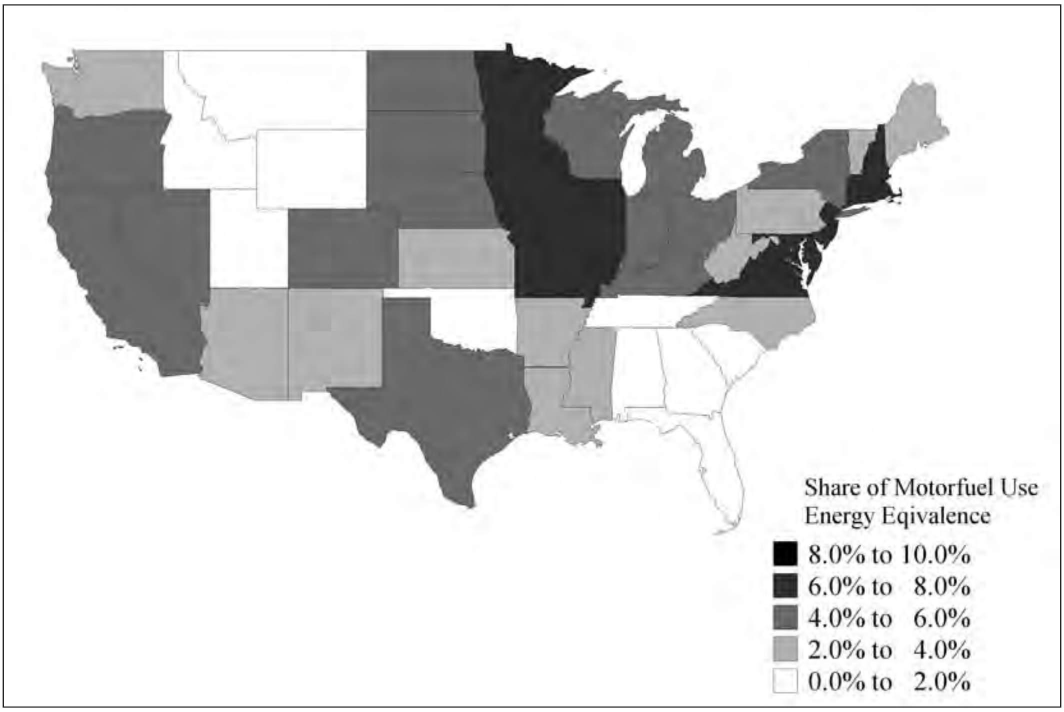
In simulation, benchmark oil and ethanol prices determine retail prices, as per equation 7. Retail prices enter into the fuel demand, equations 1-6, to determine the quantities of ethanol used as an additive, in E10 and in E85. Total ethanol transportation cost is calculated as per equation 8. So the flow of this demand-only representation is from benchmark prices of ethanol and petroleum to comparable state retail prices and then from these retail prices to consumer purchasing decisions.

SIMULATED ETHANOL TRANSPORTATION

The model is simulated in 2009 for a benchmark ethanol price of $2 per gallon and two benchmark refiner's acquisition price of oil, $75 per barrel and $150.

The simulated use of ethanol in 2009 by state as a share of motor fuel use varies from 1% to 7%, and averages 4% for the U.S. (based on energy equivalence in this discussion, not volume) on an energy equivalence basis in the case that the benchmark ethanol price is $2 per gallon and the benchmark oil price is $75 per barrel (Figure 2, Table 1). At these prices, the corresponding retail prices, including taxes and in energy equivalent terms, do not universally favor ethanol. One key determinant of local retail prices to consumers is of course the transportation costs from the Midwest. The benchmark price is assumed to represent the wholesale ethanol price throughout the Midwest, so, in part due to the lower prices of this area, the share of ethanol in total motor fuel consumption is 5%. The share of ethanol in motor fuel is almost as high in some regions that are quite distant from the Midwest, such as 4% for the West coast (PADD 5) and in some states in the

Figure 2: Simulated Ethanol Use as a Share of Total Motor Fuel Use, with Benchmark Ethanol Price of $2 per Gallon and Benchmark Oil Price of $75 per Barrel, in 2009



Northeast. The states in which ethanol accounts for 5% or more of total motor fuel use tend to be those states that already include ethanol in a large share of the fuel as an additive, as in many East Coast states, or that have a mandate, like Minnesota and Missouri. In some states, however, ethanol remains an expensive source of fuel services relative to gasoline, when oil costs $75 per barrel and, in the absence of local additive requirements, there is very little use of ethanol at all.

The share of ethanol in motor fuel use highlights critical factors that determine the concentration of ethanol use (Figure 3). Taking into account not only the share of ethanol in motor fuel use, but also the overall motor fuel quantities leads to the observation that at these prices, and taking into account local laws, the largest simulated ethanol consumption is in the Midwest. The Midwest accounts for 30% of U.S. ethanol consumption, as opposed to 27% of motor fuel use. Ethanol use in the West Coast (PADD 5) is also high. California alone accounts for 12% of U.S. ethanol use, in large part due to high additive use, and 11% of U.S. motor fuel use. But voluntary uses of ethanol are not large outside the Midwest at these prices.

The transportation needs in 2009 under these settings, namely these benchmark prices ($2 per gallon ethanol and $75 per barrel oil) and the assumption that U.S. ethanol demand is met by supplies from the Midwest, reflect both the location of ethanol consumption and the costs of getting it there (Figure 4). Shipping ethanol to the East Coast (PADD 1) accounts for 58% of total expenditures and shipping to the West Coast (PADD 5) accounts for 27%, with the cost of shipping ethanol to California alone representing 20% of the U.S. total.

Oil price changes affect these results in two ways. First, a higher oil price leads to greater transportation costs, thus implying a greater margin between a given set of benchmark prices and retail consumer prices. Second, the higher oil price also leads to a higher gasoline price and may encourage consumers to voluntarily adopt fuels in which ethanol represents a greater share, such as E85. Consumer willingness to substitute depends on how close local prices are to the point at which fuel services can be had from either fuel at equal cost. These affects vary by state, depending in particular on the role ethanol plays as an additive prior to the oil price increase.

Table 1: Quantities Demanded and Transportation Costs, with Benchmark Ethanol Price of $2 per Gallon and Benchmark Oil Price of $75 per Barrel, in 2009

	Motor Fuel Use, 1000 gallons gas equivalent	State Share of US Motor Fuel use	Ethanol Use, 1000 gallons gas equivalent	State Share of US Ethanol Use in gas equivalent	Ethanol Share of State Motor Fuel in gas equivalent	Ethanol Transportation Costs 1000 dollars	Transportation Cost Share
AK	292,621	0%	6,669	0%	2%	3,327	0%
AL	2,657,708	2%	51,461	1%	2%	13,203	1%
AR	1,456,588	1%	49,771	1%	3%	12,770	1%
AZ	3,128,947	2%	100,103	2%	3%	49,939	3%
CA	16,014,238	11%	700,813	12%	4%	349,618	20%
CO	2,212,464	2%	127,566	2%	6%	27,274	2%
CT	1,767,892	1%	119,735	2%	7%	55,751	3%
DC	140,335	0%	4,708	0%	3%	2,192	0%
DE	445,279	0%	32,087	1%	7%	14,940	1%
FL	9,110,037	6%	102,853	2%	1%	47,890	3%
GA	5,447,925	4%	27,451	0%	1%	12,781	1%
HA	468,623	0%	27,687	0%	6%	13,812	1%
IA	1,529,489	1%	105,828	2%	7%	0	0%
ID	666,111	0%	4,151	0%	1%	887	0%
IL	5,183,675	4%	374,548	6%	7%	0	0%
IN	3,211,514	2%	146,134	2%	5%	0	0%
KS	1,325,080	1%	32,326	1%	2%	0	0%
KY	2,278,143	2%	109,356	2%	5%	0	0%
LA	2,197,365	2%	68,932	1%	3%	17,685	1%
MA	2,863,559	2%	206,422	3%	7%	96,114	5%
MD	2,722,313	2%	195,880	3%	7%	91,205	5%
ME	714,516	1%	23,642	0%	3%	11,008	1%
MI	4,823,271	3%	207,340	3%	4%	0	0%
MN	2,648,114	2%	190,363	3%	7%	0	0%
MO	3,186,622	2%	227,286	4%	7%	0	0%
MS	1,613,928	1%	54,563	1%	3%	13,999	1%
MT	502,549	0%	4,075	0%	1%	871	0%
NC	4,603,863	3%	135,163	2%	3%	62,934	4%
ND	332,499	0%	18,492	0%	6%	0	0%
NE	819,553	1%	33,067	1%	4%	0	0%
NH	728,103	1%	52,431	1%	7%	24,413	1%
NJ	4,389,218	3%	317,217	5%	7%	147,702	8%
NM	1,004,380	1%	34,805	1%	3%	8,930	1%
NV	1,221,298	1%	49,015	1%	4%	24,452	1%
NY	5,642,992	4%	321,915	5%	6%	149,889	9%
OH	5,106,628	4%	204,999	3%	4%	0	0%
OK	1,908,712	1%	12,775	0%	1%	0	0%
OR	1,598,877	1%	72,037	1%	5%	35,938	2%
PA	5,219,481	4%	160,129	3%	3%	74,559	4%
RI	375,321	0%	26,960	0%	7%	12,553	1%
SC	2,695,655	2%	14,216	0%	1%	6,619	0%
SD	403,327	0%	20,706	0%	5%	0	0%
TN	3,160,488	2%	20,348	0%	1%	0	0%
TX	12,500,627	9%	657,162	11%	5%	168,605	10%
UT	1,137,243	1%	7,501	0%	1%	1,604	0%
VA	4,095,278	3%	273,304	5%	7%	127,255	7%
VT	350,372	0%	11,701	0%	3%	5,448	0%
WA	2,808,299	2%	110,128	2%	4%	54,940	3%
WI	2,505,313	2%	107,034	2%	4%	0	0%
WV	842,591	1%	20,452	0%	2%	9,523	1%
WY	319,854	0%	1,817	0%	1%	389	0%
US	142,378,876	100%	5,985,125	100%	4%	1,751,020	100%

Figure 3: Simulated Total Ethanol Use, with Benchmark Ethanol Price of $2 per Gallon and Benchmark Oil Price of $75 per Barrel, in 2009

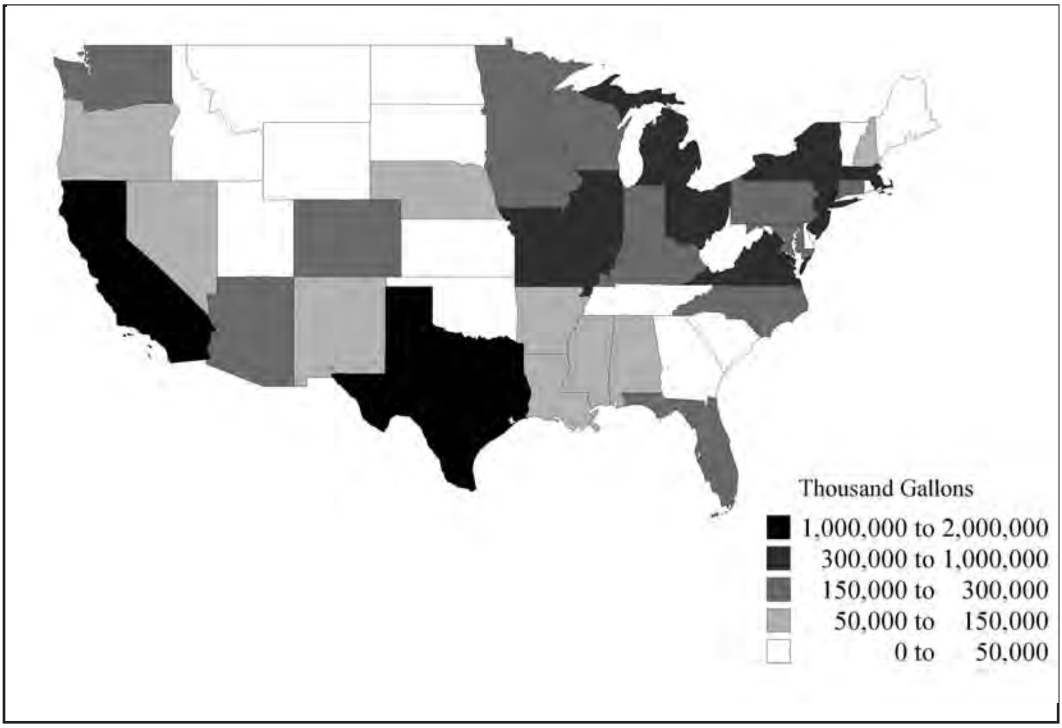


Figure 4: Simulated Total Ethanol Transportation Costs, with Benchmark Ethanol Price of $2 per Gallon and Benchmark Oil Price of $75 per Barrel, in 2009

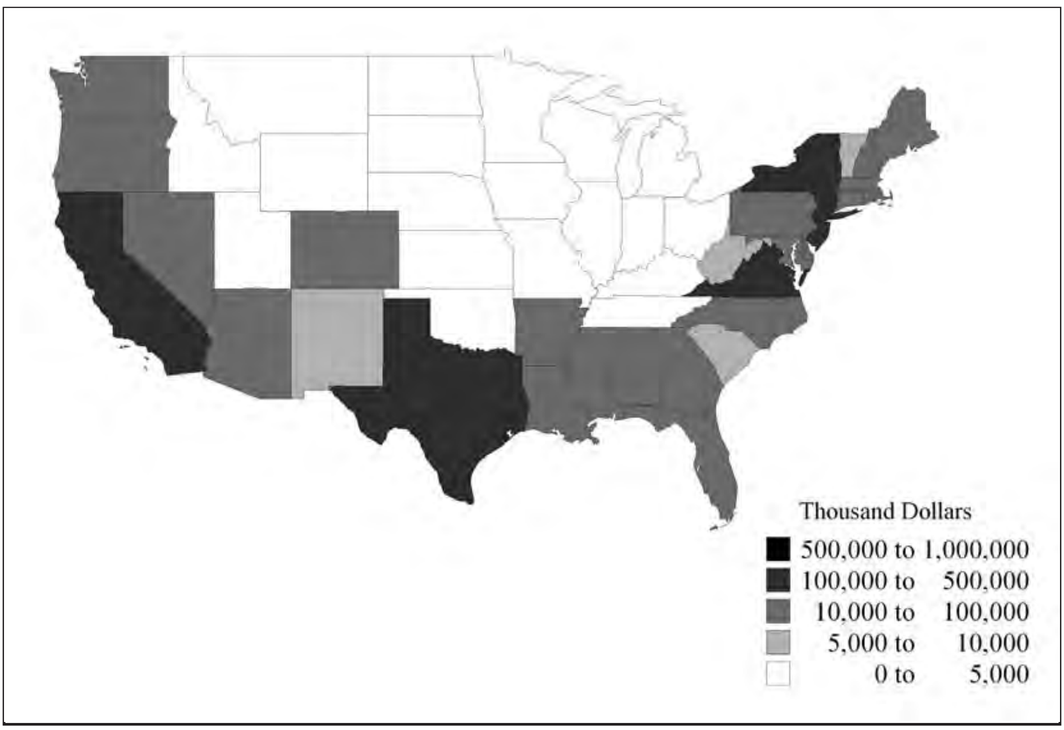
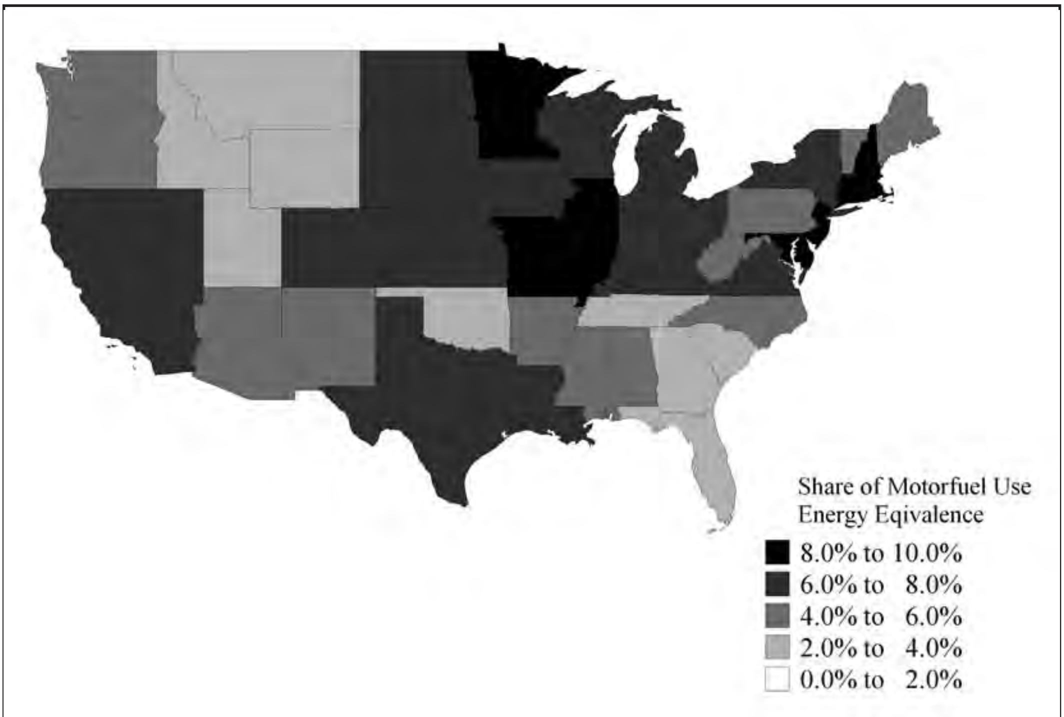


Figure 5: Simulated Ethanol Use as a Share of Total Motor Fuel Use, with Benchmark Ethanol Price of $2 per Gallon and Benchmark Oil Price of $150 per Barrel, in 2009



If the oil price were $150 per barrel, double the first case, and the ethanol price was still $2 per gallon in 2009, then the simulated use of ethanol in the U.S. increases by about one-half. This is a demand-side only affect, as in reality such an increase in quantity demanded would cause a higher ethanol price. Patterns of ethanol use and transportation costs show a sharp increase in the share of ethanol in total motor fuel use in central and Southeastern states, but less of an effect on the share in states along the West Coast and in the Northeast (Figure 5, Table 2). The share of ethanol in total motor fuel rises to 6% or so in the U.S, or by one-half relative to the case of a $75 oil price. The changes in absolute levels of ethanol use by state reflect these outcomes (Figure 6). Midwest ethanol consumption increases by more than half, and accounts for 31% of total ethanol use. Use in the West Coast increases almost as much, but its share of rising U.S. ethanol use slips to 16%. Ethanol use rises at a fast pace in Southern states, such as Florida, Georgia, and South Carolina, albeit from very low starting levels. The relative increase in use in the New England states is smaller, as illustrated by the 1% increase in the share of ethanol use in motor fuel observed in New York, but start from a higher base. The changes reflect the additive use of ethanol prior to the simulated oil price increase. In places where ethanol already accounts for a large share of motor fuel due to its inclusion as an additive, consumer prices for different fuels may be quite similar no matter the oil price. For example, an area in which ethanol serves as a fuel additive already includes 10% ethanol. Also, in such a region, shifts to E85 reduce sales of ethanol in lower blends.

The implication of a higher oil price on the costs of transporting ethanol from the Midwest to the states of consumption is to raise the transport costs per unit, which are assumed to be affected largely by fuel costs themselves and due to increased quantities of ethanol transported. According to Figure 7, more than half the overall increase in transportation expenditure is associated with East Coast states (PADD 1), as compared to 26% for the West Coast (PADD 5). Total costs of transporting ethanol are simulated to be two and a half to three times as high with the doubling in oil price. About four-fifths of the total increase in expenditures on transportation is associated with a rising quantity of ethanol being moved in order to meet higher consumer demand.

Table 2: Quantities Demanded and Transportation Costs, with Benchmark Ethanol Price of $2 per Gallon and Benchmark Oil Price of $150 per Barrel, in 2009

	Motor Fuel Use, 1000 gallons gas equivalent	State Share of US Motor Fuel use	Ethanol Use, 1000 gallons gas equivalent	State Share of US Ethanol Use in gas equivalent	Ethanol Share of State Motor Fuel in gas equivalent	Ethanol Transportation Costs 1000 dollars	Transporta ion Cost Share
AK	284,739	0%	11,052	0%	4%	11,027	0%
AL	2,582,586	2%	117,772	1%	5%	60,432	1%
AR	1,415,646	1%	74,309	1%	5%	38,130	1%
AZ	3,040,744	2%	158,342	2%	5%	157,986	3%
CA	15,559,346	11%	942,164	11%	6%	940,045	19%
CO	2,152,310	2%	161,997	2%	8%	69,271	1%
CT	1,720,097	1%	139,835	2%	8%	130,219	3%
DC	136,384	0%	6,502	0%	5%	6,055	0%
DE	432,983	0%	36,786	0%	8%	34,256	1%
FL	8,846,764	6%	318,917	4%	4%	296,986	6%
GA	5,286,047	4%	117,235	1%	2%	109,173	2%
HA	455,896	0%	28,726	0%	6%	28,662	1%
IA	1,487,004	1%	117,815	1%	8%	0	0%
ID	647,701	0%	17,127	0%	3%	7,324	0%
IL	5,041,559	4%	460,843	5%	9%	0	0%
IN	3,122,190	2%	234,438	3%	8%	0	0%
KS	1,289,011	1%	82,414	1%	6%	0	0%
KY	2,215,064	2%	162,986	2%	7%	0	0%
LA	2,135,598	2%	132,740	2%	6%	68,113	1%
MA	2,785,194	2%	237,703	3%	9%	221,357	5%
MD	2,648,297	2%	223,820	3%	8%	208,429	4%
ME	695,159	1%	33,080	0%	5%	30,806	1%
MI	4,688,288	3%	353,305	4%	8%	0	0%
MN	2,576,592	2%	212,455	2%	8%	0	0%
MO	3,097,367	2%	258,469	3%	8%	0	0%
MS	1,568,494	1%	80,804	1%	5%	41,463	1%
MT	489,002	0%	13,186	0%	3%	5,638	0%
NC	4,475,984	3%	253,424	3%	6%	235,997	5%
ND	323,737	0%	24,178	0%	7%	0	0%
NE	797,407	1%	52,401	1%	7%	0	0%
NH	708,287	1%	60,237	1%	9%	56,094	1%
NJ	4,266,755	3%	367,696	4%	9%	342,411	7%
NM	976,379	1%	52,083	1%	5%	26,725	1%
NV	1,187,982	1%	76,393	1%	6%	76,222	2%
NY	5,488,533	4%	395,014	5%	7%	367,850	7%
OH	4,969,214	4%	360,024	4%	7%	0	0%
OK	1,853,475	1%	55,388	1%	3%	0	0%
OR	1,554,774	1%	83,858	1%	5%	83,669	2%
PA	5,076,795	4%	254,230	3%	5%	236,747	5%
RI	365,364	0%	30,651	0%	8%	28,543	1%
SC	2,615,954	2%	59,770	1%	2%	55,660	1%
SD	392,362	0%	28,812	0%	7%	0	0%
TN	3,070,018	2%	90,414	1%	3%	0	0%
TX	12,151,252	9%	834,088	10%	7%	427,995	9%
UT	1,105,693	1%	28,347	0%	3%	12,121	0%
VA	3,980,869	3%	317,668	4%	8%	295,824	6%
VT	340,693	0%	16,574	0%	5%	15,434	0%
WA	2,731,835	2%	153,339	2%	6%	152,994	3%
WI	2,437,536	2%	163,296	2%	7%	0	0%
WV	819,369	1%	37,403	0%	5%	34,831	1%
WY	310,851	0%	7,922	0%	3%	3,387	0%
US	138,401,181	100%	8,538,027	100%	6%	4,917,877	100%

Figure 6: Simulated Total Ethanol Transportation Use, with Benchmark Ethanol Price of $2 per Gallon and Benchmark Oil Price of $150 per Barrel, in 2009

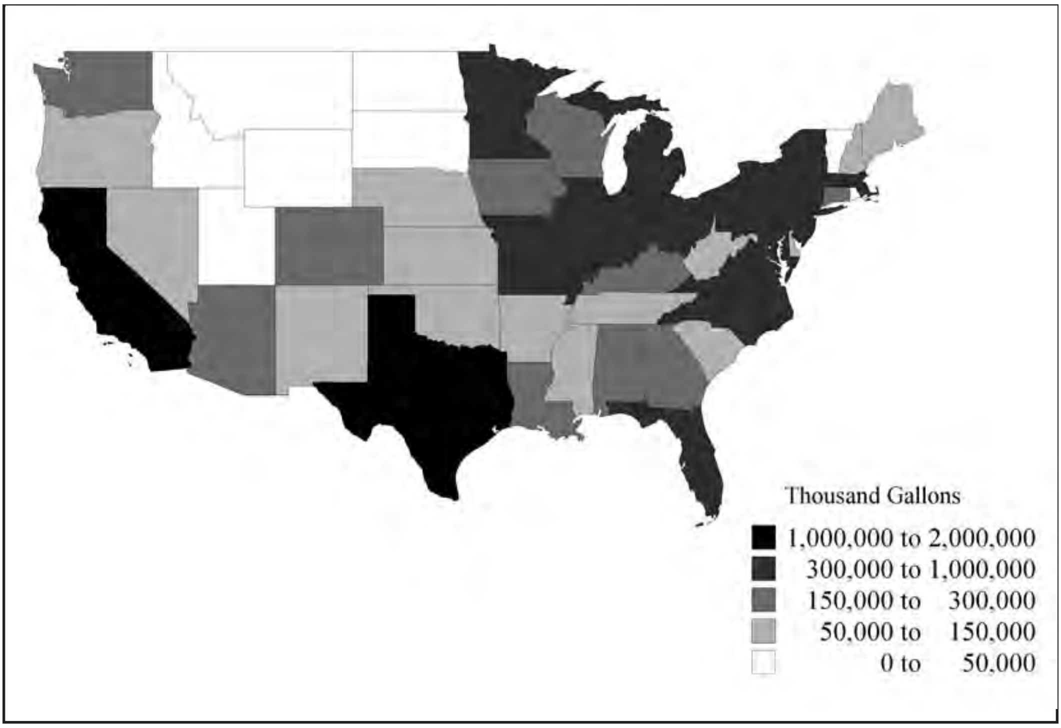
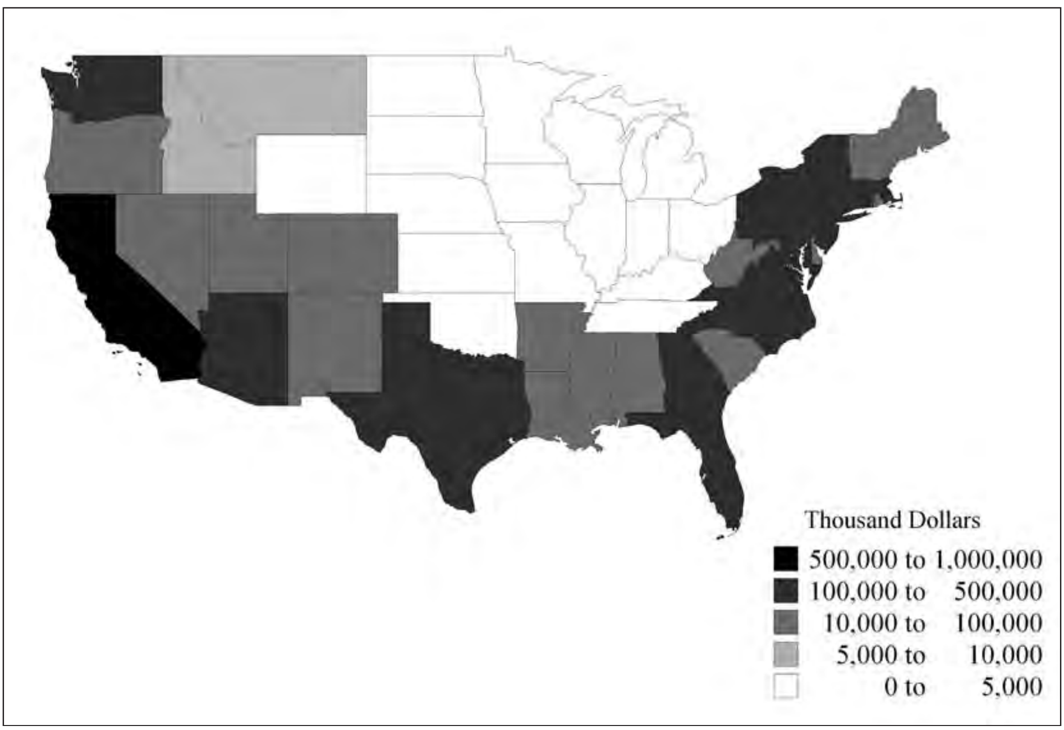


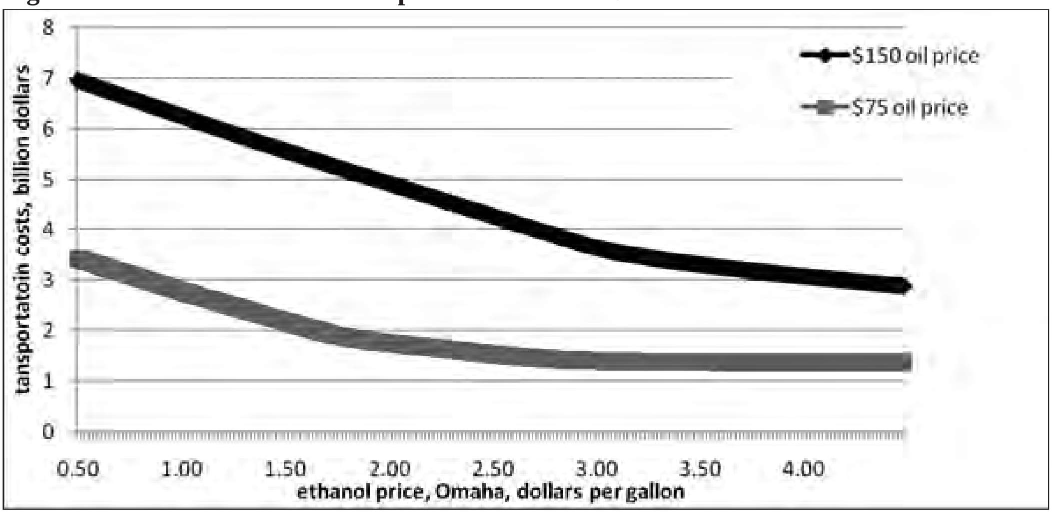
Figure 7: Simulated Total Ethanol Transportation Costs, with Benchmark Ethanol Price of $2 per Gallon and Benchmark Oil Price of $150 per Barrel, in 2009



The costs associated with transporting ethanol from the Midwest to other parts of the country depend on both ethanol and oil prices, but the relationship is not linear. A lower benchmark price of ethanol will tend to encourage consumption, leading to greater demand for transportation. A rising oil price will affect transportation prices and quantities as noted above. Non-linearity is expected in light of the low price elasticity of additive ethanol use and the limits in short-run ethanol adoption.

We explore how varying ethanol and oil prices can affect transportation costs (Figure 8). The use of ethanol as an additive is almost perfectly inelastic, even at high prices. This inflexibility of ethanol use implies that costs to move ethanol from the Midwest will be incurred as long as largely compulsory uses remain, and as long as the product is sourced from the Midwest. A lower ethanol price induces greater consumption, like any move along a demand curve, and consequently greater transportation requirements. Were the oil price to be higher, then the transport cost for a given quantity of ethanol would be greater and the demand for ethanol would tend to be greater as well, leading to higher overall transport costs. Whereas the base case of ethanol priced at $2 per gallon implies that doubling petroleum price causes transportation costs to increase 281%, doubling the oil price leads to a 279% increase in transportation costs if the ethanol price is $2.50 per gallon due to the combination of higher quantity and higher transport cost, and a 255% increase if the price is $1.50 and a smaller relative increase at very high ethanol prices.

Figure 8: Simulated Ethanol Transportation Costs of Various Ethanol and Oil Prices in 2009



CONCLUSIONS

These experiments trace out the demand and transportation costs of ethanol distributed from the Midwest in 2009 under certain conditions. The exercise treats ethanol supply transportation services as perfectly elastic at a given price, albeit one that is sensitive to oil price changes. The representation focuses on short-term U.S. demand for ethanol produced in the Midwest, introducing constraints relating to E85 in terms of consumer adoption and also infrastructure development that would not be relevant for a long-run analysis. While ignoring the potential for trade, new ethanol production technologies that may be developed in the longer term, and potential policy changes, the stylized representation leads to key results regarding the likely evolution of demand for ethanol transportation services. Results are also sensitive to assumptions about demand, which could expand more quickly in response to relative prices, as compared to the rate implied by the parameters assumed here. Alternatively, the rate could be slower or limited overall if a large share of consumers are extremely reluctant to adopt even E10.

It is nearly tautological to note that the costs of transportation overall are sensitive to the costs of transportation per unit, but the interdependence of oil and ethanol prices in determining quantities demanded leads to another avenue of causality from oil price to transportation costs. Higher oil-based fuel prices may encourage consumers to adopt fuels with ethanol, but consumers' response to higher oil-based gasoline prices may or may not be one of broad replacement with ethanol. Even setting aside the constraints imposed on short-run adoption of E85, the presence of both largely compulsory and entirely voluntary uses of ethanol lead to sharply different demand responses depending on the relative levels of local retail energy-equivalent prices. If regulatory circumstances require that consumers buy fuels that already contain 10% ethanol, the same share as in E10, then price changes lead to meaningful increases in ethanol use only if consumers opt to buy E85 and the necessary flex fuel vehicle that can use that blend.

This stylistic representation of ethanol demand shows that changing benchmark prices have non-linear affects on blends purchased and quantities of ethanol demanded and therefore on transportation expenditures. Quantities of ethanol transported to states with high levels of additive use are largely insensitive to relative fuel prices, although transportation expenditures will increase if transportation rates change. Quantities of ethanol shipped to markets in which there is low additive use may be much more price responsive, particularly if local retail prices approach the point at which fuel services are equivalently priced. Total transportation services used may also increase as ethanol's lower energy value requires a greater volume to be transported than the gasoline it is to replace. These different responses to changing ethanol prices should be considered as industry participants consider their allocation of transportation resources and ethanol transportation infrastructure investment.

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