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(CONDENSED VERSION)

by

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Abstract

A careful analysis of the costs and benefits of using MTBE as a fuel oxygenate, as compared to use of its most reasonable substitutes, finds that the net private and social costs of MTBE's alternatives are substantially higher than those of MTBE. The expected costs of future MTBE use have been revised downwards as a result of the state of California's successful program to replace and monitor underground fuel storage tanks, as well as more complete estimates of the incremental clean up costs from MTBE contamination. Moreover, as California has begun to seriously consider the logistics and costs of removing MTBE from gasoline, it has become clear that the cost of MTBE alternatives is higher than previously anticipated. In light of the information that has come to light since California's 1999 decision to phase out MTBE use by 2003, that decision may merit revisiting.

Key Words: MTBE, oxygenate, California, groundwater, RFG, contamination, ethanol, alkylates.

Introduction

In the early 1990s, oxygenated gasoline was widely hailed as a solution to many of the nation's air quality problems, especially in the so-called federal nonattainment geographic regions. At that time, it was expected that MTBE (methyl tertiary butyl ether), would be widely used as a gasoline oxygenate. Even though the anticipated air quality benefits of oxygenated gasoline were, in fact, realized, the large-scale use of MTBE as a gasoline oxygenate resulted in adverse impacts to water quality. As MTBE was detected in water supplies in the late 1990s, public concern intensified and proposals to ban the use of MTBE in gasoline surfaced in several states.

In 1999, the State of California passed the first legislation in the United States that was motivated by the water quality impacts of MTBE. Under the authority granted by this legislation, the governor of the State of California announced in March 1999 that MTBE would be banned in gasoline in California beginning in 2003.[2] Several other states have moved to reduce or eliminate the use of MTBE as well, and the U.S. Environmental Protection Agency (EPA) is evaluating a federal ban on MTBE. At the same time that the State of California moved to ban MTBE, California also requested that the EPA waive the federal minimum oxygenate requirement for reformulated gasoline sold in California.[3] While

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[2] Governor Gray Davis, Executive Order D-5-99, 25 March 1999.
[3] Governor Gray Davis, letter to Carol Browner, 12 April 1999.

this request has been denied,[4] California congressional representatives have introduced legislation that would waive the federal oxygenate requirement, with the result that the production and sale of non-oxygenated gasoline would be possible throughout California, as well as the rest of the United States.

As the pendulum has swung from public concern about air quality to public concern about water quality, the risk has increased that special interests will dominate implementation of policy reforms that ill-serve society. Unfortunately, this risk has not been mitigated by the studies that have been conducted to date. Many of these studies evaluate only separable components,[5] and those that propose to perform a comprehensive evaluation of the cost and benefits are incomplete and internally inconsistent.[6] Given the billions of dollars of potential consequences that can be quantified, it is surprising that the proposed banning of MTBE has not been subjected to a serious and internally consistent analysis.

The purpose of this paper is to better inform those involved in the policy debate by providing a comprehensive and internally consistent cost-benefit analysis of the gasoline formulation alternatives for California, based on the best information that is currently

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[4] United States Environmental Protection Agency, "EPA issues decision on California waiver request," press release, 12 June 2001; United States Environmental Protection Agency, "Analysis of and Action on California's Request for a Waiver of the Oxygen Content in Gasoline," EPA 420-S-01-008, June 2001.

[5] See, for instance, California Energy Commission, "Analysis of the Refining Economics of California Phase 3 RFG"; and "An Evaluation of MTBE Impacts to California Groundwater Resources," Lawrence Livermore National Laboratory.

[6] See, for instance, Arturo A. Keller, Linda Fernandez, Samuel Hitz, Heather Kun, Alan Peterson, Britton Smith and Masaru Yoshioka, "An integral cost-benefit analysis of gasoline formulations meeting California Phase 2 Reformulated Gasoline requirements," Bren School of Environmental Science and Management, UCSB, Santa Barbara, CA, 1998.

available. Such an analysis must distinguish between sunk and incremental costs,[7] and must consider both private and social costs.[8] The analysis must also recognize the economic responses of consumers and firms to changes in prices and costs, and must consider not only costs in the immediate market in question, but also costs from spillovers to other markets.

Analysis

We present a comprehensive and internally consistent cost-benefit analysis of the gasoline formulation alternatives for California. The cost-benefit model considers: impacts on fuel production costs; impacts on water quality; and, impacts on air quality.

Several categories of cost that are important to any comprehensive cost-benefit analysis have been neglected in the existing literature. These costs include: (i) the cost to taxpayers of increased ethanol consumption, due to the ethanol tax subsidy; (ii) the increases in the cost of oil imports caused by replacing MTBE volumes with blending components made from other

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[7] *Sunk costs* are those costs that cannot be averted by future action. For instance, the past use of MTBE may result in current sites of groundwater contamination that will result in future remediation costs. However, even if MTBE is removed from gasoline now, this will not affect the (past, current and future) costs from existing contamination sites. Therefore, these remediation costs are not a cost of continuing to use MTBE in gasoline. Only those remediation costs from future releases of gasoline containing MTBE are a cost of the continued use of MTBE.

[8] *Private costs* are costs reflected in the market prices of products. The most obvious example is the change in the price of gasoline faced by consumers. Private costs should also take into account effects in related markets such as natural gas. Other private costs are the less obvious impacts on the effective price of gasoline to consumers, such as changes in the amount of gasoline required to drive a mile attributable to replacement of MTBE with other blending components. *Social costs* are costs not necessarily included in market prices, or considered by consumers and producers in their decisions on how much to buy and sell. The impact of MTBE on water resources is a social cost. The impact of changes in air quality (and thus on human health) is another example of a social cost. Prior studies have assumed, correctly, that the performance requirements for reformulated gasoline, stated in terms of required reductions in emissions in ozone precursors — nitrogen oxides and reactive hydrocarbons — and carbon monoxide, would not be compromised if there were a ban on MTBE. However, there are differences in the emissions of some air toxics and potential carcinogens among gasoline alternatives, and these differences need to be carefully considered.

substitutes; (iii) the effects of changes in gasoline prices on gasoline consumption and thus on automobile emissions; and (iv) the potential effect of MTBE substitutes, such as ethanol, on water quality.

Overall, our analysis indicates that the continued use of MTBE in California gasoline has clear and significant economic benefits relative to either the use of ethanol or the use of non-oxygenated reformulated gasoline (RFG) containing alkylates. The increased cost resulting from a ban of MTBE in California when ethanol replaces MTBE ranges from $0.88 billion to $1.33 billion per year, with an expected value of $1.24 billion per year. If non-oxygenated RFG replaces MTBE, the annual increased costs range from $0.55 billion to $1.01 billion, with an expected value of $0.90 billion. The model results are robust to reasonable ranges of uncertainty; even under the worst case for MTBE and the best case for the other substitutes, it still follows that banning MTBE will lead to an increase in the total cost associated with gasoline use in the state of California.

MTBE Alternatives

In the event of an MTBE ban, there are two feasible alternative gasoline formulations that preserve the clean air benefits of RFG with MTBE: (i) RFG in which MTBE is replaced with ethanol; and (ii) a non-oxygenated RFG, produced by replacing MTBE with alkylates. Both of these alternatives require that other properties of the gasoline be adjusted to compensate for the changes in fuel characteristics created by the blending of ethanol or alkylates into the fuel.

To achieve a 2% by weight oxygen content, MTBE is blended in gasoline at approximately 11.5% by volume. Therefore, in addition to incorporating oxygen with gasoline, MTBE has the effect of diluting other undesirable constituents in gasoline such as benzene and sulfur.[9] MTBE also increases the octane of gasoline, and does not adversely affect other important gasoline properties such as Reid Vapor Pressure (RVP) and cold weather starting performance. Moreover, MTBE is widely available, and RFG made with MTBE is relatively inexpensive and easy to blend, store and transport. MTBE has another important attribute: it is derived from natural gas by combining methane (the primary constituent of natural gas) and butane (a natural gas liquid). Most MTBE used in the United States is produced in refineries and merchant plants from natural gas produced in the United States and Canada. [10] Its use in gasoline reduces, by an equivalent quantity (in energy terms), oil imports, since oil imports are the marginal source of petroleum supplies into the United States [19]. On the other hand, the use of MTBE increases U.S. imports of natural gas from Canada. Moreover, the use of MTBE to manufacture RFG has resulted in adverse impacts on water resources, particularly groundwater. Finally, the use of MTBE may increase automobile emissions of formaldehyde.

Ethanol also has beneficial properties when used as a fuel oxygenate. Like MTBE, ethanol increases the octane of gasoline. Moreover, ethanol is produced from corn and other plant

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[9] According to the United States Energy Information Administration, "MTBE is an important blending component for RFG because it adds oxygen, extends the volume of the gasoline and boosts octane, all at the same time. In order to meet the 2% (by weight) oxygen requirement for federal RFG, MTBE is blended into RFG at approximately 11% by volume, thus extending the volume of the gasoline [8].

[10] In addition, about 29% of U.S. demand for MTBE is met through imports. (Average for the period 1998-2000 [9]).

materials, and is thus often considered a “renewable” fuel.[11] However, ethanol has several undesirable properties as a gasoline additive. Ethanol results in higher volatile organic compound (VOC) emissions from gasoline, and the higher volatility of ethanol makes it more difficult to meet summertime evaporative emissions criteria for RFG. In order to compensate for the higher volatility of ethanol, while maintaining performance characteristics such as cold weather starting, the “base” gasoline blend stock must be adjusted. This adjustment is costly and increases the production cost of the resulting RFG. Moreover, since ethanol contains considerably more oxygen (by weight) than does MTBE, RFG with ethanol contains only about 5% ethanol by volume (compared to 11.5% by volume, for RFG with MTBE). The difference in volume must be made up with gasoline, which leads to increased demand for crude oil. Ethanol also has lower energy density than MTBE, and RFG made with ethanol results in lower fuel economy than does RFG made with MTBE. Lower fuel economy performance results in higher costs to gasoline consumers and higher emissions per mile driven (even when emissions per gallon burned are held constant). Evaporative emissions can increase substantially when a motorist mixes ethanol-containing gasoline with ethanol-free gasoline in the same vehicle. Ethanol is also considerably more difficult to transport and handle in the refining system, because it absorbs water and can cause corrosion and other problems in the refinery. Separate storage tanks and handling equipment are required, and ethanol must be transported in dedicated facilities. As a result, ethanol is generally blended into gasoline at distribution terminals rather than at refineries. Ethanol is generally produced in the U.S. Midwest, and transportation costs to California are substantial. The market price of

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[11] The degree to which ethanol is “renewable” depends on the “net energy balance” of ethanol as well as the source of the energy used to produce corn and manufacture and transport ethanol.

ethanol is kept artificially low by a federal tax subsidy on ethanol production. Thus, the full cost of ethanol is significantly higher than the cost of MTBE. In addition, the use of ethanol may also have several adverse environmental impacts. These may include increased smog formation from ethanol-containing gasoline, as well as levels of acetaldehyde emissions. In addition, ethanol may have adverse, but substantially less than MTBE impacts on groundwater quality.

It is also possible to produce a fuel that satisfies the California Phase II RFG emissions criteria without use of oxygenates, by replacing MTBE with alkylates [16, 17, 25]. Other blending adjustments are also required to achieve properties that produce acceptable emissions under the predictive model. In a typical case, switching from MTBE to a purely non-oxygenated fuel requires increasing the volume of alkylates from 14% to 25% of the gasoline produced [16].[12] Alkylates are a high quality petroleum blend stock and have few undesirable properties other than cost and limited availability.[13] Alkylates are produced in refineries, from petroleum feedstocks and ultimately crude oil. Gasoline refiners can either purchase alkylates, or (at a cost) convert capacity currently used to produce MTBE from petroleum feedstocks to produce alkylates (from isobutylene). In either case, the cost (per gallon) of alkylates to refiners is higher than the cost of MTBE, and a greater volume of

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[12] A study by Oak Ridge National Laboratory concluded that to meet federal RFG requirements in PADD 1, a no-oxygenates case would require alkylates to increase from 10% to 35% of the gasoline produced [20].

[13] According to the California Energy Commission study, "Alkylate is an important component of EPA-reformulated gasoline produced on the U.S. Gulf Coast (USGC) and is a component of high-value premium gasolines as well as aviation gasolines produced in all regions of the world" [21, pp. 6]. "Alkylate is the ideal CARB gasoline blend stock. Alkylate contains no olefins, no sulfur, no aromatics, no benzene and has low vapor pressure. Alkylate has attractive octane characteristics. There is no property relevant to CARB gasoline in which alkylate has poor characteristics. Alkylate from California refiners and that produced elsewhere is essentially the same in all respects" [21, pp. 68].

alkylates is required per gallon of RFG. Finally, because alkylates are derived from crude oil, replacement of MTBE with alkylates will increase US crude oil imports.

Impacts on Fuel Production Costs

When replacing MTBE in reformulated gasoline, a number of factors impact gasoline production costs. (See Figure 1 for an overview.) These costs can be separated into six components: (i) the change in cost to refiners to manufacture RFG without MTBE; (ii) the change in the amount of fuel that consumers must purchase to meet their driving needs when the miles per gallon obtainable from gasoline changes; (iii) the real resource costs of ethanol production that are paid by taxpayers through the ethanol tax subsidy; (iv) the costs to the U.S. economy associated with changes in oil imports; (v) the consumer surplus loss attributable to reduced fuel consumption; and, (vi) net changes in producer and consumer surplus and import costs in natural gas markets, due to the effects of an MTBE ban on demand for natural gas.

The cost of producing RFG using ethanol is estimated to be 5.5 cents per gallon more than the MTBE-based reference fuel. This cost includes all refining costs (4.9 cents per gallon), ancillary and logistics costs (0.4 cents per gallon), and the value to the consumer of lost fuel economy (0.2 cents per gallon) [4]. The ethanol price used in this estimate was the effective cost to the refiner, which is less than the cost of producing ethanol by the amount of the blender's tax credit.

To estimate the annual increase in production costs to California, the increase in cost per gallon is multiplied by total consumption of gasoline in California, approximately 14.5 billion gallons in 2000[14] [10]. The expected annual increase in refinery costs attributable to using ethanol in RFG, relative to continued use of MTBE, is approximately $763.1 million per year.

The estimated cost of producing non-oxygenated RFG is 4.9 cents per gallon, including all refining costs (5.5 cents per gallon), ancillary and logistics costs (0.3 cents per gallon), and an offset for the value to the consumer of improved fuel economy (0.9 cents per gallon).[15] [16] As in the case of ethanol, the increase in cost per gallon is multiplied by total consumption of gasoline in California in order to estimate the annual increase in refining cost. The expected increase in refinery costs from replacing MTBE with a non-oxygenated gasoline is approximately $835.8 million per year.

The use of ethanol as a fuel additive is subsidized by the federal government (in the form of an exemption from the gasoline excise tax).[17] Therefore, the cost to refiners for ethanol is substantially less than the cost to produce this ethanol. In studies done before 1996 it was often claimed that the reduction in federal motor fuel taxes granted to ethanol had either

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[14] In order to take into account the effect that the higher gasoline prices caused by an MTBE ban would have on demand for gasoline, the estimate of gasoline consumption used in this calculation has to be reduced below the actual amount that is consumed in the absence of an MTBE ban. Based upon the available literature, a range of price elasticities of demand for gasoline is used to calculate the reduction in demand that would be caused by the higher price if the ethanol option is used. The basis for the choice of these elasticities, and details of the calculation, is provided in Appendix A.

[15] In the 1998 California Energy Commission Report, Mathpro estimated a range of 1.9 to 8 cents per gallon, depending on whether the flat or averaging limits of the predictive model are utilized and how much time is allowed for refiners to make capital investments to change refiner configurations [4].

[16] Oak Ridge National Laboratory performed a similar study for PADD I (the East Coast), and concluded that a non-oxygenated gasoline would cost 2.4 to 6 cents per gallon more than federal RFG [20].

[17] Ethanol currently receives a federal excise tax exemption of 54 cents per gallon, which is scheduled to decline to 53 cents in 2001, 52 cents in 2003, and 51 cents in 2005. Legal authority for the federal tax exemption expires in 2007, but this exemption has been renewed several times since it was initiated in 1978. The tax exemption reduces payments of the federal Motor Fuels Excise Tax, which goes into the Highway Trust Fund and largely serves the purpose of funding highway construction and maintenance. Therefore, the excise tax can be seen as a Pigouvian tax that internalizes the costs of the roads and highways to the motorists who use them. As a result, any reduction in the tax on gasoline containing ethanol provides ethanol users with an inappropriate incentive to drive more, and impose more costs on the highway system. We do not include such costs in our cost-benefit model. We do include, however, the cost of highway construction and maintenance that other taxpayers must make up due to the gasoline tax exemption from the use of ethanol.

neutral or beneficial revenue impacts, because it raised corn demand and market prices, and reduced deficiency payments to farmers [31, 32]. Even at the time, that conclusion was dubious, because it was based on a particular set of assumptions about how the Secretary of Agriculture would exercise discretion in managing the acreage reduction program. Moreover, the 1996 Farm Bill effectively made the payments to farmers independent of market prices. Therefore, recent studies all agree that ethanol subsidies have no direct effect on outlays for farm income support.[18]

For a 5.7% blend of ethanol that provides 2% oxygen content by weight, the subsidy increases the cost of ethanol-blended RFG by $0.03078 per gallon, which results in a total increase in gasoline production costs of $449.2 million to $451.3 million per year, relative to the use of MTBE. This cost would be higher with blends containing more ethanol.

Replacing MTBE with either alkylates or ethanol increases total petroleum use in the United States, resulting in increased oil imports. Many social costs of oil imports have been cited in the literature [1, 2, 12], but here we only include a cost that has a clear economic rationale. This is the increase in the price of imported oil that is caused by higher levels of oil imports. While the higher price of oil represents a transfer payment, the payment is from the

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[18] "The increase in ethanol production with a MTBE phase-out would be eligible for the federal excise tax exemption on gasoline, or equivalent tax credit which would reduce federal tax revenues. The exemption is currently $0.54 per gallon and it is scheduled to drop to $0.53 on January 1, 2001, $0.52 on January 1, 2003 and $0.51 on January 1, 2005. Under the current law, the tax exemption expires on December 31, 2006. 'Under the FY 2000 President's Budget baseline, farm crop prices are expected to strengthen from current levels, which results in increased ethanol use having little to no impact on the cost of farm price and income support programs during the projection period…' and since 1996 Farm Bill production flexibility contract payments are not tied to the level of market prices, these farm program costs do not fall as market prices of corn and other grains increase, compared with the baseline." Hence our analysis is based on the U.S. corn policy regime reflected in the 1996 Farm Bill. Please note, however, that an expansion of corn demand resulting from an expansion in ethanol demand will not necessarily lead to higher equilibrium corn prices. Such potential outcomes will depend on corn supply response under alternative farm subsidy programs [27].

United States to foreign oil producers. Therefore, from the point of view of the United States, the additional payments for oil are a net cost.

The impact on oil imports of replacing MTBE with alkylates in non-oxygenated gasoline is straightforward.[19] Alkylates are petroleum products, so that we assume a one for one substitution (in energy terms) of oil imports for MTBE. The impact of replacing MTBE with ethanol is more complex. MTBE is largely produced from domestically produced natural gas, and ethanol is produced from agricultural products, so that if equal quantities of ethanol and MTBE were used there would be no impact on US oil imports. However, MTBE contains less oxygen by weight than ethanol. Therefore, to produce a fuel containing 2% oxygen requires adding only 5.7% ethanol but a full 11.5% of the final volume of MTBE. The difference, 5.8% of the volume of gasoline sold in California, must be made up with petroleum-based blending components. This increased use of petroleum-based blending components contributes to higher oil imports.

Three other factors must be taken into account in calculating the effect on oil imports. First is the energy content of the blending components being substituted for gasoline. Lower fuel economy per gallon must be made up for with greater total volume of gasoline purchases. This also increases oil imports. Second, the reduction in total demand for gasoline due to higher gasoline prices will tend to reduce oil imports. Third, reduced gasoline consumption leads to a loss in consumer welfare (consumer surplus) equal to the value to the consumer of the foregone consumption. In an ultimate supply and demand equilibrium, all these factors are included in the calculation of the net change in oil imports and gasoline consumption.

The increase in the U.S. import bill, loss of consumer surplus from gasoline consumption, and change in fuel efficiency adds between $263.8 million and $330.5 million annually to the cost of replacing MTBE with ethanol. The cost of an MTBE ban in which a non-oxygenated fuel is the replacement is from $326.0 million to $420.3 million annually.

An MTBE ban will tend to reduce natural gas demand. Lower demand for natural gas as an MTBE feedstock will lead to a lower price in North American natural gas market. We assume as a worst case that all the MTBE used in U.S. refineries is produced from North American natural gas feedstocks. If some MTBE or methanol as a feedstock were imported from other locations, the benefits we calculate in North American gas markets would be less. The expected net gain in producer and consumer surplus, plus the expected saving on the gas import bill due to lower prices being paid for remaining imports, ranges from a minimum of $109.4 million to a maximum of $326.1 million per year, with a expected value of $179.8 million per year.

Our analysis indicates that the total annual increase in gasoline production costs resulting from the replacement of MTBE with ethanol in California would range from $1.22 billion to $1.37 billion with an expected value of $1.33 billion. Should a waiver be granted allowing non-oxygenated fuel to be used in California, the increase in gasoline production costs would be $0.93 billion to $1.05 billion, with an expected value of $1.03 billion.

Impacts on Air Quality

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[19] A model of the California gasoline market and its connections with the world oil market is provided in Appendix A. Here we generally discuss our calculations, their rationale, and the resulting estimates of social costs of an MTBE ban.

The CAAA requires that reformulated gasoline provide specific reductions in emissions for the two ozone precursors, nitrogen oxides and reactive hydrocarbons. Under federal and California regulations, all legal fuels must achieve at least as great a reduction in NOx (nitrogen oxides) and ROG (reactive organic gas) as does a specified reference fuel. Therefore, we assume there is no increase in emissions of ozone precursors resulting from the replacement of MTBE by ethanol or alkylates. The direct air quality effects that can be expected to result from such substitution are: (i) reductions in driving due to higher fuel costs; and, (ii) changes in emissions of such air toxics as formaldehyde and acetaldehydes due to specific properties of MTBE and ethanol. (See Figure 2 for an overview.)

Higher gasoline prices reduce driving and provide air quality benefits that are not reflected in standard estimates of the effects of different gasoline formulations on air quality. Typically, standard estimates use models that assume driving patterns that are the same across all fuel formulations considered. However, like most goods, the demand for gasoline is responsive to price, and as gasoline prices increase the amount of gasoline consumed will decline. To quantify the value of air quality improvement due to higher gasoline prices, it is necessary to: (i) calculate the increase in the gasoline price "at the pump," due to the increased cost of manufacturing and distributing non-MTBE RFG; (ii) calculate the reduction in driving resulting from the price increase; (iii) calculate the reduction in air emissions attributable to the reduction in driving; and, (iv) place a monetary value on the emissions reduction.

It is presumed that refined products are produced at a fixed markup to the price of crude oil. Under these circumstances, the supply curve of refined products is perfectly elastic, and any increase in costs is passed dollar for dollar into the price of refined products. To calculate the reduction in emissions due to higher gasoline prices, we assume all reductions in gasoline consumption are achieved through reduced driving.[20] Percentage reductions in driving are multiplied by the on-road mobile source's (ORMS) share of total emissions for each region [18]. This gives the percentage reduction in total emissions for each region. Multiplying the percentage reduction in emissions attributable to reduced driving by the total residual damages gives the reduction in residual damages attributable to reduced driving.[21]

To provide a comprehensive evaluation of the benefits of reduced driving, we must estimate the marginal health damages expected under the currently adopted programs. Health effects, and marginal damages, from air pollution vary with the concentration of various pollutants in the atmosphere. California has adopted a set of programs that are deemed to be sufficient to achieve compliances with the National Ambient Air Quality Standards (NAAQS). Accordingly, the NAAQS targets are taken to be the probable future levels of air pollution at which marginal health damages should be estimated. Unless emissions standards are made less stringent in light of the emissions reductions resulting from reduced driving, there will be a net fall in total emissions equal to those attributable to reduced driving. The resulting health benefits will be equal to the marginal health damages at planned levels of emissions multiplied by the reduction in emissions.[22]

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[20] The percentage reductions in gasoline consumption are based on a range of demand elasticities as described in Appendix A.

[21] The relevant calculation is *Total Avoided Damage/Year = Marginal damage/person-year * Percent reduction in emissions * Plan level of emissions * Population.* The term (*Percent reduction in emissions * Plan level of emissions*) equals the incremental change in emissions. Therefore the calculation is equivalent to the more familiar formula *Total Avoided Damage/Year = Marginal damage/person-year * Incremental Change in Emissions * Population.*

[22] Note that we extend this analysis to include the entire country, since a change in crude oil prices will impact gasoline prices both inside and outside of California.

We estimate the national benefits of reductions in air pollution due to reduced driving to be from $5.4 million to $10.8 million per year for ethanol and from $5.2 million to $10.6 million per year for non-oxygenated fuel.

Changes in emissions for the four air toxics (benzene, butadiene, acetaldehyde and formaldehyde) are calculated using the California Air Resources Board (CARB) predictive model for each of the fuels. It is necessary to translate these changes in emissions into changes in concentrations of pollutants in the atmosphere, which allows the use of CARB risk factors to estimate additional cancer deaths per ppb concentration. We then convert changes in atmospheric concentration to changes in annual deaths (using the CARB risk factors). Averted annual deaths are valued by the EPA canonical number for the value of a statistical life.

The percentage change in emissions for each of the four air toxics predicted by the Phase 3 predictive model are shown in Table I. These percentages are calculated for both ethanol and non-oxygenated fuel relative to a reference fuel that is presumed to have emissions identical to that of MTBE RFG. Use of MTBE leads to higher emissions of formaldehyde, while use of ethanol leads to higher emissions of acetaldehyde. Both ethanol and alkylates lead to slightly lower emissions of benzene and butadiene. These percentage changes in emissions are converted to percentage changes in concentrations of air toxics, in order to estimate the changes in predicted cancer cases. Ambient concentrations and the predicted cancer deaths from exposure to the reported ambient concentrations over a 70-year period are estimated by CARB.[23] The fraction of total emissions attributable to motor vehicles is

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[23] Available on the CARB website, http://www.arb.ca.gov/aqd/toxics/statesubstance.html.

estimated from various sources.[24] Unit risks values are taken from CARB, based on California Office of Environmental Health Hazard Assessment (OEHHA) reports.

In terms of reductions in the four major air toxics, health benefits from replacing MTBE with ethanol total $23.5 million annually and benefits with a non-oxygenated fuel total $17.1 million.

In total, replacing MTBE with ethanol would result in a total increase in air quality benefits ranging from $28.9 million to $34.3 million, with an expected value of $31.6 million. If a waiver were granted allowing non-oxygenated fuel to be used throughout California, the estimated air quality benefits of switching from MTBE to this non-oxygenated RFG would range from $22.4 million to $27.7 million, with an expected value of $25.0 million.

Water Quality Impacts

Costs associated with water quality are the incremental costs attributable to the specific formulation of gasoline (i.e., MTBE, ethanol or non-oxygenated RFG) for the cleanup of gasoline spills. These costs include (i) response costs at Leaking Underground Storage Tank (LUST) sites, (ii) costs to treat drinking water wells impacted by gasoline releases, (iii) response costs from pipeline leaks for gasoline, and (iv) the costs to monitor surface water reservoirs. The ethanol and MTBE RFG formulations are expected to increase water quality impacts of gasoline spills, relative to impact of spills of conventional gasoline, and it is predicted that MTBE may have a larger impact on water quality than ethanol.[25]

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[24] See WORKING PAPER for details.

[25] There is some indication that the use of alkylates will increase the response costs at LUST sites [14]. We do not include this cost in our analysis.

The calculation of the incremental impact of MTBE and ethanol on the cost to investigate and remediate LUST sites is presented in Figure 3. The calculation begins with an estimate of the number of underground storage tanks containing gasoline. This population of tanks is then partitioned between upgraded and non-upgraded tanks.[26] This distinction is important, since upgraded tanks are expected to fail (i.e., leak) with less frequency than non-upgraded tanks [6]. The proportion of tanks that fall into the upgraded category has been increasing through time.[27]

Based on the frequency of tank failure (leakage), and the number of upgraded and non-upgraded tanks, the number of new LUST sites in each year can be calculated. Upgraded tanks are expected to fail at an annual rate between 0.07% and 2% [6, 15].[28] Non-upgraded tanks are expected to fail at an annual rate between 2.5% and 3%.[29] [30] Some, but not all, of these failures will impact groundwater. The probability that a LUST impacts groundwater has been estimated to be 51%, and this probability is independent of whether the gasoline contains MTBE or ethanol [11].[31]

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[26] Data on the number of upgraded and non-upgraded tanks is taken from the California State Water Resources Control Board website at http://www.swrcb.ca.gov/cwphome/ust/docs/tank_stats.htm. We are told by the SWRCB that this data source likely overestimates the percent of active tanks that are not upgraded. This will tend to bias upward our estimate of the groundwater impact of MTBE.

[27] Moreover, the Environmental Protection Agency UST upgrade program — that required the upgrade or closure of most gasoline containing USTs by 1998 — resulted in the closure of approximately half the USTs in California. Therefore, not only is a greater percentage of the tank population becoming less prone to leak, but the total number of tanks that may leak is declining through time as well.

[28] One source estimates that the upper bound on the annual failure rate of upgraded tanks is no higher than 1% [26].

[29] Couch and Young [6] report that annual failure rates of non-upgraded tanks are between 2.5% and 2.9%.

[30] We estimate between 471 and 3526 new LUST sites will occur annually in California. Data from the State of California LUSTIS database indicates that the annual number of new LUST sites is approximately 2200.

[31] The analysis ignores the sites that do not impact groundwater. While these sites do have to be cleaned up, the cost of cleanup is not sensitive to whether the gasoline contains MTBE or ethanol [15]. Therefore, there is no incremental impact of MTBE or ethanol at these sites.

All LUST sites that impact groundwater must be investigated. Investigation is a one-time cost, and this cost occurs in the year the tank leak is detected. Investigation costs for LUST sites where the tank contained gasoline with MTBE may be greater than if the tank contained only "conventional" gasoline. Investigation costs are assumed to be greater because plumes from tanks that contain MTBE may be longer. Longer plumes may generally take more effort to fully define and characterize (more investigation wells may have to be drilled, etc.).[32] The degree to which investigation costs are increased is uncertain, and we assume the increase in costs could range from no increase to an increase of 47%.[33] "Baseline" (no MTBE) investigation costs range between $20,000 and $170,000 [15, Table 7].

Ethanol appears to increase the length of benzene plumes. Therefore, if MTBE increases site investigation costs because MTBE plumes tend to be longer, then the same should be true for ethanol. Accordingly, the impact of both ethanol and MTBE on investigation costs is modeled consistently. We rely on existing estimates of the impact of MTBE on site investigation costs. The corresponding impact of ethanol on site investigation costs is treated as proportional to the relative increases in plume length from ethanol and MTBE. For instance, available data suggest that the degree to which MTBE lengthens a LUST plume may be from 18% to 350% [7, 23]. Available data also suggest that ethanol may increase plume length by approximately 25% to 250% [22, 24]. Therefore, the impact of ethanol on site investigation costs will range from equal to the MTBE impact (since 18% and 25% are

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[32] Note, however, there is some reason to believe that there may be little impact on site investigation costs as the size of the plume increases. The use of sophisticated modeling allows the edge of the plume to be predicted with some accuracy. The presence of MTBE and or ethanol can be incorporated into these models, thus obviating the need for a "grid search" pattern of well drilling.

[33] Data from Table 7 of Keller, et al. [15], suggest MTBE may increase remediation costs by as much as 47%. Remediation engineers with whom we have spoken suggest that MTBE may have no impact on investigation

approximately equal) to approximately one twelfth the MTBE impact (since 25% is approximately one twelfth of 350%). The distribution utilized in the Monte Carlo analysis for the relative impact of ethanol on groundwater is skewed toward the lower bound, reflecting a high likelihood that the impact of ethanol on groundwater is small relative to the impact of MTBE.

All LUST sites that impact groundwater require some form of remediation. While the costs of remediation at any specific site will be driven by unique, site-specific factors, it is useful to distinguish between two types of sites: (i) those addressed by natural attenuation; and (ii) those that are actively remediated. The costs for addressing a site by active remediation are significantly higher than the cost of addressing a site by natural attenuation. If the presence of MTBE or ethanol increases the probability that a site will have to be actively remediated rather than naturally attenuated, response costs will increase (even if there is no increase in the actual cost of actively treating the site).

Absent MTBE it is estimated that the percent of LUST sites impacting groundwater that would be addressed by natural attenuation is between 47% and 75%.[34] It has been hypothesized that the presence of MTBE in a LUST plume will make it more likely that the site will have to be actively remediated [15]. The rationale for this hypothesis is not entirely clear, but may stem from either the assumption that plumes with MTBE will be longer, or that MTBE itself presents a heightened concern to groundwater, perhaps because it degrades more

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costs. Data showing MTBE plumes are not significantly larger than benzene plumes also suggest that the impact of MTBE on remediation will be small.

[34] In a 1996 study, the U.S. EPA reported that 47% of LUST sites were addressed by natural attenuation [30, pp. 16]. We understand that the percent of sites addressed by natural attenuation may have been increasing through the mid-1990s. Therefore, we allow the possibility that, absent concerns over MTBE, up to 75% of LUST sites may currently be able to be addressed by natural attenuation.

slowly. Note, however, that both of these factors — longer plume lengths and slower degradation of the contamination — also occur (although perhaps to a lesser degree) when ethanol is present in the plume. Therefore, to the degree that the presence of MTBE increases the probability that a LUST site will have to be actively remediated, the same should be true for ethanol (although, again, perhaps to a lesser degree).

There is little empirical evidence to suggest that plumes from gasoline that contains MTBE or ethanol result in a higher probability that a LUST site requires remediation. Some remediation engineers with whom we have spoken have concluded that the presence of MTBE is not a driving factor in whether the site is actively remediated. Moreover, a survey of the Regional Water Quality Control Boards in California indicates that MTBE is not a clear factor in determining whether the site will be actively remediated.[35] No RWQCB appears to have either a formal policy or written guidance on which LUST sites must be actively remediated versus which should be addressed by natural attenuation. Approximately half the Boards surveyed thought that the presence of MTBE would increase the likelihood that the site would have to be actively remediated, while half the Boards thought the presence of MTBE would have no effect. Given the uncertainty of the impact of MTBE and ethanol on the remediation approach at a site, it is possible that MTBE or ethanol may have no effect on whether the site has to be actively remediated. We also allow for the possibility that MTBE or ethanol make it as much as twice as likely that the site will have to be actively remediated. It

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[35] We surveyed the nine California Regional Water Quality Control Boards (RWQCBs) in March 2001. We were unable to reach representatives at one region (Region 6), and representatives from one region (Region 9) declined to participate in the survey. Of the remaining seven regions, three regions reported that the presence of MTBE may increase the likelihood that the site would need to be actively remediated. The remaining four regions reported that the presence of MTBE itself was not a decisive factor in deciding whether a site needed to be actively remediated.

is presumed that sites with ethanol are less likely to be actively remediated than those with MTBE.

Costs at sites addressed by natural attenuation are independent of whether the site contains MTBE or ethanol. Response costs at sites that are actively remediated may be higher if the gasoline contains MTBE or ethanol. Response costs may increase because the plume is longer, an effect that would result from the presence of either MTBE or ethanol. However, response costs may also increase because the methods used to remove benzene from water are not as effective at removing MTBE. This may lead to an increase in remediation costs; such impacts would be specific to MTBE and not occur when ethanol is present (since ethanol typically does not have to be removed from the groundwater). The impact of MTBE or ethanol on remediation costs is uncertain. As a result, the analysis allows for the possibility that the increase in costs may range from 10% to 80% (of the costs that would be incurred had the LUST plume contained only conventional gasoline).[36] Moreover, the analysis assigns a larger impact on remediation costs to MTBE than to ethanol. Baseline annual remediation costs are assumed to range from $97,000 to $610,000, and remediation length is expected to range from 2 to 5 years [15].

The estimated annual benefit of replacing MTBE with ethanol, in terms of reduced water quality costs associated with gasoline released from LUSTs, ranges from nearly zero to $283.3 million, with an expected value of $37.1 million. The estimated annual benefit of replacing MTBE with alkylates, in terms of reduced water quality costs associated with gasoline released from LUSTs, ranges from nearly zero to $317 million, with an expected

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[36] Keller, et al [15], estimate the increase in remediation costs due to MTBE may be as high as 80%. Hitzig, Kostecki and Leonard [13] report that at many sites, MTBE has little (or no) effect on remediation costs.

value of $55.2 million. The range of incremental costs of MTBE is relatively wide, due to the uncertainty of the impact of MTBE on groundwater. However, even under the worst-case scenario — where the incremental impact of MTBE is assumed to be very large — the costs of switching to ethanol or alkylates still exceed the water quality costs of MTBE.

LUST plumes may result in costs other than those costs to address and remediate the site. If gasoline constituents from the LUST reach a drinking water well, treatment (or replacement) of the well may be required. Both MTBE and ethanol may increase the likelihood that a LUST plume will reach a drinking water well — since both chemicals may result in longer plumes.

The California Department of Health Service (DHS) has comprehensively monitored most public drinking water sources for MTBE since 1997. These data show that each year approximately 0.48% of all groundwater sources sampled show some level of MTBE detection. Assuming a total of 13,919 public sources in California [11], this percentage implies that approximately 76.5 public sources will be newly impacted by MTBE each year. Extrapolating this percentage to private wells (which are estimated to number 464,621 [11]), approximately 2,242 private wells will be newly impacted by MTBE per year.

These estimates include all MTBE detections, no matter how minor. A more meaningful statistic might be the number of newly impacted groundwater sources that show levels of MTBE at or above the California secondary maximum contaminant level (5 ppb). DHS data show that this represents approximately 0.15% of all groundwater sources sampled per year. This is equivalent to roughly 21.1 public and 704 private sources per year.

It is likely that the treatment costs for wells showing new detections may increase because of the presence of MTBE. Consistent with the modeling of LUSTs, the incremental impact of MTBE on treatment costs for wells will range from 10% to 80%.

Ethanol may increase the length of BTEX plumes by 26% to 250% (although the general consensus tends to the lower bound). Longer BTEX plumes would increase the number of wells that show detectable levels of BTEX. For each year since 1997, approximately 0.75% of all public wells have shown new BTEX detections; the percentage of public wells showing BTEX detections greater than the MCL has been approximately 0.043%. Extrapolating to all public wells, the expected number of all new BTEX impacts will be 118.9, and the number of new impacts greater than the MCL will be 7.4. The corresponding number of private wells impacted will be 3,484 and 247, respectively. Assuming the increase in the number of wells impacted by benzene is proportional to the increase in the length of benzene plumes, the use of ethanol is estimated to increase the number of wells annually impacted by benzene by 26%.

The estimated annual difference of replacing MTBE with ethanol, in terms of reduced water quality costs associated with impacted drinking water wells, ranges from a cost of $1.7 million to a benefit of $83.6 million, with an expected value of $24.7 million. The estimated annual benefit of replacing MTBE with alkylates, in terms of reduced water quality costs associated with impacted drinking water wells, ranges from $5.4 million to $162.3 million, with an expected value of $47.9 million.

Pipelines that contain gasoline may also leak. For the reasons discussed above, the presence of MTBE or ethanol may increase the cost to address these gasoline releases. The modeling of the incremental impact of MTBE or ethanol from pipeline gasoline releases is similar to that presented for LUSTs.

The Office of the State Fire Marshall reported that the average number of gasoline releases in California resulting from pipeline leaks ranges from 5 to 10 releases per year [26]. If MTBE is present, response costs may be increased. Consistent with other components of the model, this increase may range from 10% to 80% over and above the cost of addressing a spill of conventional gasoline alone. The presence of ethanol may also impact the cost of addressing the spill. Consistent with the modeling of the effect of ethanol elsewhere in the model, the incremental impact of ethanol will be between 7.45% and 100% of the incremental cost attributable to MTBE. The baseline cost to address a pipeline leak of gasoline is estimated to range from $10.5 million to $28 million [15].

The estimated annual benefit of replacing MTBE with ethanol, in terms of reduced water quality costs associated with pipeline leaks of gasoline, ranges from nearly zero to $1.2 million, with an expected value of $0.3 million. The estimated annual benefit of replacing MTBE with alkylates, in terms of reduced water quality costs associated with pipeline leaks of gasoline, ranges from nearly zero to $1.4 million, with an expected value of $0.5 million.

While groundwater is the focus of much discussion concerning MTBE, MTBE has also been found in surface water sources. Gasoline is found in surface water due primarily to the release of un-combusted gasoline from boat motors. If the gasoline contains MTBE, there may be a heightened concern about these releases. Certain surface reservoirs in California are reportedly monitoring for MTBE. We are unaware of any surface water being treated for MTBE.

Due to the heightened concern over MTBE, we assume that all surface water reservoirs in California that allow boating and which are also used as drinking water sources, are periodically monitored for MTBE.[37] The total number of reservoirs to be monitored is between 100 and 150, and the annual cost of monitoring per reservoir is $10,000 to $25,000 [15]. The total cost of this monitoring is attributed to MTBE. We do not attribute any incremental cost to MTBE for the treatment of surface water, since there does not appear to be any such treatment occurring. We also do not attribute any incremental cost to ethanol for surface water monitoring or treatment.

The estimated annual benefit of replacing MTBE with ethanol, in terms of reduced water quality costs associated with gasoline contamination of surface water, ranges from $1.0 million to $3.7 million, with an expected value of $2.2 million. The estimated annual benefit of replacing MTBE with alkylates, in terms of reduced water quality costs associated with gasoline contamination of surface water, ranges from $1.0 million to $3.7 million, with an expected value of $2.2 million.

The expected savings in water monitoring and treatment costs attributable to switching from MTBE to ethanol range from $3.5 million to $308.7 million with an expected value of $59.6 million. The expected savings in water monitoring and treatment costs attributable to switching from MTBE to non-oxygenated RFG range from $15.0 million to $401.0 million, with an expected value of $105.8 million.

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[37] This assumption is contained in the 1998 University of California analysis of MTBE [15]. It is not clear, in fact, that all reservoirs in California that both supply drinking water and allow boating are routinely monitored for MTBE. To the degree that some reservoirs are not so monitored, the resulting cost of MTBE would be less, and the benefit of MTBE over ethanol greater.

Conclusion

Cost benefit analyses of environmental regulations are often criticized because they compare the "hard" costs of implementing the regulation with the beneficial human health or ecological consequences of the regulation. It is often difficult to agree on the valuation for the human health or ecological benefits, and indeed, some object on principle to the economic valuation of human health and ecological resources. The case of MTBE is somewhat unique, since the costs and benefits of an MTBE ban are overwhelmingly "hard" economic impacts. On the cost side, removing MTBE from gasoline is certainly possible – it is simply a matter of how much we are willing to pay to produce gasoline. On the benefit side, MTBE's adverse impacts are almost all in the form of increased *costs* to remediate gasoline releases that would otherwise still exist. There is no serious allegation that MTBE meaningfully increases the health risks of these releases. Unlike most chemicals (including benzene), the level of exposure at which MTBE might pose a health risk is higher (probably far higher) than the level at which MTBE gives water an unpalatable taste and odor. Therefore, it is very unlikely that anyone would be unwittingly exposed to MTBE in drinking water at high enough levels for a long enough period for adverse health consequences to result. As such, the question of whether MTBE should be used in gasoline is a straight "dollar to dollar" comparison. How much will it increase the cost of gasoline if MTBE is not permitted, and how much more will it cost to clean up gasoline releases if MTBE is permitted?

The costs to remove MTBE from gasoline while maintaining the air quality benefits of RFG will significantly increase the cost to produce and distribute gasoline in California. These costs include both costs incurred by California residents, as well as costs borne by U.S.

residents as a whole. Even if one looks only at the likely "out of pocket" costs to California gasoline consumers, the cost to remove MTBE from gasoline is very high. To put the issue in perspective, annual gasoline consumption in California is approximately 14.5 *billion* gallons per year (and is increasing rapidly). Given this level of consumption, for every one cent increase in gasoline prices, California consumers are effectively "taxed" $145 million. There is wide consensus that removing MTBE from California gasoline will result in price increases of at least about five cents per gallon.[38] This translates into an "out of pocket" cost to California consumers of almost $750 million per year. In addition, if ethanol is substituted for MTBE, the reduction in tax payments to the Highway Trust Fund will be almost $500 million per year.

Measured against this staggering cost is the impact that MTBE may have on the water resources of the State. While it is clear that MTBE is likely to have an incremental adverse impact on water resources, beyond the impact of releases of gasoline that does not contain MTBE, it is also clear that this impact is likely to be modest. Because of the intense focus since 1998 on the threat of MTBE to groundwater, the number of underground storage tanks that release gasoline in a year is known with a fair degree of certainty. This number is relatively small and declining. Moreover, very widespread monitoring of drinking water wells in California reveals that the number of wells impacted by MTBE is quite small, that the vast majority of these wells show MTBE at low levels, and that MTBE is not persistent in most wells where it is detected. Moreover, everyone agrees that MTBE can be cleaned up at LUST sites and can be removed from drinking water. There *is* significant disagreement on

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[38] In the long-run. In the short-run, price spikes of as much as $0.50/gallon have been predicted by the State of California.

the cost of remediating MTBE at LUST sites or in drinking water. However, even if one takes the most pessimistic projections of the cost of removing MTBE from LUST sites and drinking water, these costs are relatively small. There are simply too few LUST sites and too few drinking water wells where MTBE is detected for the costs to be of the same magnitude as the cost of removing MTBE from gasoline. Given these facts, it is clear that the cost to address the presence of MTBE in gasoline releases is far less than the cost to gasoline consumers of replacing MTBE with either ethanol or alkylates.

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APPENDIX A: QUANTIFICATION OF COSTS AND BENEFITS

MARKETS

- Reformulated gasoline in California, remainder of U.S.
- U.S. and world petroleum (crude oil, refined products)
- U.S. and Canadian natural gas

REPRESENTATION OF MARKETS

In this section, we write down the explicit market models algebraically, and derive the expressions that will be used compute consumer and producer surpluses as integrals under explicit demand and supply curves. We also explain the concepts of producer and consumer surplus we are using, and why they are the appropriate measures of net private and social costs.

Variable	**Description**	**Value or Range**
Demand		
D_{GX}	Demand for gasoline in region X where X can be California or the rest of the United States	
D_{RPX}	Demand for refined products in region X where X can be the U.S. or the rest of the world. Note that for the U.S. this number reflects demand for all refined products *except* gasoline, whereas for the rest of the world this number represents all refined products *including* gasoline.	
D_{NX}	Demand for natural gas in region X where X can be the U.S. or Canada	

Supply

S_{CX}	Supply of crude oil in region X where X can be the U.S. or the rest of the world
S_{NX}	Supply of natural gas in region X where X can be the U.S. or Canada

Prices

P_{GX}	Price of gasoline (to consumer) in region X where X can be California or the rest of the U.S.
P_{RPX}	Price of refined products in region X where X can be the US or the rest of the world
P_{Crude}	Price of crude oil
P_N	Wellhead price of natural gas

Driving

VMT	Vehicle miles traveled
MPG	Fuel economy

ELASTICITIES

σ_{G}	Elasticity of demand for gasoline	0.2 to 0.4
σ_{RP}	Elasticity of demand for refined products	0.08 to 0.16

σ_{VMT}	Elasticity of demand for VMT	0.1 to 0.2
σ_{MPG}	Elasticity of demand for fuel economy	
σ_N	Elasticity of demand for natural gas	0.09 to 0.27
ε_{CX}	Elasticity of supply of crude oil	0.2
ε_N	Elasticity of supply of natural gas	0.25 to 0.75

DEMAND FOR GASOLINE

$$D_G = A_G * P_G^{-\sigma_G}$$

Gasoline demand is the product of two variables, miles driven (VMT) and gallons consumed per mile (1/MPG). Therefore, we can express

$$\sigma_G = \sigma_{VMT} - \sigma_{MPG}$$

We distinguish between demand for gasoline in California D_{GCal} and demand for gasoline in the rest of the US, D_{GXCal}. Demand for other refined products is denoted D_{RPUS} and total demand for petroleum products in the U.S. is $D_{GCal} + D_{GXCal} + D_{RPUS}$. We denote demand for refined products outside the US as D_{RPNUS}.

In general, demand for gasoline and refined products is a function of the world oil price plus the appropriate refiners margin, written as $P_{crude} + RM_{product,\ region}$. For simplicity, $RM_{product,\ region}$ is assumed to be fixed, equivalent to assuming constant marginal refining costs.

EFFECTS OF MTBE ON GASOLINE DEMAND IN CALIFORNIA

The increase in refining cost, including the value of lost fuel economy, increases the price of gasoline in California. The per-gallon cost of producing a replacement for MTBE is added to the refiner's margin for gasoline in California. We include the calculated value of the loss in fuel economy in the cost of producing the MTBE replacement.

The quantity of gasoline demand in California is shifted outward by the two additive factors of the net loss in volume due to removal of MTBE and the reduction in fuel economy. We define *MTBEShift* to be the sum of the effects of replacing MTBE volume and the change in fuel economy. It is calculated by multiplying the percentage loss of volume and change in fuel economy by baseline gasoline consumption in California. Thus, in the MTBE ban, the demand for gasoline in California is represented by

$$D_{GCal}(p_{CrudeMTBEBan} + RM_{GcalMTBEBan}) + MTBEShift$$

where $RM_{GcalMTBEBan} = RM_0 + Fuelcst$ equals the absolute increase in cost of refining plus the value of lost fuel economy.

WORLD OIL MARKET

The supply of crude oil in the U.S. is S_{CUS} and supply of crude oil in the rest of the world is S_{CXUS}. Crude supply is a function of the price of crude oil, P_{crude}.

The market clearing equilibrium condition that must be satisfied by P_{crude} is

$D_{GCal} + D_{GXCal} + D_{RPUS} + D_{RPNUS} = S_{CUS} + S_{CXUS}$.

The model is benchmarked to year 2000 forecasts from the EIA Annual Energy Outlook 2001, and then solved with the shifts in demand and supply associated with the MTBE ban to estimate impacts of the demand on supply, demand and prices.

NATURAL GAS SUPPLY AND DEMAND

$$D_N = A_N * P_N^{-\sigma_N}$$

$$S_N = B_N * P_N^{\varepsilon_N}$$

Natural gas supply is a function of the wellhead price of natural gas, P_N. The market clearing equilibrium that must be satisfied by P_N is:

$D_{NUS} + D_{NCanada} = S_{NUS} + S_{NCanada}$

DATA

The following table provides the data used to benchmark the oil supply and demand model, elasticity assumptions, and values for MTBE ban costs and shift factors.

2000 Data	
U.S. Natural Gas	
Demand	22.24 Tcf
Production	18.72 Tcf
Imports	3.51 Tcf
Canada Natural Gas	
Demand	3.1 Tcf
Production	6.61 Tcf
Crude Oil Production	
U.S.	9.16 mmbd
Rest of World	67.48 mmbd
Demand for Refined Products	
California Gasoline	14,490 mgal/year
Rest of U.S. Gasoline	114,895 mgal/year
Other U.S. Refined Products	11.05 mmbd.
Rest of World Refined Products	56.50 mmbd.
World Oil Supply	76.65 mmbd
U.S. Oil Consumption	19.48 mmbd
Prices	
California Gasoline	1.64 $/gal

World Oil Price	27.59 $/bbl
Natural Gas Wellhead Price	3.28 $/mmbtu

Sources: EIA AEO 2001, NPC 1999

	Ethanol	**Non-Oxy**
Refiner Cost ($/gallon)	0.055	0.049
Change in Fuel Economy	-0.4%	0.8%
Petroleum Volume Offset	5.8%	11.5%
Natural Gas Volume Increase	11.5%	11.5%

ESTIMATION OF CONSUMER SURPLUS LOSS

Consumer surplus in the California gasoline market

The MTBE ban causes the following impacts to the effective price of California gasoline:

1. An additive increase in the refiner's margin equal to the change in refining cost (including the fuel economy penalty)
2. An additive increase in the price of gasoline equal to the increase in the world crude oil price

These changes alter the limits of integration used for calculating consumer surplus. The change in fuel economy alters gasoline consumption, but we assume that welfare is proportional to driving, not gasoline consumption, and do not include any welfare gain from the greater gasoline consumption required to provide the same VMT after the MTBE ban.

Consumer surplus in other products

Consumer surplus in other refined product markets, including gasoline consumed in the rest of the country and all other refined products, is affected only by the change in the world crude oil price.

Cost of producing crude oil

The increase in real resource cost of producing crude oil domestically is determined by the increase in the world crude oil price.

Cost of oil imports

The real resource cost of increased oil imports is the increase in the world oil price times the equilibrium quantity of imports after the MTBE ban. Other costs of increased oil imports are accounted for in consumer surplus losses in refined product consumption and cost increases in crude oil production attributable to higher oil prices.

Welfare loss plus cost of additional petroleum supply

The total change in consumer and producer surplus, including all these factors, is given by the formula

$$Surplus_{Total} = \begin{array}{l} \int_{p_{Crude0}+RM_{GCal0}}^{p_{CrudeMTBEBan}+RM_{GCalMTBEBan}} D_{GCAL}(p)\,dp + \\ \int_{p_{Crude0}}^{p_{CrudeMTBEBan}} \left[D_{GXCAL}(p+RM_{GXCal})+D_{RP}(p+RM_{RP})-S_C(p)\right]dp \end{array}$$

We obtain the price of crude oil with and without the MTBE ban from the world oil market model described above. The refiner margin for California includes the adjustment for the cost of producing an alternative to MTBE and the penalty for lost fuel economy. In addition, petroleum demand in the U.S. is shifted up by the two additive factors of the net loss in volume due to removal of MTBE and the reduction in fuel economy. These two factors are not included in the values of supply or demand using the formula above so that the total cost of an MTBE ban equals

$$TotalCost = Surplus_{Total} + MTBEShift * [p_{CrudeMTBEBan} - p_{Crude0}]$$

where *MTBEShift* is the sum of the effects of replacing MTBE volume and lost fuel economy.

Since all demand functions have the same form, we can write the consumer surplus integral as

$$\int_{p_0}^{p_{MTBEBan}} D(p)dp = \int_{p_0}^{p_{MTBEBan}} Ap^{-\sigma}dp = \frac{A}{1-\sigma}\left[p_{MTBEBan}^{1-\sigma} - p_0^{1-\sigma}\right]$$

and the area between the supply curve and the y-axis as

$$\int_{p_0}^{p_{MTBEBan}} S(p)dp = \int_{p_0}^{p_{MTBEBan}} Bp^{\varepsilon}dp = \frac{A}{1+\varepsilon}\left[p_{MTBEBan}^{1+\varepsilon} - p_0^{1+\varepsilon}\right].$$

These integrals are evaluated numerically using the equilibrium values for supply, demand and prices in the base case (p_0 for example) and the MTBE ban case ($p_{MTBEBan}$ for example), for either an ethanol or a non-oxygenated replacement.

TABLE I: REDUCTIONS IN AIR TOXICS (% CHANGE RELATIVE TO REFERENCE FUEL)

Compound	Ethanol	Non-Oxy
Benzene	-7.1	-3.6
Butadiene	-6.1	-2.9
Formaldehyde	-4.7	-10.7
Acetaldehyde	23.7	-9.1

Table II: Monte Carlo (50,000 repetitions) Results for Cost of Ethanol Scenario Relative to Cost of MTBE Scenario

Fuel Impacts	**Lower Bound**	**Expected Value**	**Upper Bound**
Refiner Costs	$761,306,102	$763,113,161	$764,866,459
Ethanol Tax Credit	$449,163,418	$450,229,566	$451,263,995
Oil Surplus (Less Refiner Costs)	$263,801,847	$295,576,579	$330,451,887
Effects of MTBE ban on Natural Gas Demand	($326,087,188)	($179,764,710)	($109,436,821)
Total Difference in Fuel Costs	**$1,220,108,677**	**$1,329,154,595**	**$1,365,369,322**
Air Quality			
Air Toxics	($23,462,241)	($23,462,241)	($23,462,241)
Reduced Fuel Consumption	($10,815,115)	($8,113,654)	($5,412,081)
Total Difference in Air Quality Costs	**($34,277,356)**	**($31,575,895)**	**($28,874,322)**
Water Quality			
Surface Water	($3,712,945)	($2,186,771)	($1,012,566)
Ground Water			
LUST	($283,254,696)	($37,138,227)	($14,230)
Pipeline	($1,214,412)	($321,745)	($226)
Wells	($83,617,803)	($19,906,463)	$1,651,546
Total Difference in Water Quality Costs	**($308,651,595)**	**($59,553,206)**	**($3,524,220)**
Total Incremental Cost	**$897,257,294**	**$1,238,025,494**	**$1,326,943,300**

Table III: Monte Carlo (50,000 repetitions) Results for Cost of Alkylate Scenario Relative to Cost of MTBE Scenario

Fuel Impacts	**Lower Bound**	**Expected Value**	**Upper Bound**
Refiner Costs	$834,050,061	$835,792,630	$837,470,286
Ethanol Tax Credit	$0	$0	$0
Oil Surplus (Less Refiner Costs)	$326,002,752	$371,115,399	$420,314,951
Effects of MTBE ban on Natural Gas Demand	($326,086,923)	($180,093,793)	($109,436,831)
Total Difference in Fuel Costs	**$931,307,411**	**$1,026,814,236**	**$1,052,232,644**
Air Quality			
Air Toxics	($17,124,593)	($17,124,593)	($17,124,593)
Reduced Fuel Consumption	($10,610,220)	($7,903,606)	($5,237,420)
Total Difference in Air Quality Costs	**($27,734,813)**	**($25,028,199)**	**($22,362,013)**
Water Quality			
Surface Water	($3,729,381)	($2,186,926)	($1,014,377)
Ground Water			
LUST	($317,033,257)	($55,217,808)	($1,097,740)
Pipeline	($1,440,267)	($492,552)	($58,037)
Wells	($162,299,839)	($47,884,182)	($5,400,769)
Total Difference in Water Quality Costs	**($401,032,428)**	**($105,781,469)**	**($15,001,467)**
Total Incremental Cost	**$547,528,969**	**$896,004,569**	**$1,008,679,214**

Figure 1: Overview of Fuel Cost Impact of Switching from MTBE

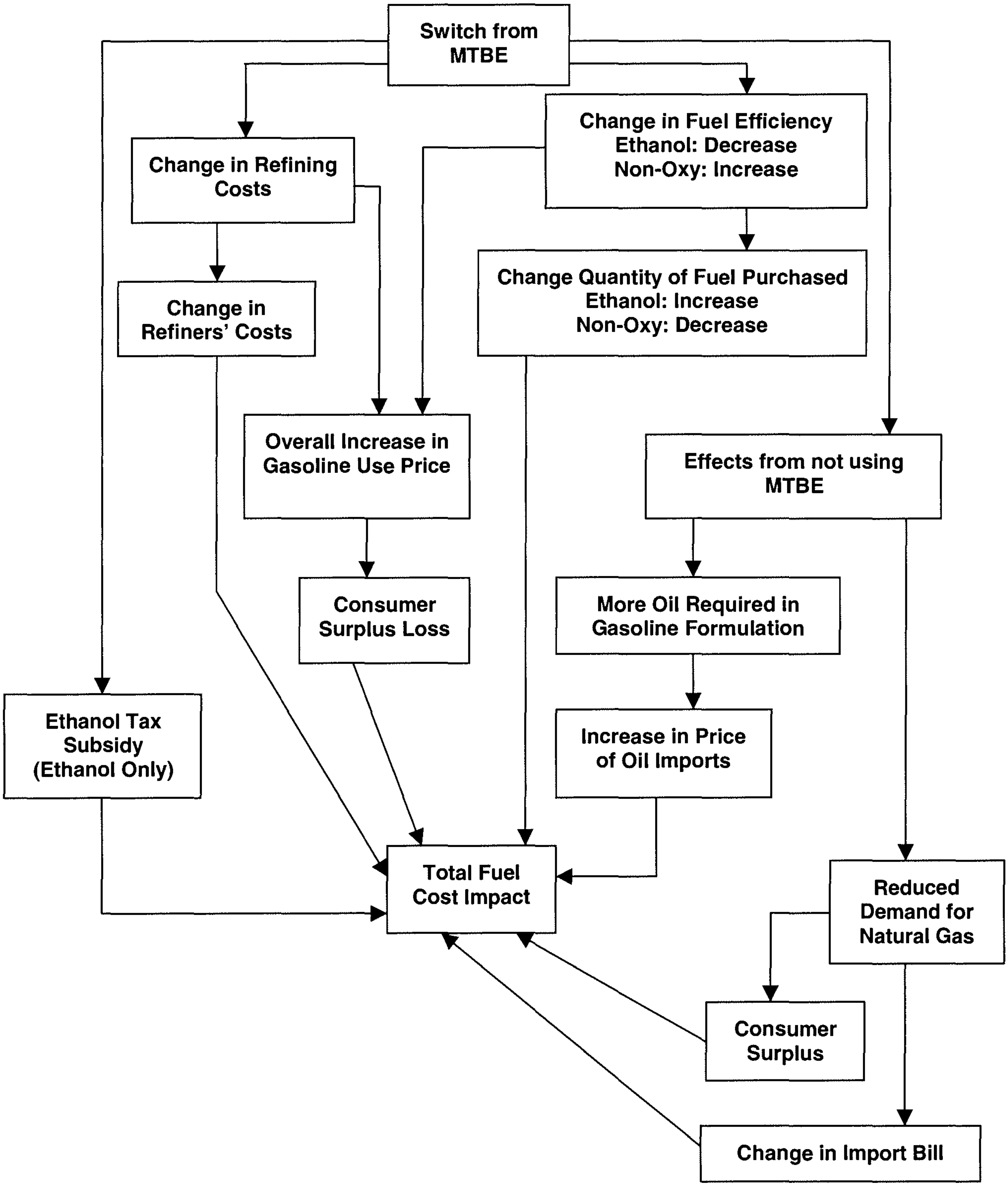

Figure 2: Overview of Air Quality Impact of Switching from MTBE

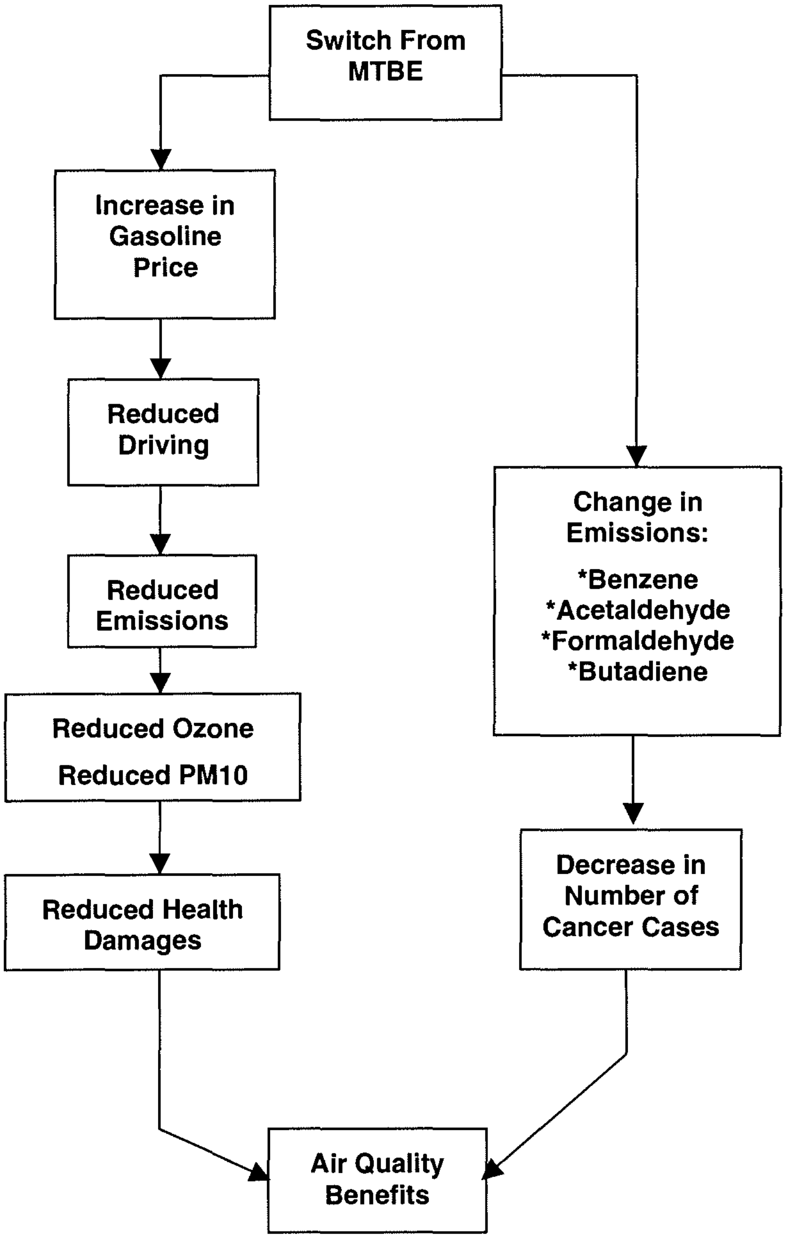

Figure 3: Change in Leaking Underground Storage Tank Remediation Costs due to Switching from MTBE