

The benefits and costs of ethanol: an evaluation of the government's analysis

Robert Hahn · Caroline Cecot

Published online: 16 September 2008
© Springer Science+Business Media, LLC 2008

Abstract Ethanol production in the United States has been steadily growing and is expected to continue growing. Many politicians see increased ethanol use as a way to promote environmental goals, such as reducing greenhouse gas emissions, and energy security goals. This paper provides a benefit-cost analysis of increasing ethanol use based on an analysis by the Environmental Protection Agency. We find that the cost of increasing ethanol production to almost ten billion gallons a year is likely to exceed the benefits by about three billion dollars annually. We also suggest that earlier attempts aimed at promoting ethanol would have likely failed a benefit-cost test, and that Congress should consider repealing ethanol incentive programs, such as the ethanol tariff and tax credit.

Keywords Benefit-cost analysis · Regulation · Energy policy · Environmental economics · Ethanol

JEL Classifications D61 · D78 · L50 · Q48 · Q5

1 Introduction

Ethanol is a fuel that has been touted by politicians and technologists for a variety of reasons related to both energy security and the environment. It figures prominently in President Bush's strategy to address climate change (Bush 2007). Largely as a result of government policies, the production of ethanol in the United States is expected

R. Hahn (✉) · C. Cecot
Reg-Markets Center at AEI, 1150 17th Street, NW, Washington, DC 20036, USA
e-mail: rhahn@aei.org

C. Cecot
e-mail: caroline.cecot@gmail.com

to grow dramatically during the next decade. As of September 2007, there were 128 ethanol plants in the United States (U.S.) with a total capacity of almost 7 billion gallons per year.¹ This capacity is expected to exceed 13 billion gallons per year after new projects are completed. Most existing plants produce ethanol from corn.² Interest group support for ethanol has been a major factor behind the increase in production. Many politicians see increased ethanol use as a way to provide farm income support, promote environmental goals, and enhance energy security. This paper analyzes the costs and benefits associated with increasing ethanol production in the U.S.

Ethanol has widespread support in the U.S. An April 2007 poll by CBS News/New York Times found that 70% of the public agreed with the statement that ethanol made from corn is a good idea because it is an American-made substitute for foreign oil that causes less air pollution. In January 2007, President Bush announced his plan to reduce U.S. gasoline consumption by 20% in ten years mostly through increased ethanol use.³

Most ethanol incentive programs are justified by concerns with improving energy security or air quality. Energy security is typically understood to mean reducing U.S. reliance on foreign oil or insecure sources of foreign oil. Because ethanol is currently made from corn and domestic corn production is limited by available land, ethanol is not expected to have a large impact on U.S. oil imports in the short term.

The environmental argument for ethanol relates to possible reductions in greenhouse gas emissions and improvements in local air quality. The evidence on the environmental benefits is mixed. Although ethanol is likely to reduce carbon dioxide emissions, it may not decrease overall greenhouse gas emissions (Crutzen et al. 2007; Searchinger et al. 2008; Fargione et al. 2008). Ethanol use is also likely to reduce carbon monoxide emissions and some air toxics emissions, such as benzene (Environmental Protection Agency (EPA) 2007a). At the same time, ethanol use increases annual emissions of nitrogen oxides, and ethanol production and transportation may increase emissions of sulfur oxides, particulate matter, and volatile organic compounds (EPA 2007a). There is also evidence that ethanol use may increase ground-level ozone and water contamination, especially in the Gulf of Mexico, and increase food prices (Niven 2005; Scavia 2007; Elobeid and Hart 2007).

Increasing the production of ethanol is likely to be costly relative to gasoline. On an energy basis, ethanol typically costs more than oil, and is also more costly to distribute in the U.S. In addition, one needs to take into account the deadweight costs of raising revenue to fund government programs aimed at promoting ethanol, such as the tax credit.

This paper provides a benefit-cost analysis of substantially increasing ethanol production based on an Environmental Protection Agency (EPA) analysis of the renewable

¹ See the Renewable Fuels Association website for production details, <http://ethanolrfa.org>.

² We refer to ethanol made from corn as corn ethanol.

³ A 15% reduction is planned through the increased use of renewable fuels such as ethanol and a 5% reduction is based on new fuel economy standards (Bush 2007).

fuels standard.⁴ In general, we find that policy rationales for ethanol do not justify its widespread support. Ethanol made from corn is not likely to boost energy security and its environmental benefits are uncertain. We find that the cost of increasing ethanol production to almost ten billion gallons a year is likely to exceed benefits by about three billion dollars annually in 2012 if current policies continue.⁵ We also suggest that earlier attempts aimed at promoting ethanol would have likely failed a benefit-cost test. Finally, we offer some suggestions for the more cost-effective development of energy alternatives that would rely less on prescriptive regulation that selects particular fuels or technologies.

We provide an overview of laws and regulations related to ethanol in Sect. 2. Section 3 presents the likely benefits and costs of promoting ethanol. We present a sensitivity analysis that incorporates key uncertainties in our estimates in Sect. 4. Section 5 concludes and offers suggestions for improving energy policy.

2 Laws and regulations

Ethanol production in the U.S. has been steadily growing and is expected to continue to grow. The growth in this industry is a result of subsidies and regulations at the federal and state level. This section provides an overview of laws and regulations in the U.S. and the rest of the world aimed at promoting ethanol.

The major factor behind the development of the U.S. fuel ethanol industry is the Volumetric Ethanol Excise Tax Credit, the federal subsidy for ethanol that is used in gasoline. In 2006, about \$2.5 billion was distributed to gasoline blenders through the tax credit, which provides a 51 cent credit against gasoline taxes for every gallon of ethanol blended with gasoline. The federal tax credit was created in 1978 by the Energy Tax Act, which provided blenders with 40 cents for every gallon of ethanol that they blended with gasoline. Although only ethanol blenders could claim this credit, the subsidy benefits other groups indirectly, such as ethanol producers and owners of land where corn can be produced. Congress has increased and decreased the federal tax credit for ethanol blending over the years, but it has always been extended (Energy Information Administration (EIA) 2006). The current law, for example, has been extended through 2010. Although recently lowered to 51 cents per gallon, the total amount of the subsidy is actually rising rapidly due to the increased production of ethanol that is caused by a number of factors, including the tax credits and other laws supporting production, the ban of methyl tertiary butyl ether (MTBE), and the high price of gasoline. For example, the Energy Information Administration (EIA) predicts that annual production of ethanol will exceed 10 billion gallons in 2010. If the entire amount is blended into gasoline, the federal government could incur almost \$5 billion annually in direct costs through the tax credit alone. Figure 1 shows the level of this tax subsidy over the years.

⁴ We focus on the costs and benefits associated with replacing gasoline with ethanol. We do not analyze separate ethanol policies in detail. We also do not analyze the costs and benefits of ethanol as an oxygenate because we focus our analysis on increasing ethanol production beyond the level needed as an oxygenate.

⁵ All values are in constant year 2004 dollars, deflated using the Consumer Price Index.

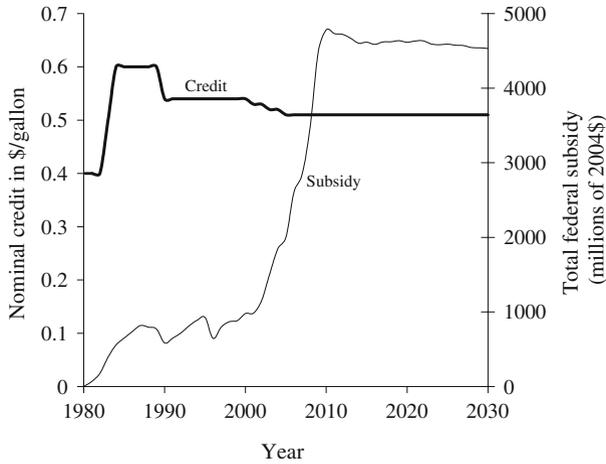


Fig. 1 Federal subsidy for fuel ethanol, 1980–2030. *Source:* EIA (2007) and authors' calculations. *Notes:* Subsidy amount beyond 2006 is estimated using information from the EIA. The credit per gallon of ethanol is in nominal terms

The federal tax credit is not the only incentive program for ethanol production. Other incentive programs include the tariff on imported ethanol, grants and loans, the renewable fuel standards, and corn subsidies. Ethanol received between \$5 and \$7 billion in subsidies in 2006 from federal and state governments (Koplow 2006). Most of the support comes from tax incentives. The General Accounting Office (GAO) (2000) estimates that more than \$19 billion in support was given to the ethanol industry between 1980 and 2000 in the form of tax incentives.⁶ In absolute size, these subsidies are lower than the subsidies given to energy sources such as fossil fuels and nuclear fission, but the subsidies exceed all other government subsidies to energy in per unit energy terms (GAO 2000). Many of these programs have been in place for decades.

One of the most controversial incentive programs is the Omnibus Reconciliation Tax Act enacted in 1980, which established the tariff on imported ethanol. This tariff provides market price support for ethanol producers because the imported ethanol would otherwise drive down the price of domestic ethanol. Because all ethanol was eligible for the blending tax credit, Congress feared the benefits of the credit would go to countries such as Brazil, where sugarcane ethanol is cheaper to produce (California Energy Commission 2004). Hence, Congress subjected all fuel ethanol to an added duty, which is currently set at 54 cents per gallon.⁷

The federal government also offers grants and guaranteed loans. In 1980, the Energy Security Act insured loans for small ethanol producers that covered up to 90% of construction costs on ethanol plants. The act also allocated \$600 million to the Department

⁶ The General Accounting Office is now the Government Accountability Office. GAO (2000) compares the historical support to the petroleum and ethanol industries. Although the absolute level of support to the petroleum industry was higher, the support per energy unit was significantly higher for ethanol.

⁷ Many countries from Central America and the Caribbean are exempt from this tariff under the Caribbean Basin Initiative (Yacobucci 2006).

of Energy and the Department of Agriculture for biomass research. There are currently about 12 federal programs that offer grants or loans for energy efficiency and renewable energy projects in the United States. Most of these programs were ostensibly enacted to address air quality concerns.

The 1990 Clean Air Act Amendments boosted the demand for ethanol by mandating the use of oxygenated fuels in areas that did not meet the air quality standards for carbon monoxide. Ethanol adds oxygen to gasoline and helps the engine run more smoothly, reducing carbon monoxide in older engines. Although methyl tertiary butyl ether (MTBE) was previously the most commonly used oxygenate, ethanol became more popular after many states banned MTBE because of its role in groundwater contamination. Hence, ethanol as an oxygenate is one source of ethanol demand.⁸

The renewable fuel standard provision of the Energy Policy Act of 2005 ensured the future demand for ethanol by requiring at least 7.5 billion gallons to be purchased in 2012. Interestingly, assuming that the ethanol tax credits are extended, the [EIA \(2006\)](#) already predicts that the 7.5 billion gallon mandate will be reached long before 2012 due to government production incentives, such as the tax credit and the tariff on foreign ethanol, as well as the ban on the gasoline additive MTBE.

Because almost all of the current ethanol produced for fuel in the U.S. is made from corn, ethanol producers also benefit from the federal subsidies given to corn. The International Institute for Sustainable Development estimates that about 15% of the total subsidy to ethanol comes from ethanol's share of corn producers' subsidies, which is about \$1 billion annually ([Koplow 2006](#)). The actual amount may be lower since some of the subsidies given to corn fall as the price of corn increases.

In addition to these federal incentive programs, many states have their own incentive programs for ethanol. For example, Iowa has an ethanol tax credit available to fuel stations that sell mostly gasoline blended with ethanol. Once owners pass a 60% sale threshold, they are eligible for a tax credit of 2.5 cents for every additional gallon of gasoline blended with ethanol and sold during the year. Indiana has an ethanol production tax credit of 12.5 cents per gallon of ethanol produced with specific caps.

The U.S. is not alone in its support for ethanol. Brazil, the world leader in ethanol production, started to develop its industry in the mid-1970s by initiating a government program that guaranteed demand, offered low-interest loans for ethanol plants, and fixed the price of ethanol as compared to gasoline at the pump. During the 1990s, the government eliminated many of the ethanol support programs. Nevertheless, Brazil still requires 20–25% ethanol blends. The European Union (EU) also has legislation and other mechanisms in place to encourage biofuel production, which includes ethanol and any other fuel made from biomass. For example, the EU has set a 5.75 percent biofuels target for transport fuels by 2010. Though meeting the target is voluntary, member states are expected to report the steps they are taking toward the target each year and the biofuel's share of total transport fuel use ([Schnepf 2006](#)).

Despite widespread support, lawmakers realize that corn ethanol cannot achieve their energy security and other goals because of limits on corn production. Today, many ambitious policies depend on the availability of ethanol from biomass sources

⁸ We assume that the levels we analyze exceed the amount of ethanol used as an oxygenate in place of MTBE. Our analysis focuses on the costs and benefits of replacing gasoline with ethanol.

such as cellulosic ethanol. For example, cellulosic ethanol production is an important part of President Bush's plan to reduce the U.S.'s gasoline consumption by 20% in ten years. Cellulosic ethanol is produced from the structural material of plants, which can be found in agricultural and forestry waste and fast-growing crops such as switchgrass. It uses less energy in its production than does ethanol made from corn, resulting in lower greenhouse gas emissions (Farrell et al. 2006; Newell 2006). Unfortunately, it is much more difficult to break down cellulose into the simple sugars necessary to make ethanol than it is to break down corn (Hammerschlag 2006) with the result that it is not currently cost-effective.

U.S. ethanol incentive programs have different, and in some cases, conflicting goals. In fact, the ultimate goals of individual laws are rarely made clear, making the policies seem uncoordinated. On the one hand, most government biofuel expenditures subsidize corn ethanol. On the other hand, lawmakers are aware that corn ethanol by itself cannot meet the U.S.'s energy and environment goals, though it could conceivably help. Below, we consider economic rationales for intervening in energy markets, and perform a cost-benefit analysis of ethanol.

3 Benefits and costs of the U.S. ethanol program: base case

The potential benefits of supporting ethanol include energy security and environmental benefits. Energy security relates to the idea that problems resulting from abrupt changes in energy supply and price disruptions can be reduced by importing or consuming less oil (Bohi and Montgomery 1982). By displacing a certain amount of gasoline, increased ethanol use may contribute to reduced U.S. consumption of oil. We also include an economic benefit because of the effect a U.S. reduction in oil imports may have on the world price of oil. The environmental benefits of increased ethanol in gasoline include lower greenhouse gas emissions and other air quality benefits (EPA 2007a; Hill et al. 2006).⁹

The potential costs include the increased cost of producing and distributing ethanol in fuel relative to producing or purchasing petroleum; and the deadweight costs associated with raising revenue to support government incentive programs.¹⁰ In addition, there are likely to be some environmental costs in the form of emission increases. We consider these in turn.

Our primary interest here is in quantifying those costs and benefits that can be measured with some degree of certainty. We also identify some potential costs and benefits that are not easily quantified and consider how that might change our findings. We present a detailed analysis of the ethanol industry in 2012 as presented by the EPA, modifying only a few assumptions. In particular, our analysis monetizes some

⁹ The reference case assumes the same proportion of ethanol in gasoline as in 2004, adjusted to 2012 gasoline consumption levels. The two scenarios we consider assume a target amount of ethanol blended in gasoline and no MTBE in gasoline. Although we acknowledge that some of the ethanol will substitute for MTBE, our analysis of the costs and benefits of increased ethanol production focuses on the ethanol used as a substitute for gasoline, though the environmental costs are applicable to all ethanol.

¹⁰ We do not quantify the direct deadweight loss of the ethanol policies themselves, which would contribute further to the costs of the government incentive programs.

of the EPA's cost and benefit numbers, which the EPA had not monetized, according to established benefit values and adds some costs and benefits that the EPA did not consider. We then compare the costs and benefits accordingly. We find that the costs of increasing ethanol production to ten billion gallons a year are likely to exceed benefits relative to our baseline production estimate of four billion gallons of ethanol a year.¹¹ A monte carlo analysis suggests our findings are robust to changes in key parameter values. Below we provide important details about the monetized costs and benefits, including a discussion of possible biases in some of the estimates.

3.1 Methodology

We rely on estimates from the literature along with a regulatory impact analysis from the EPA in our base case. Where possible, we compare estimates from different sources. The base case uses best estimates where they are available. In a few cases, we use government estimates that may not reflect our view of best estimates, and may be biased in favor of ethanol. We incorporate our subjective judgments in the uncertainty analysis and note when this occurs. We will argue below that the particular choice of parameters is unlikely to have a dramatic effect on the key qualitative result that the costs of increasing ethanol production are likely to exceed the benefits.

We follow the EPA's methodology and define impacts as the changes resulting from increasing ethanol production from a baseline of four billion gallons per year to the renewable fuel standard (RFS) of almost seven billion gallons per year. The RFS is actually 7.5 billion gallons of ethanol in 2012, but EPA analyzes 6.7 billion gallons of ethanol in 2012. We also assume that the increased amount of ethanol will be used as an oxygenate or as an octane enhancer for no more than 10% ethanol gasoline blends. Higher blends of ethanol in gasoline require the use of flexible-fuel vehicles.¹²

The EPA also considers a second scenario where ethanol production reaches almost ten billion gallons per year, called the EIA scenario. The EIA predicts that level of production will be reached by 2012 if current subsidies remain in place.¹³ If the EIA is correct, then the RFS is not binding. We include it because it can become binding if the EIA scenario is not reached.

We monetize cost and benefit impacts using estimates obtained from the literature on the benefit per ton of emission reductions and benefit per barrel of oil displaced. This methodology is called benefits transfer. These benefit numbers are rough approximations of marginal benefits (Kirchhoff et al. 1997; Brouwer and Spaninks 1999). We base our calculations on the benefits and costs that we could monetize. Most items that could not be monetized were environmental costs and therefore unlikely to change our conclusions.

¹¹ We take the EPA's baseline assumption as given (EPA 2007a). This baseline estimate of ethanol production in 2012 was calculated by extrapolating ethanol use in 2004. U.S. production currently exceeds this baseline.

¹² We do not consider the diffusion of new technologies in our analysis. Keefe et al. (draft) focus on the technology changes associated with E85 and find that the technology has net costs from a private and social perspective.

¹³ The EIA predicts even higher production of ethanol in its 2008 energy outlook projections (EIA 2007).

The EPA makes certain assumptions in its analysis which are implicit in our analysis since we take the EPA's numbers as given. For example, the agency assumes a constant oil price of \$48 per barrel of crude oil, which is lower than current oil prices.¹⁴ Ethanol production could be expected to increase further if the oil price is higher. Based on our analysis, this could lead to even higher net costs because the environmental costs of ethanol would increase, though some of the production costs might decrease. We do not analyze ethanol costs under different scenarios. In particular, we do not do a general equilibrium analysis, and note that such an analysis could yield different results (Hazilla and Kopp 1990; Goulder and Williams 2003).¹⁵

3.2 Benefits

The quantifiable benefits of increased ethanol use include those related to reducing oil imports and the environment. The EPA models the oil displacement, greenhouse gas (GHG) emission reductions, and air toxic emission reductions in its regulatory impact analysis. Our unit benefit values are averages taken from the literature. The first part of Table 1 presents the estimates used in the base case. Quantity refers to the amount of displacement or reduction, while unit value is the value per unit of the relevant quantity.

The value of decreased oil imports, called the oil premium, is based on the benefit associated with U.S. buying power in the oil market, and the avoided costs of economic shocks. Because the U.S. is a large importer of oil, a reduction in U.S. oil imports could lead to a reduction in the world price of oil. If so, the U.S. would then pay less for the oil it still imports. This external economic benefit is sometimes referred to as the monopsony benefit (Broadman 1986).¹⁶ In addition, energy dependence can impose costs through the economic shocks of sudden oil price increases (Hickman et al. 1987). In the 1970s, there were two major oil crises. In both cases, instability and war in the Middle East led to high gasoline prices, which were followed by unemployment and inflation in the U.S. (Barsky and Kilian 2004). Although there may be an empirical link between oil price increases and economic slumps, the exact mechanism is unclear (Toman 2002). Some scholars, such as Bohi (1990), suggest that other factors, such as monetary policy, account for the impact on output and employment. Blanchard and Gali (2007) suggest that today's economy may be more resilient to shocks than the economy of the 1970s. We use a value of \$8 per barrel for the external economic benefits, which is an average taken from the published literature.¹⁷ In addition, some scholars suggest that reductions in the direct cost of protecting oil in the Middle East

¹⁴ The EPA does, however, vary some parameters such as grain prices.

¹⁵ Hazilla and Kopp (1990) find that incorporating the general equilibrium effects could increase estimates of the social costs of environmental regulation, but they do not explore the impact on benefits.

¹⁶ We include a monopsony benefit for reducing oil imports, but do not trace out the impact of lower oil prices on the demand for gasoline.

¹⁷ We use the low and average estimates calculated by Leiby (2007). We believe that the high estimates in the study may overstate the benefits significantly. Leiby (2007) uses older estimates of supply, demand, and import elasticities that may overstate the monopsony benefits and the estimate of the economic shock does not include new research about the resilience of the current economy.

Table 1 Benefits and costs of the RFS and EIA scenarios (in millions of 2004\$)

	RFS scenario			EIA scenario		
	Quantity	Unit value	Benefit/cost	Quantity	Unit value	Benefit/cost
Benefits						
Oil displaced by corn ethanol	25	\$8	\$200	60	\$8	\$480
Greenhouse gas reductions	9	\$11	\$100	14	\$11	\$150
Air toxics	0.0021	\$1,500	\$3	0.0024	\$1,500	\$4
Carbon monoxide	0.6	\$0	\$0	1.7	\$0	\$0
Total benefits			\$300			\$600
Costs						
Production cost	\$820	NA	\$820	\$1,700	NA	\$1,700
Deadweight loss of subsidies	\$340	NA	\$340	\$720	NA	\$720
Nitrogen oxides	0.059	\$3,200	\$190	0.10	\$3,200	\$320
Volatile organic compound	0.0065	\$1,400	\$9	0.035	\$1,400	\$49
Particulate matter-10	0.012	\$550	\$6.6	0.024	\$550	\$10
Sulfur oxides	0.025	\$6,500	\$160	0.051	\$6,500	\$330
Total costs			\$1,500			\$3,100
Net benefits			-\$1,200			-\$2,500

Source: For quantities, see EPA (2007a). For unit values, see Leiby (2007), Parry and Darmstadter (2003), Huntington (2003), IPCC (2007), EPA (1997, 2007a), Muller and Mendelsohn (2007), and Office of Management and Budget (2006)

Notes: Quantities are in million tons, except for the oil displacement, which is in million barrels, and the production costs and deadweight loss of subsidies, which are in million dollars. We convert all metric tons to 2,000 pounds per ton. We round estimates to two significant digits. The benefits and costs are calculated by multiplying the quantity by the value. Net benefits equal the total benefits minus the total costs

is another benefit. It is difficult, however, to estimate the direct cost of protecting oil in the Middle East because the U.S. involvement in the Middle East is not just related to oil (Toman 2002; Parry and Darmstadter 2003). We do not include a value for reduced military expenditures.¹⁸ Another possible benefit of reducing the U.S. oil purchases is less funding for terrorist activities that could adversely impact the U.S. We do not include this potential benefit because we are not aware of any scholarly effort to monetize it on a per barrel basis.¹⁹

We use the average value for the greenhouse gas emission reductions from the Intergovernmental Panel on Climate Change (IPCC 2007). Their estimate includes the net economic costs of damages from climate change across the globe. They surveyed more than 100 peer-reviewed estimates to find an average discounted value of \$11 per ton of carbon dioxide reduced.²⁰ We could not find values for domestic decreases in greenhouse gas emissions, which are likely to be lower if such decreases do not translate into equal decreases in net global emissions.²¹

¹⁸ Delucchi and Murphy (2004) suggest an average value between 2 and 18 cents per gallon of all gasoline and diesel motor fuel in 2004. We do not include a value for reduced military expenditures because we believe that this value is likely to be small or negligible at the margin.

¹⁹ We believe that the unit value range in our monte carlo analysis indirectly deals with this issue.

²⁰ The range for this estimate is large and we incorporate that uncertainty in our monte carlo analysis.

²¹ Again, recent evidence suggests that ethanol is not likely to lower GHGs at all. Including this benefit value might overstate the benefits of ethanol.

To monetize the air toxic emissions reductions, we use the average health and welfare benefit value per ton of volatile organic compound reductions from EPA (2007a), EPA (1997), and Muller and Mendelsohn (2007), which is about \$1,400. We also add about \$83,000 in benefits to approximate the cancer incidence reductions due to reducing air toxic emissions.²²

Carbon monoxide reductions are valued at zero because their economic value is thought to be de minimis. Using a zero value does not imply that carbon monoxide is harmless. At low concentrations, carbon monoxide can have mild health effects such as fatigue. In higher concentrations, it can cause dizziness, confusion, and nausea. At very high concentrations, it can cause death.²³ Dangerous levels, however, are not likely to be found in ambient air. Most areas in the U.S. comply with the ambient carbon monoxide standard.

The benefits range from about \$300 million for the RFS scenario and more than \$600 million for the EIA scenario. We multiply the quantity estimates by the unit values obtained from the EPA (2007a) and other literature.

3.3 Costs

The second part of Table 1 provides estimates for the future costs of increased ethanol production. Unlike in many benefit-cost analyses, the costs in the case of ethanol include more than just monetary costs. The costs also include the values of the negative air quality impacts associated with increased ethanol. As before, we use the EPA's best estimates for the production cost and the increased emissions from ethanol production and use.²⁴ The emission increases mostly come from the emissions associated with ethanol production and transport.²⁵ The production cost includes the increase in direct production costs and the distribution costs (EPA 2007a). We calculated deadweight loss of raising revenue to support government programs by multiplying the subsidy by a factor of 0.25.²⁶

²² We calculate the approximate cancer incidence reduction using information from EPA (2006). In EPA (2006), the EPA calculated an upper bound cancer incidence reduction of 0.01 for a 1,700 ton reduction in air toxics, assuming 70 years of exposure 24 h a day for all individuals in a given location. We extrapolate that result to obtain a 0.012 cancer incidence reduction for the RFS scenario and a 0.014 cancer incidence reduction for the EIA scenario given the tons of air toxics reduced. We multiply the cancer risk reduction by the value of statistical life used by the EPA to obtain about \$90,000 each year for each scenario (Dockins et al. 2004). This methodology is similar to methodology used in Hahn (2008). This is a crude approximation of the cancer incidence reductions, but we could not find a better method in the literature.

²³ EPA provides a fact sheet on the health effects of carbon monoxide, which can be found at <http://www.epa.gov/iaq/co.html>.

²⁴ We describe these costs in the appendix. The appendix also includes our independent estimate of costs based on the EIA's most recent projections to ensure that the EPA's costs are reasonable (EIA 2006).

²⁵ The nitrogen oxide emissions, however, result from ethanol use in vehicles (EPA 2007a).

²⁶ We use a factor of 0.25. The actual deadweight loss of raising revenue for the subsidy may be higher; Feldstein (1999) calculated a deadweight loss of 30% of revenue raised. We vary the deadweight loss factor from 0 to 0.25 in our monte carlo analysis, using 0.25 as the best estimate. In addition, a subsidy on ethanol may induce welfare changes in the markets of substitutes, such as gasoline (Harberger 1974). We do not analyze these changes. Finally, see the appendix for a discussion of the tax credit's effect on farm loan benefits and countercyclical payments.

The values used to monetize increased emissions of nitrogen oxides, volatile organic compounds, particulate matter-10, and sulfur oxides are also summarized in Table 1. Significantly, the average value we use to monetize the increased nitrogen oxides emissions (around \$3,000 per ton) is much lower than the value the EPA (2007a) suggests because we use the average value from many published studies.

The total costs are significantly higher than the total benefits, ranging from about \$1.5 billion for the RFS scenario to about \$3 billion for the EIA scenario.

3.4 Benefits and costs

Costs exceed benefits by about \$1 billion in the RFS scenario and by about \$3 billion in the EIA scenario. Our results suggest that increases in the production of ethanol from four billion gallons to almost ten billion gallons a year, as currently predicted by the EIA, will cost society much more than they will benefit society.²⁷

4 Uncertainty analysis

To take into account uncertainties associated with the quantity and unit value estimates, we run a monte carlo simulation of 3,000 trials for both the RFS and the EIA scenarios.²⁸ We select probability distributions for key parameters in the simulation, which then estimates the benefits and costs based on those distributions. In performing this exercise, there is inevitably a degree of subjectivity because not all distributions are well defined in the literature. Where estimates are not available, we substitute our best judgment.²⁹ Even when we take into account large uncertainties in some of the estimates, both the EIA scenario and the RFS scenario still produce costs in excess of benefits in about 99% of trials. Here, we summarize key assumptions used in the uncertainty analysis and briefly discuss the basis for our assumptions.

4.1 Quantity and unit value

Table 2 summarizes the quantity and unit value parameters used in the RFS and EIA scenarios, incorporating the uncertainty found in the literature. Typically, we include the lowest, highest, and average estimate from the literature and impose a triangular distribution; the apex of the triangle is the average estimate. In some cases, we diverge from this general strategy.³⁰ For oil displacement and greenhouse gas reductions, we estimate a lower bound.³¹ In the case of the deadweight loss, we vary the percentage of

²⁷ We assume that production of ethanol at four billion gallons has zero net costs or negative net costs. We provide our reasoning later. Already, ethanol production is over four billion gallons, which we believe is providing society with net costs.

²⁸ We used @Risk to run the analysis. The data converged after 3,000 trials.

²⁹ See appendix for details.

³⁰ See appendix for details.

³¹ We impose a triangular distribution where the apex is the upper bound. See appendix for details.

Table 2 Monte carlo parameter estimates

	RFS quantity estimates			EIA quantity estimates			Unit value estimates		
	Low	High	Best	Low	High	Best	Low	High	Best
<i>Benefits</i>									
Gasoline displacement (mill barrels)	23 ^a	25	25	54 ^a	60	60	\$0	\$23	\$8
Greenhouse gas reductions (mill tons)	8 ^a	9	9	13 ^a	14	14	-\$3	\$83	\$11
Air toxics reductions (mill tons)	0.001	0.003	0.0021	0.0006	0.004	0.0024	\$370	\$3,200	\$1,500
Carbon monoxide reductions (mill tons)	0.45	0.66	0.6	1.3	2.0	1.7	\$0	\$0	\$0
<i>Costs</i>									
Production cost (mill 2004\$)	-\$260	\$2,930	\$820	-\$850	\$5,800	\$1,700	-	-	-
Deadweight loss (mill 2004\$)	\$1,400	\$1,400	\$1,400	\$2,900	\$2,900	\$2,900	0	0.25	0.25
Nitrogen oxide emissions (mill tons)	0.036	0.082	0.059	0.067	0.13	0.10	\$310	\$12,000	\$3,200
Volatile organic compound emissions (mill tons)	-0.015	0.028	0.0065	0.007	0.063	0.035	\$330	\$3,200	\$1,400
Particulate matter-10 emissions (mill tons)	0.009	0.015	0.012	0.018	0.03	0.024	\$220	\$820	\$550
Sulfur oxide emissions (mill tons)	0.02	0.03	0.025	0.041	0.061	0.051	\$990	\$1,900	\$6,500

Source: For quantities, see EPA (2007a) and authors' calculations. For unit values, see Leiby (2007), Leiby et al. (1997), Parry and Darmstadter (2003), Huntington (2003), IPCC (2007), and Office of Management and Budget (2006)

^a This estimate was calculated as 90% of the high estimate. See appendix for details

the subsidy that makes up the deadweight loss, and multiply that value by the amount of the subsidy to obtain an estimate of the loss.

4.2 Results

For the RFS scenario, the uncertainty analysis yielded a mean net benefit of negative \$1.5 billion with a standard deviation of about \$700 million. The net benefits were negative in more than 99 percent of the trials. For the EIA scenario, the uncertainty analysis yielded a mean net benefit of negative \$2.9 billion with a standard deviation of about \$1.5 billion. The net benefit was negative in about 99% of the trials. The

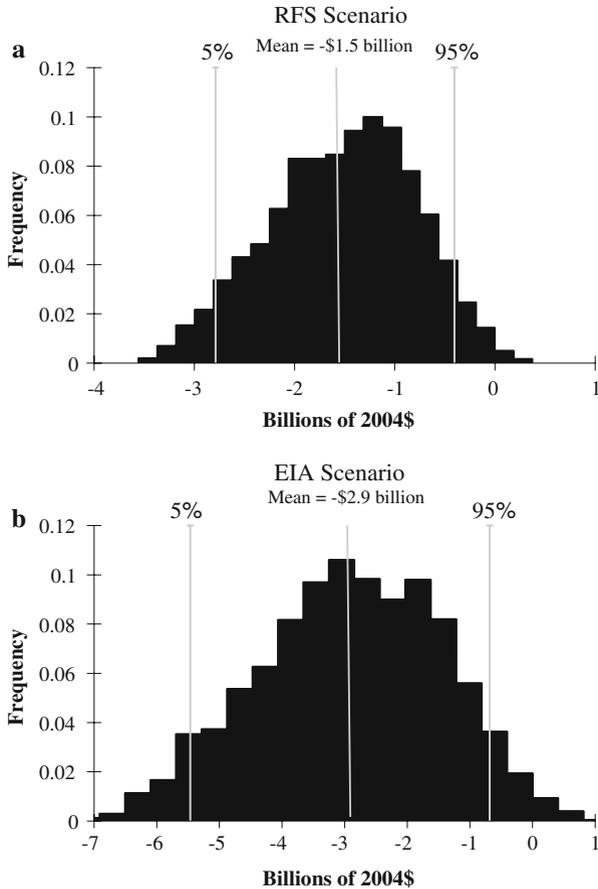


Fig. 2 The distribution of net benefits for the (a) RFS and (b) EIA scenarios. *Notes:* We indicate the 90% confidence interval and the mean

90% confidence interval fell between negative \$2.8 billion and negative \$400 million for the RFS scenario and between negative \$5.4 billion and negative \$480 million for the EIA scenario. Figure 2 shows the distribution of our results for the RFS and EIA scenarios, indicating the mean and 90% confidence interval.

A number of factors were left out of this analysis, the majority of which would have the effect of increasing the net costs. These include ethanol's adverse effects on land use, biodiversity loss, groundwater contamination (especially its role in increasing the "dead zone" in the Gulf of Mexico), soil erosion, heavy water use, the effect of food prices, and acidification (Niven 2005; Scavia 2007; National Research Council 2007; Elobeid and Hart 2007; Jacobson 2007).³² We exclude these because of difficulties in estimating their value. We also keep carbon dioxide reductions as a benefit of

³² There are also impacts on the rest of the world that are outside the scope of the analysis. See, for example, Elobeid and Hart (2007) for a discussion of how rising food prices will hurt some developing countries.

increasing ethanol, although recent studies suggest that ethanol may actually increase carbon dioxide emissions, adding to the overall costs of ethanol (Crutzen et al. 2007; Searchinger et al. 2008; Fargione et al. 2008). Of course, if recent studies are correct, ethanol becomes even more unattractive, since the supposed greenhouse gas reductions contribute about \$100 to \$150 million in benefits. Also, the focus on ethanol as a way to reduce greenhouse gases may make it difficult for policy makers to select better climate policy options later. For example, once an ethanol plant is built, it will be hard for a politician to close it down by withdrawing the subsidy. That is another cost to ethanol policy that we did not monetize. The bottom line is that the net costs of ethanol could be substantially larger than we have estimated here.

Our analysis strongly suggests that it is very unlikely that increasing ethanol production to the level fostered by current subsidies will result in net benefits for society.³³ While our analysis does not directly address the past benefits and costs of ethanol policies, we are skeptical that these programs have yielded net benefits. The reason is that production costs have likely declined over time with technological improvements, but marginal benefits in terms of energy and the environment have not changed that much.³⁴ Therefore, if relative prices did not change dramatically, ethanol would likely have been less attractive from a social standpoint than it is today. Of courses, prices did change, so a thorough benefit-cost analysis of historical support for ethanol would need to take this into account.³⁵

5 Conclusion and recommendations

It is difficult to build an economic case for providing special support for ethanol on the basis of alleged market failures. Ethanol made from corn is not likely to boost energy security much and its environmental benefits appear to be relatively small. Our analysis of the projected increase in ethanol production suggests that the costs are likely to exceed benefits by about three billion dollars annually in 2012 if current policies continue, which would put ethanol production at ten billion gallons a year. Though we do not directly analyze the contribution of different policies to this total, we assume that the tax incentives and other support have at least some contribution to the increased ethanol production. The tax credit, the largest component of current support, is generally accepted to be an inefficient method for dealing with externalities.

Contrary to current opinion, we argue that continued support for ethanol is not a sure thing. Our best guess is that ethanol can expect to receive some level of government support in the future, but will not enjoy the same kind of open-ended support it has in the past. The reason is that some interest groups will likely mobilize in opposition

³³ We also ran a “conservative” monte carlo analysis, in which we did not alter any of the estimates from the literature. The analysis had no lower bounds for the oil displacement and greenhouse gas emission reductions. In addition, we included no deadweight loss costs, assuming that the deadweight loss was completely offset by the decrease in farm deficiency payments. We still found that net benefits were negative in more than 96% of trials for both the RFS and EIA scenarios.

³⁴ Shapouri and Gallagher (2005) find some savings in the average costs to build new plants, for example.

³⁵ To our knowledge, such an analysis has not been done. Indeed, Miranowski (2007) suggests that past support for ethanol may have resulted in net benefits.

to further support for ethanol, and other interest groups may reduce their support. As increases in the price of corn affect other interest groups, such as livestock producers, they will become more vocal in their opposition to corn ethanol.³⁶ Furthermore, as it becomes clearer that the environmental benefits of ethanol are small, or even negative, environmentalists are likely to reduce their support. One study by [Kruse et al. \(2007\)](#) found that removing the ethanol tax credit and tariff when they expire will reduce ethanol production by about four billion gallons. If this is correct, our analysis suggests that removing the tax credit and tariff could save society roughly a billion dollars annually. Future research should consider the benefits and costs associated with removing the ethanol tax credit and tariff on imported ethanol.

The U.S. Congress should consider more sensible approaches to environmental and energy goals that take advantage of market signals to achieve the desired end. The government should learn a lesson from its ethanol policy, and refrain from picking winners and losers. We suggest four policies related to ethanol that can promote energy security and environmental goals more efficiently. First, the U.S. should repeal the ethanol import tariff, which expires at the end of 2008. Its costs are likely to outweigh its benefits ([Slaski 2008](#); [Wolak 2007](#)).

Second, the U.S. should limit direct domestic support for alternative energy sources to basic research. Basic research for ethanol could be supported, but it is only one of many alternative fuels that should be considered. For example, an argument can be made for a small subsidy to cellulosic ethanol plants, phased out over time, if there are learning-by-doing benefits from the initial plants that can spill over to future producers of cellulosic ethanol.³⁷ There is only so much land in the U.S. that could be effectively planted, however, and other uses should not have to compete with a subsidized ethanol program. In fact, some scholars worry that the increased attention to ethanol takes focus away from real energy solutions ([Jacobson 2007](#); [Patzek 2004](#)).

Third, the U.S. should consider taxing key externalities, such as those related to energy security and the environment. Implementing such taxes is not a simple matter; however, it can be done if there is political support. Moreover, taxes represent a simple, cost-effective method for inducing appropriate levels of conservation for different types of fuels and energy conservation and efficiency should be encouraged by the government.

Fourth, some scholars recommend modifying the nature of the ethanol tax credit, so that it is tied to gasoline prices ([Miranowski 2007](#)). Given that corn ethanol cannot survive on its own even in times of high gasoline prices, it may be unreasonable to subsidize it at all. At most, a gallon of ethanol should be subsidized by the amount of benefits associated with a gallon of ethanol. According to our analysis, this amount is roughly 0–5 cents per gallon.

In addition, we believe it would have been informative if the EPA had provided a more detailed economic analysis of the renewable fuel standard. President Clinton's Executive Order 12866 requires regulatory agencies to assess the benefits and costs

³⁶ [Westcott \(2007\)](#) summarizes some of the changes in the agricultural sector.

³⁷ A learning-by-doing argument can be made for almost any technology, which can create a slippery slope. Corn ethanol production, for example, is a mature industry and should not be subsidized.

of alternatives, including the alternative of not regulating.³⁸ The fact that EPA did not monetize benefits, compare benefits and costs, and did not consider alternatives, such as eliminating the tax credit, suggests that the process for developing better regulation could be dramatically improved (Hahn and Tetlock 2008). Our analysis does some of these things using EPA's estimates and finds that costs of increased ethanol production outweigh the benefits even according to the EPA's own analysis.

We are not optimistic that legislators will ignore political realities, and implement an economical solution to the problems of energy security and improving the environment. At the same time, we believe policy makers are more likely to consider changes when the consequences of their policy decisions are more widely appreciated. Moreover, we believe that other political imperatives, such as those driven by livestock producers and the need to respond to climate change, may present opportunities to adopt more economically efficient policies.

Acknowledgements The authors would like to thank Bruce Gardner, John Graham, James Griffin, Howard Gruenspecht, Bill Hogan, Hill Huntington, Ryan Keefe, Al McGartland, Ian Parry, Richard Newell, Robert Taylor, David Victor, and Paul Westcott for helpful comments. They especially thank Peter Nagelhout for answering detailed questions about the underlying economic and environmental components of ethanol. Ryan Hughes and Molly Wells provided valuable research assistance. This research was supported by the Reg-Markets Center. The views expressed in this paper reflect solely those of the authors and do not necessarily reflect those of the institutions with which they are affiliated.

Appendix

This appendix provides rationales for key assumptions used in the monte carlo analysis.³⁹ It explains the estimates summarized in Table 2.

Quantity

The EPA estimates the gasoline displacement due to corn ethanol in 2012 to be about 25 million barrels under the RFS scenario and 60 million barrels under the EIA scenario.⁴⁰ There are reasons to think these estimates are optimistic. For example, EPA (2007a) assumes that one energy unit of ethanol displaces one energy unit of oil. This one-for-one assumption is not likely to hold because as ethanol production increases, the price of oil can be expected to decline due to lower U.S. oil imports. The lower price of oil could lead to more use of oil in the U.S., a limitation that is acknowledged by the EPA. Thus, some factor less than one-for-one is appropriate. We assume a lower bound of 90 percent of EPA's estimate.⁴¹

³⁸ In this case, the EPA faced a tight deadline on the analysis and the alternative to the regulation being analyzed was the business as usual, or EIA, scenario. Nonetheless, the EPA should have considered the alternative of repealing the tax credit that is driving the increased demand for ethanol since the agency has an obligation to consider alternatives that maximize net benefits (Clinton 1993).

³⁹ In principle, one might want to consider correlations across different variables if such data were available.

⁴⁰ We convert from quadrillion Btus to barrels using standard conversion factors from the EIA.

⁴¹ Our choice of a lower bound is arbitrary, but, changing these parameters does not significantly change the results.

Many studies suggest that ethanol made from corn will result in lower greenhouse gas emissions relative to gasoline, and the U.S. government uses this assumption in its support of ethanol (Hill et al. 2006; Wang et al. 1997; EPA 2007a). The regulatory impact analysis for the EPA's renewable fuel standard estimates that increasing ethanol use in 2012 would result in a net 11–17% decrease in greenhouse gas emissions, a result similar to that calculated by other studies. This corresponds to about 8 million tons of greenhouse gas emission reductions for the RFS scenario and 13 millions tons for the EIA scenario.⁴²

There are reasons to believe that these estimated greenhouse gas reductions might also be greatly overstated. The assumption that one energy unit of ethanol displaces one energy unit of oil is not likely to hold in a global economy because as the price of oil declines due to lower U.S. oil imports, more oil will be used in the U.S. and worldwide. This increase in oil consumption would increase expected greenhouse gas emissions. Another problem is that many studies do not adequately take into account the impact that lower U.S. corn exports could have on corn production elsewhere. The decrease in corn exports may cause other countries to convert previously unused marginal land into farm land, which will also increase global emissions of greenhouse gases. Two recent papers focus on the impact land use changes can have on net carbon dioxide reductions, and find that the land use changes as a result of increased ethanol production may actually increase overall carbon dioxide emissions (Searchinger et al. 2008; Fargione et al. 2008). Some scholars, such as Hill et al. (2006), acknowledge that the small reduction in greenhouse gas emissions associated with ethanol use may not be robust to alternate assumptions.

One of the greatest challenges to the greenhouse gas reductions attributed to ethanol is from a recent study led by Nobel Prize winner Paul Crutzen (Crutzen et al. 2007). They find that the nitrous oxide emissions from agriculture were previously underestimated. Accounting for these emissions actually results in net *increases* in greenhouse gases from the production and use of biofuels such as ethanol. If correct, this study could drastically alter the perception of the greenhouse gas benefits of ethanol. We ignore the recent findings of Crutzen et al. (2007) in our analysis and use the EPA's estimate, creating a lower bound that is only 10% less than the initial estimate. The recent work by Searchinger et al. (2008), Fargione et al. (2008), and Crutzen et al. (2007) suggest that our estimate of greenhouse gas reductions may be an overestimate.

Air toxic emissions reductions include reductions in benzene, 1,3-butadiene, and formaldehyde emissions. The reductions are offset by increases in acetaldehyde emissions from the combustion of ethanol, another air toxic (Jacobson 2007). For the reductions in air toxics, we use a low and high estimate defined by the EPA (2007a) in its analysis. Importantly, however, a recent EPA air toxics rule establishes a trade-able benzene fuel content requirement, which is equivalent to a cap on benzene levels (EPA 2007b). Because of this rule, increasing ethanol could reduce the costs of complying with the requirement, but would not reduce actual levels of benzene. We do not include the EPA air toxics rule in our analysis.

⁴² The greenhouse gas reductions include the expected increases in methane and nitrous oxide, two other greenhouse gases, which partially offset the expected carbon dioxide reductions. We convert from metric tons to 2,000 pound tons for consistency.

In the base case, we took the EPA's best estimate of the production cost as given. The EPA (2007a) bases its estimate of costs on the additional capital, investment, fuel, and distribution costs faced by refineries to increase their production of ethanol from four billion gallons a year to about seven billion gallons per year in the RFS scenario, and to about ten billion gallons per year in the EIA scenario. The agency finds that while changes in investment decisions lead to cost savings, the costs associated with the lower energy density of gasoline outweigh those cost savings. The EPA (2007a) also presented a low and high estimate under different assumptions for the projected price of corn and other grains. We add these to the uncertainty analysis, and use a triangular distribution.

We also tried to independently check the EPA's cost estimate by using the projected price for ethanol compared to gasoline in 2012 from the EIA's most recent projections of crude oil prices (EIA 2006). EIA (2006) assumes higher oil prices than the EPA (2007a). If we assume that the relative price of gasoline to ethanol reflects the extra costs associated with ethanol, the extra cost of ethanol production for the RFS and EIA scenarios is \$1.4 billion and \$2.8 billion, respectively. These estimates are close to the best estimates we use in our analysis and certainly within our range. Of course, this is a very rough estimation meant only to establish that the EPA numbers are reasonable. The ranges used in our monte carlo analysis are larger and include negative production costs, which the EPA calculated under certain assumptions, for added security.

Some costs may be offset by decreases in payments to farmers, notably price-sensitive marketing loan benefits and countercyclical payments when the price of corn falls below a certain level. It appears that the avoided deficiency payments are likely to be substantially less than the ethanol tax credit. For example, Kruse et al. (2007) find that removing the ethanol tax credit will save taxpayers about \$7 billion on average, while increasing deficiency payments by about \$1 billion. We do not include avoided deficiency payments in our analysis.

To incorporate the uncertainty regarding our estimate of deadweight loss, we impose a triangular distribution and allow the deadweight loss to range from 0 to 25% of the subsidy, using 25% as the best estimate. Fortunately, our qualitative conclusions do not depend on the inclusion of deadweight losses from the subsidy.

We do not alter the estimates of nitrogen oxides, volatile organic compounds, sulfur oxides, or particulate matter-10. The EPA (2007a) provides high and low estimates for both and we average to obtain the best estimate. We impose a triangular distribution on these inputs.

Unit value

The values for the oil premium range in the literature from \$0 to \$23 (Parry and Darmstadter 2003; Leiby 2007). In our base case, we use a modified average estimate from the Leiby (2007) study because of concerns we had about his high estimates. The study uses older estimates of supply and demand elasticities that may overstate the monopsony benefits and the estimate of the economic shock does not include new research about the resilience of the current economy. In the monte carlo analysis, we

allowed the oil premium to range up to the high end estimated by Leiby (2007) but we left the average as \$8, the value we used in our base case analysis.⁴³

For the other emission increases, we include the high and low values from the literature. These reflect some of the geographic differences in the costs of these emissions increases that are not included in the base case. We do not include a range for benefits from the carbon monoxide reductions because we have not found credible estimates.

References

- Barsky, R. B., & Kilian, L. (2004). Oil and the macroeconomy since the 1970s. *Journal of Economic Perspectives*, 18(4), 115–134.
- Blanchard, O. J., & Gali, J. (2007). The macroeconomic effects of oil shocks: Why are the 2000s so different from the 1970s? NBER Working Paper No. 13368.
- Bohi, D. R. (1990). *Energy price shocks and macroeconomic performance*. Washington, DC: Resources for the Future.
- Bohi, D. R., & Montgomery, W. D. (1982). *Oil prices, energy security, and import policy*. Washington, DC: Resources for the Future.
- Broadman, H. G. (1986). The social cost of imported oil. *Energy Policy*, 14(3), 242–252.
- Brouwer, R., & Spaninks, F. A. (1999). The validity of environmental benefit transfer: Further empirical testing. *Environmental and Resource Economics*, 14, 95–117.
- Bush, G. W. (2007). Twenty in ten: Strengthening America's energy security. <http://www.whitehouse.gov/stateoftheunion/2007/initiatives/energy.html>.
- California Energy Commission. (2004). Ethanol fuel incentives applied in the U.S. reviewed from California's perspective. Staff Report P600-04-001.
- Clinton, W. J. (1993). Executive Order 12866: Regulatory Planning and Review. Public Papers of the Presidents. Washington, DC: General Printing Office.
- Crutzen, P. J., Mosier, A. R., Smith, K. A., & Winiwarter, W. (2007). N₂O release from agro-biofuel production negates global warming reduction by replacing fossil fuels. *Atmospheric Chemistry and Physics Discussions*, 7, 11191–11205.
- Delucchi, M. A., & Murphy, J. (2004). U.S. military expenditures to protect the use of Persian-Gulf oil for motor vehicles. Report #15 in the series: The Annualized Social Cost of Motor-Vehicle Use in the United States, based on 1990-1991 Data. UCSD-ITS-RR-96-3 (15)2.
- Dockins, C., Maguire, K., Simon, N., & Sullivan, M. (2004). Value of statistical life analysis and environmental policy: A white paper for presentation to Science Advisory Board- Environmental Economics Advisory Committee. Environmental Protection Agency, Office of Policy, Economics and Innovation, National Center for Environmental Economics.
- EIA. (2006). Annual Energy Outlook 2007: Legislation and regulations. http://www.eia.doe.gov/oiaf/aeo/pdf/leg_reg.pdf.
- EIA. (2007). Annual Energy Outlook 2008 with Projections to 2030. http://www.eia.doe.gov/oiaf/aeo/aeoref_tab.html.
- Elobeid, A., & Hart, C. (2007). Ethanol expansion in the food versus fuel debate: How will developing countries fare?" Explorations in Biofuels Economics, Policy and History Special Issue. *Journal of Agricultural & Food Industrial Organization*, 5(6), 1–23.
- EPA. (1997). Economic analysis for the National Emission Standards for Hazardous Air Pollutants for source category: Pulp and paper production; Effluent Limitations guidelines, pretreatment standards, and new source performance standards: Pulp, paper, and paperboard category-Phase 1. OAQPS. Research Triangle Park, NC. <http://www.epa.gov/ttn/ecas/econdata/Rmanual2/7.2.html>.
- EPA. (2006). Part II: EPA—National emission standards for hazardous air pollutants for organic hazardous air pollutants from the synthetic organic chemical manufacturing industry; Proposed rule. *Federal Register*, 71(114), 34422–34446.
- EPA. (2007a). Regulatory impact analysis: Renewable fuel standard program. EPA 420-R-07-004. <http://www.epa.gov/otaq/renewablefuels/420r07004.pdf>.

⁴³ Including the high estimate only changes the average by one dollar.

- EPA. (2007b). Control of hazardous air pollutants from mobile sources. *Federal Register*, 72(37), 8427–8570.
- Fargione, J., Hill, J., Tilman, D., Polasky, S., & Hawthorne, P. (2008). Land clearing and the biofuel carbon debt. *Science*, 319(5867), 1235–1238.
- Farrell, A. E., Plevin, R. J., Turner, B. T., Jones, A. D., O'Hare, M., & Kammen, D. M. (2006). Ethanol can contribute to energy and environmental goals. *Science*, 311(5760), 506–508.
- Feldstein, M. (1999). Tax avoidance and the deadweight loss of the income tax. *The Review of Economics and Statistics*, 81(4), 674–680.
- GAO. (2000). Tax incentives for petroleum and ethanol fuels. GAO/RCED-00-301R. <http://www.gao.gov/new.items/rc00301r.pdf>.
- Goulder, L. H., & Williams III, R. C. (2003). The substantial bias from ignoring general equilibrium effects in estimating excess burden, and a practical solution. *Journal of Political Economy*, 111, 898–927.
- Hahn, R. W. (2008). Ethanol: Law, economics, and politics. *Stanford Law and Policy Review, Energy Symposium* (forthcoming).
- Hahn, R. W., & Tetlock, P. C. (2008). Has economic analysis improved regulatory decisions? *Journal of Economic Perspectives*, 22(1), 67–84.
- Hammerschlag, R. (2006). Ethanol's energy return on investment: A survey of the literature 1990-present. *Environmental Science and Technology*, 40(60), 1744–1750.
- Harberger, A. C. (1974). *Taxation and welfare*. The University of Chicago Press.
- Hazilla, M., & Kopp, R. (1990). Social cost of environmental quality regulations: A general equilibrium analysis. *The Journal of Political Economy*, 98(4), 853–873.
- Hickman, B. G., Huntington, H. G., & Sweeney, J. L. (1987). *Macroeconomic impacts of energy shocks*. Elsevier Science Publishers.
- Hill, J., Nelson, E., Tilman, D., Polasky, S., & Tiffany, D. (2006). Environmental, economic, and energetic costs and benefits of biodiesel and ethanol biofuels. *Proceedings of the National Academy of Sciences*, 103(30), 11206–11210.
- Huntington, H. G. (2003). Energy disruptions, interfirm price effects and the aggregate economy. *Energy Economics*, 25(2), 119–136.
- IPCC. (2007). Summary for policymakers. In *Climate Change 2007: Impacts, adaptation and vulnerability*. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.
- Jacobson, M. Z. (2007). Effects of ethanol (E85) versus gasoline vehicles on cancer and mortality in the United States. *Environmental Science and Technology*, 41(11), 4150–4157.
- Keefe, R., Griffin, J., & Graham, J. D. (2007). The benefits and costs of new fuels and engines for cars and light trucks. RAND Draft Working Paper.
- Kirchhoff, S., Colby, B. G., & LaFrance, J. T. (1997). Evaluating the performance of benefit transfer: An empirical inquiry. *Journal of Environmental Economics and Management*, 33, 75–93.
- Koplow, D. (2006). Biofuels—at what cost? Government support for ethanol and biodiesel in the United States. Prepared for the Global Subsidies Initiative of the International Institute for Sustainable Development. http://www.globalsubsidies.org/IMG/pdf/biofuels_subsidies_us.pdf.
- Kruse, J., Westhoff, P., Meyer, S., & Thompson, W. (2007). Economic impacts of not extending biofuels subsidies. Food and Agricultural Policy Research Institute, FAPRI-UMC Report #17-07.
- Leiby, P. N. (2007). Estimating the energy security benefits of reduced U.S. oil imports. United States Department of Energy, ORNL/TM-2007/028.
- Leiby, P. N., Jones, D. W., Curlee, T. R., & Lee, R. (1997). Oil imports: An assessment of benefits and costs. Oak Ridge National Laboratory Paper 6851.
- Miranowski, J. A. (2007). Biofuel incentives and the energy title of the 2007 Farm Bill. Part of Agricultural Policy for the 2007 Farm Bill and Beyond. American Enterprise Institute. <http://www.aei.org/research/farmbill/publications/pageID.1476,projectID.28/default.asp>.
- Muller, N. Z., & Mendelsohn, R. (2007). Measuring the damages of air pollution in the United States. *Journal of Environmental Economics and Management*, 54(1), 1–14.
- National Research Council. (2007). Water implications of biofuels production in the United States. Committee on Water Implications of Biofuels Production in the United States. The National Academies Press.
- Newell, R. G. (2006). What's the big deal about oil? How we can get oil policy right. Resources for the Future, Resources Issue No. 163.

- Niven, R. K. (2005). Ethanol in gasoline: Environmental impacts and sustainability review article. *Renewable and Sustainable Energy Reviews*, 9(6), 535–555.
- Office of Management and Budget. (2006). Draft 2006 comment to Congress on the costs and benefits of federal regulations. http://www.whitehouse.gov/omb/inforeg/reports/2006_draft_cost_benefit_report.pdf.
- Parry, I. W. H., & Darmstadter, J. (2003). The costs of U.S. oil dependency. Resources for the Future, Discussion Paper No. 03-59.
- Patzek, T. W. (2004). Thermodynamics of the corn-ethanol biofuel cycle. *Critical Reviews in Plant Sciences*, 23(6), 519–567.
- Scavia, D. (2007). The Gulf of Mexico's dead zone: Mess, problem, or puzzle? Resources for the Future, Weekly Policy Commentary.
- Schnepf, R. (2006). European Union biofuels policy and agriculture: An overview. Congressional Research Service Report to Congress RS22404. <http://italy.usembassy.gov/pdf/other/RS22404.pdf>.
- Searchinger, T., Heimlich, R., Houghton, R. A., Dong, F., Elobeid, A., Fabiosa, J., et al. (2008). Use of U.S. croplands for biofuels increases greenhouse gases through emissions from land-use change. *Science*, 319(5867), 1238–1240.
- Shapouri, H., & Gallagher, P. (2005). USDA's 2002 ethanol cost-of-production survey. United States Department of Agriculture, Agricultural Economic Report Number 841.
- Slaski, A. (2008). The economic and environmental effects of eliminating the U.S. tariff on ethanol. Thesis submitted to the Goldman Interschool Program in Environmental Science, Technology, and Policy of Stanford University.
- Toman, M. A. (2002). International oil security: Problems and policies. Resources for the Future, Issue Brief No. 02-04.
- Wang, M., Saricks, C., & Wu, M. (1997). Fuel-cycle fossil energy use and greenhouse gas emissions of fuel ethanol produced from U.S. Midwest Corn. Prepared for Illinois Department of Commerce and Community Affairs.
- Westcott, P. C. (2007). *U.S. ethanol expansion driving changes throughout the agricultural sector*. Amber Waves: United States Department of Agriculture.
- Wolak, F. A. (2007). An ethanol policy that benefits all Americans. Stanford Institute for Economic Policy Research Policy Brief.
- Yacobucci, B. D. (2006). Biofuels Incentives: A summary of federal programs. Congressional Research Service Report to Congress RL33572. <http://www.ncseonline.org/NLE/CRSreports/07Feb/RL33572.pdf>.