Journal of Public Economics 161 (2018) 1–14

Contents lists available at ScienceDirect

Journal of Public Economics

journal homepage: www.elsevier.com/locate/jpube

Who did the ethanol tax credit benefit? An event analysis of subsidy incidence

David A. Bielen[a], Richard G. Newell[b,c,f,*], William A. Pizer[d,e,f]

[a] National Renewable Energy Laboratory, United States
[b] Resources for the Future, United States
[c] Nicholas School of the Environment, Duke University, United States
[d] Sanford School of Public Policy, United States
[e] Nicholas Institute for Environmental Policy Solutions, Duke University, United States
[f] National Bureau of Economic Research, United States

ARTICLE INFO

JEL classification:
H22
Q11
Q41
Q42
Q47

Keywords:
Ethanol
Subsidy
Tax credit
Policy
Incidence
Event study
Futures price

ABSTRACT

At the end of 2011, the Volumetric Ethanol Excise Tax Credit (VEETC), which had subsidized the blending of ethanol in gasoline, was allowed to expire. During its tenure, the subsidy was the subject of intense scrutiny concerning who benefited from its existence. Using commodity price data, we estimate the subsidy incidence accruing to corn farmers, ethanol producers, gasoline blenders, and gasoline consumers around the time of expiration. Our empirical approach contributes methodologically to the event studies literature by analyzing futures contract prices (as opposed to spot prices) when possible. Ultimately, we find compelling evidence that, at the date of VEETC expiration, ethanol producers captured about 25¢ of the 45¢ subsidy per gallon of ethanol blended. We find suggestive, albeit inconclusive, evidence that a portion of this benefit (about 5¢ per gallon) was passed further upstream from ethanol producers to corn farmers. Most of the remainder seems most likely to have been captured by the blenders themselves. On the petroleum side, we find no evidence that oil refiners captured any part of the subsidy. We also find no evidence that the subsidy was passed downstream to gasoline consumers in the form of lower gasoline prices.

1. Introduction

> *"It might cost you more to fill up with gas as early as New Year's Day. If all other variables stay the same, gas prices should be higher since the tax credit oil companies have received to blend ethanol with their petroleum won't be available."*
>
> Jeff Scates, Illinois Corn Growers Association President (Illinois Corn, 2011)
>
> *"As a result, oil companies have been able to set demand and price levels for ethanol, keeping prices low and pocketing much, if not all, of the VEETC as profit."*
>
> Natural Resource Defense Council Policy Fact Sheet (Greene and Lyutse, 2010)
>
> *"While those who support the program put forth various reasons for their support—that ethanol will reduce greenhouse gases or curb our reliance on foreign oil—in reality, it is merely a wealth transfer program from the general taxpayer to corn producers."*
>
> Washington Examiner Op-Ed Piece (Wolfram, 2011)

The energy sector in the United States is host to a myriad of policies—regulations, taxes, and subsidies—that shift behavior away from a laissez-faire outcome. Such policies are often motivated by the association of different forms of energy use with significant non-market consequences related to the environment and energy reliability. An important question is whether the benefits from these policies exceed the costs, requiring a careful analysis of non-market benefits (National Research Council, 2010).

Often missing from the aggregate benefit-cost analysis are distributional assessments of who pays or, in the case of a subsidy, who benefits. Incidence is not obvious, as burdens and benefits can accrue to both producers and consumers depending on relative elasticities of response, and may be passed up and down a particular supply chain. Moreover, for incentive-based policies, including taxes and subsidies, the distinct consequences for winners and losers can be many times the aggregate net cost or benefit (Burtraw and Palmer, 2008). In many policy debates, it is these consequences for particular stakeholders that

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[*] Corresponding author at: Resources for the Future, United States.
E-mail addresses: david.bielen@nrel.gov (D.A. Bielen), newell@rff.org (R.G. Newell), william.pizer@duke.edu (W.A. Pizer).

https://doi.org/10.1016/j.jpubeco.2018.03.005
Received 6 July 2016; Received in revised form 16 March 2018; Accepted 18 March 2018

help determine both enactment and survival, regardless of the aggregate net benefit analysis. For both equity in its own right and equity's link to acceptance, it is important to consider these distributional effects.

Perhaps nowhere is this more evident than ethanol, which was the object of the single most expensive energy subsidy in recent history, the Volumetric Ethanol Excise Tax Credit (VEETC).[1] Regardless of one's stance on whether more ethanol is or is not desirable, or whether the subsidy was effective at encouraging more ethanol, advocates claimed the subsidy lowered motor fuel prices for consumers while critics claimed the subsidy simply enriched ethanol producers. Which view does the evidence support? The answer is relevant not only for the subsidy, but also for understanding the market structure underlying an industry that continues to be the subject of considerable policy intervention through the federal Renewable Fuel Standard.

Policy effects are often difficult to measure because the no-policy counterfactual cannot be observed. Further complicating matters, multiple policies often target the same objective, making it difficult to disentangle the effects of any single policy. This is particularly evident in the case of policies that promoted ethanol, where three different policies were in place from 2005, when both ethanol mandates and an effective ban on MTBE as a fuel additive began, until the end of 2011, when the VEETC was ended.

Nonetheless, the end to the VEETC in December 2011 offers a unique opportunity to observe the incremental consequences of a single policy. In particular, at the time of its termination, was the ethanol subsidy benefiting primarily ethanol producers or consumers? Was the value being passed further up or down the supply chain? By comparing prices along the supply chain immediately before and after the subsidy expired, we can isolate the effect of the subsidy termination holding other influences constant, and thereby determine the subsidy incidence. In concept, our estimation approach is similar to the typical event study, a technique that has spawned a large literature. However, we innovate on the typical event study approach by analyzing futures contract prices rather than spot market prices whenever possible, which allows us to avoid the estimation window issues that often plague event studies.[2]

The results suggest that most—perhaps 25¢—of the 45¢ per gallon of ethanol blended subsidy accrued to ethanol producers at the time the subsidy expired. Moreover, there is some evidence that a portion (about 5¢ per gallon) of the benefits were passed up the supply chain to corn farmers, although data limitations prevent us from making more confident statements on this front.[3] Random variation in prices for petroleum products makes it difficult to estimate the incidence on oil refiners or gasoline consumers precisely, but the point estimates suggest that these stakeholders received very little, if any, benefit from the subsidy. This refutes the notion that the subsidy largely benefited consumers. Based on the evidence, we conclude that most of the remaining third of the subsidy was likely being captured by fuel blenders at the time the subsidy expired.

In order to estimate the ethanol subsidy incidence, we use several data sources and empirical techniques. When possible, we use one-month calendar spreads constructed from the futures markets for ethanol, corn, and gasoline blendstock (petroleum). These spreads, reflecting expected one-month price changes, provide a means to differentiate sharply between the prices of products that could benefit from the tax credit, and those (produced after expiration) that could not. For commodities without exchange-traded futures markets, specifically finished gasoline, we use standard time-series regression techniques on spot price data to analyze whether the subsidy expiration coincided with a significant change in the gasoline blending margin around the time of expiration. To obtain our final estimates and confidence intervals, we implement a simulation procedure that imposes that the total incidence sums up to 45¢.

This paper is organized as follows: Section 2 provides background on the industry structure for gasoline production and biofuels policy in the United States. Section 3 summarizes the related literature on renewable fuel policies and event studies of policy changes. Section 4 lays out the conceptual framework and discusses how the subsidy might manifest in commodity prices. Section 5 presents the empirical approach and model, describes the data, and discusses the results. Section 6 concludes.

2. Gasoline and biofuels policy

Gasoline production in the United States involves the convergence of two supply chains: one for refined petroleum from crude oil and an agricultural supply chain for ethanol from corn. The process can be described by the schematic outlined in Fig. 1 and elaborated below (including how certain producers might be connected at the corporate level).

On the agricultural side, production begins on the farm and ends with blending at the fuel terminal. Corn is harvested, and then shipped to ethanol production facilities for processing.[4] The amount of corn used for fuel production is significant: in 2011, which was the last year for the VEETC, ethanol production accounted for about 40% of corn consumption in the United States (Brester, 2012). The other major input to ethanol production is fuel used to generate electricity for the plant, typically natural gas. The major outputs of the production process are ethanol and distillers grains, which can be sold as animal feed. Once production has occurred, the ethanol is shipped, typically via truck or railcar, to fuel terminals to be blended into gasoline.

Meanwhile, on the petroleum side, production begins with extraction of crude oil and other petroleum liquids and, as with ethanol, ends with blending at the fuel terminal. Crude oil is extracted, possibly shipped, and transported via pipeline to refineries. Refiners process crude oil into several different refined petroleum products, including petroleum blendstock, which is a precursor to finished gasoline. Reformulated blendstock for oxygenated blending (RBOB) and conventional blendstock for oxygenated blending (CBOB) are refined products specifically engineered to be blended with an oxygenate, such as ethanol.[5] These refined petroleum products are then transported, usually via pipeline, to a fuel terminal.

Finished gasoline is the product of combining fuel ethanol, an oxygenate, with gasoline blendstock. From a performance standpoint, oxygenate blending increases the octane of the fuel, which serves the dual purpose of preventing engine "knock" in motor vehicles and also creates a cleaner-burning fuel. However, when used in blends higher than about 5%, ethanol transitions from being a complement to petroleum to a substitute.

Once both products are in storage at the terminal, they are blended in one of two ways. Either both fuels are combined in a designated blending tank, or they are "splash" blended aboard a fuel truck.[6] The proportion of ethanol in a gallon of finished gasoline can vary: the most

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[1] The VEETC accounted for $5 billion per year, or roughly one-quarter of all energy related, non-stimulus subsidies in 2007 and 2011 (U.S. Energy Information Administration, 2011).

[2] For a comprehensive discussion of potential sources of bias in event studies and how prediction markets can mitigate them, see Snowberg et al. (2011).

[3] Using a conversion factor of 0.37 bushels per gallon, this translates to 13.5¢ per bushel of corn.

[4] Our focus for this paper is restricted to corn-derived ethanol. The use of other, more advanced biofuel feedstocks is, for the most part, in the research or early commercialization phase, but not yet commercially significant.

[5] RBOB is used in the production of reformulated gasoline, a product blended to burn more cleanly than conventional gasoline (produced from CBOB). The Clean Air Act requires reformulated gasoline to be used in cities with high smog levels, since petroleum combustion contributes to ground-level ozone formation.

[6] A small number of retail stations, primarily located in the Midwest, perform splash blending at the pump.

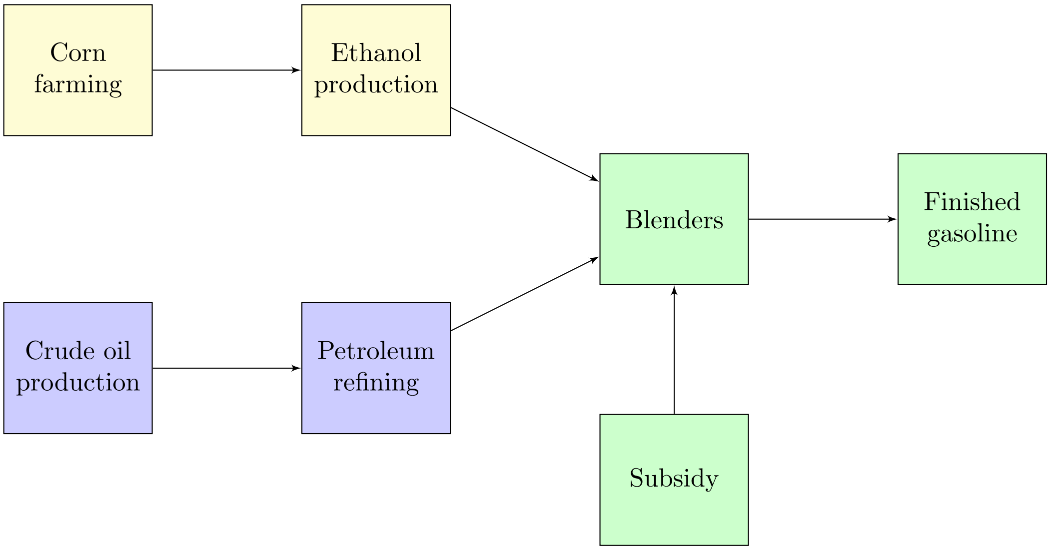

Fig. 1. U.S. gasoline production with ethanol blending.

common forms are a 10% ethanol blend (called E10), usable in most passenger cars, and an 85% blend (E85), which can only be used in certain "flex fuel" vehicles.

The blended fuel, while still at the terminal, is referred to as wholesale finished gasoline. Relative to wholesale gasoline prices, retail gasoline prices also include the costs of transporting the fuel from the terminal to the retail gas station (typically via a fuel truck), incorporation of federal and state fuel taxes, and retail distribution margins.[7]

Although we will treat ethanol producers, oil refiners, and fuel blenders as if they are distinct entities, the corporate structures are actually quite varied and complex. Often, companies that own oil refineries also own fuel blending operations. Moreover, some refining companies are not only blenders, but ethanol producers as well. For particularly large companies, such as Valero, the corporate structure can include refineries, ethanol production facilities, blending facilities, and retail distribution operations. However, while there is a significant amount of vertical integration in the gasoline supply chain, there are many companies that specialize in a particular component. For most products along the supply chain, well-defined spot and futures markets exist, suggesting a large volume of arms-length transactions.

Against this backdrop of private enterprise, and in part underpinning it, the US federal government has long supported biofuels, particularly corn ethanol. There are several commonly cited justifications for supporting the domestic ethanol industry, which have changed little over time. Perhaps the most prevalent rationale is reducing U.S. dependence on imported oil. Encouraging rural development, enhancing farm incomes, and reducing air pollutant emissions are often invoked as well. Historically, the bulk of support for ethanol was provided in the form of subsidies and import tariffs. Over the past decade tax credits have given way to mandates, particularly the federal Renewable Fuel Standard (RFS).

The VEETC, and a complementary ethanol import tariff, were initially put in place more than three decades ago, though the level of support has varied over time. The Energy Tax Act of 1978 established a 40¢ per gallon of ethanol tax credit for ethanol blending, regardless of where or how the ethanol was produced.[8] Shortly thereafter, an import tariff of 40¢ per gallon was established to prevent subsidization of imports and thereby protect the domestic industry from Brazilian sugarcane-derived ethanol. Over the years, the levels of the tax credit and the tariff were adjusted. At the time of expiration, the tax credit was at 45¢ per gallon of ethanol and the tariff was at 54¢ per gallon.

In addition to the VEETC and import tariffs, the ethanol industry has also benefited from mandated blending. With the passage of the Energy Policy Act of 2005, the RFS was born. The RFS targets a minimum percentage of ethanol in finished gasoline for all obligated parties, specifying a lower-bound for the level of ethanol that must be blended. Compliance can be achieved by blending ethanol or purchasing credits (called Renewable Identification Numbers, or RINs) from other obligated parties. At the time of the VEETC expiration, the price of a RIN was effectively zero, suggesting that the mandate was not binding; that is, blending was above the lower-bound established by the RFS (Irwin and Good, 2013).[9,10]

Beyond direct subsidization and import protection, the ethanol industry has also enjoyed increased demand for its product due to local air and water pollution policies. The Clean Air Act Amendments of 1990 required that gasoline be reformulated to reduce smog, which promoted ethanol and MTBE use. By 2006, however, MTBE had been phased out due to concerns over groundwater contamination, leaving ethanol as the oxygenate of choice in the United States.

These policies, together with a significant increase in oil prices over the prior decade, led to substantial growth in the ethanol industry. By 2011, fuel ethanol consumption had reached 12.9 billion gallons, up from 83.1 million gallons in 1981 (Koizumi, 2014). With the advent of the RFS, critics of ethanol policy maintained that the VEETC had become a wasteful policy, providing a subsidy for an activity that had become mandatory. The expansion of ethanol production also caused the total tax expenditure on the subsidy to expand to about $5 billion per year. The subsidy was ultimately allowed to expire at the end of 2011.

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[7] For a more detailed schematic and description of the gasoline production process see Bullock (2007).

[8] See, for example, Duffield et al. (2008) and De Gorter and Just (2008).

[9] RIN prices were near zero from 2010 through the end of 2012, before increasing dramatically in early 2013.

[10] At the same time that the RFS sets a lower-bound on ethanol blending, an upper-bound exists as well in the form of an E10 "blend wall," which prevents the aggregate proportion of ethanol in the gasoline supply from rising much above 10%. Infrastructure, legal, and regulatory limitations have limited sales of higher ethanol blends such as E15 and E85 and are expected to continue to do so, at least in the short run (Babcock and Pouliot, 2014; Irwin and Good, 2015).

3. Previous research on biofuels policy and event studies

Over the past decade, a substantial literature has emerged that analyzes the welfare and distributional consequences of biofuel policies, primarily through analytic and simulation models. Many of these papers, particularly in recent years, focus on the impacts of a mandate such as the RFS, whereas our interest is on the incidence of the VEETC. De Gorter and Just (2008) analyze the joint impact of an import tariff and ethanol subsidy on prices and output in the ethanol and fuel markets using an analytic model, which they parameterize to simulate the effect of removing the policies. Taheripour and Tyner (2007) investigate the incidence of the ethanol subsidy in an analytic framework, testing their results over a wide range of parameter values.

Gardner (2007) compares the impact of an ethanol subsidy to a direct corn subsidy on farmers and ethanol producers in a stylized setting, and simulates the short- and long-run outcomes resulting from removal of the ethanol subsidy. Babcock (2008) performs a similar analysis to study the distributional consequences of removing the tax credit, assuming a closed economy. Kruse et al. (2007) and McPhail and Babcock (2008) simulate removal of the tax credit and/or tariff in a stochastic, short-run setting. These studies generally find that the bulk of incidence accrues to ethanol producers, with varying amounts of pass-through to corn farmers.[11]

Abbott (2014) also develops a simple analytic model of corn supply, ethanol production, and gasoline blending and uses short-term data on supply, use, and prices to explain the mechanisms through which biofuels demand influenced corn and other agricultural commodity prices over the 2005–2012 time period. Although the focus of that paper is on investigating how and at which points in time a variety of policy-induced constraints influenced the behavior of agricultural and biofuels markets, the author uses monthly price data to crudely estimate that fuel blenders captured 15¢ of the 45¢ per gallon subsidy, and that the rest was passed along to ethanol producers.

Although our empirical strategy differs substantially from the one implemented in Abbott (2014), the conclusions are similar. However, all of the other studies described above focus on prospective outcomes of policy changes in a simulation framework, using assumed supply and demand elasticities. In contrast, we use the VEETC phase-out to empirically measure incidence. Most other econometric studies of the corn–ethanol–petroleum complex focus on testing for long-run cointegrating relationships and price volatility transmission[12] or focus on the RFS.[13] Among the latter, Lade et al. (2018) discuss the incidence of the RFS as measured by changes in commodity prices and stock returns around the time of change to the 2014 mandate, making it perhaps the most similar in spirit to our study.

Methodologically, this research draws from a long literature on event studies, but with an important innovation: we look at calendar spreads in futures markets rather than changes over time in spot prices. For example, Bushnell et al. (2013) use spot prices to determine the stock market valuations of affected firms before and after a sharp devaluation in CO_2 permit prices in the EU ETS.[14] Like other event studies, they then relate this valuation to policy changes, assuming market beliefs effectively capitalize the policy impact into firm valuation.

In this study, we similarly look at price changes to estimate changes in profitability. However, we rely on price differences for futures contracts specifying delivery before versus after the VEETC expiration. We use this to gauge the markets' beliefs about the incidence of the VEETC. That is, differences in these prices provide evidence as to which prices the market expected to change when the VEETC expired and, in turn, who was benefiting from the subsidy. A major advantage of this approach, relative to using spot prices, is that the information available to the market at the time of measuring the event impact (through future price spreads) is the same. Moreover, examination of other future contracts (beyond the relevant one-month calendar spread) shows how prices are expected to evolve over several months before and after the expiration. In contrast, unobserved information is also changing when one uses spot price changes over time to measure event impacts. Changes in spot prices must be measured over a relatively short interval to reduce this problem. We believe this approach is preferable for event studies more generally whenever liquid derivative contracts exist.

4. Modeling subsidy incidence

The VEETC is a subsidy provided to fuel blenders for each gallon of ethanol used to produce gasoline. As reviewed by Fullerton and Metcalf (2002) in a general public finance context and noted by Bullock (2007) in the context of ethanol, the economic incidence of a tax or subsidy is often passed along a vertically-linked market chain, manifesting in deviations of equilibrium prices and quantities from the non-distortionary environment. In the case of the supply chain for blended ethanol depicted in Fig. 1, this suggests potential deviations in corn, ethanol, RBOB, and retail gasoline prices and quantities. Depending on how these different prices and quantities change, the incidence of the subsidy will differ across corn farmers, ethanol producers, fuel blenders, oil refiners, and consumers.

Following Abbott (2014), we make several assumptions regarding behavior of supply and demand in these markets in order to estimate the subsidy incidence, which we emphasize is best viewed as short-term incidence calculation. First, we assume simple linear production technologies for ethanol, RBOB, and gasoline around the time of the subsidy expiration, with

$$\begin{aligned} C_{ethanol} &= 0.37P_{corn} + C_{0,ethanol}; \\ C_{RBOB} &= P_{oil} + C_{0,RBOB}; \\ C_{gasoline} &= 0.1(P_{ethanol} - S_{ethanol}) + 0.9P_{RBOB} + C_{0,gasoline}; \end{aligned} \tag{1}$$

where C represents the unit (per gallon) cost of production for each commodity, P represents market prices for inputs (per gallon or per bushel, for corn), and C_0 represents other per unit costs. In other words, one gallon of ethanol requires 0.37 bushels of corn (Mosier and Ileleji, 2006), one gallon of blendstock requires one gallon of crude oil, and one gallon of gasoline blends 10% ethanol and 90% blendstock. $S_{ethanol}$ is the ethanol subsidy: either 45¢ per gallon before or zero after expiration.

Second, we assume that we can ignore changes in quantity as we calculate incidence. This is appropriate if the quantity changes are relatively small, and/or if quantity decisions are unrelated to price changes due to subsidy removal in the short run (here, short run is the one to two-month horizon that we examine once the subsidy is removed). Unexpected short-run deviations in supply and demand of ethanol, blendstock, and gasoline are instead met through changes in inventories of each commodity rather than price changes.[15] Persistent price changes will ultimately influence supply and demand decisions as stockpiles change and fixed investments can eventually adjust. Viewed

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[11] An exception is Babcock (2008), which attributes most subsidy incidence to fuel blenders.

[12] For a recent review of empirical work on the relationships between food and fuel prices, see Serra and Zilberman (2013). According to the authors, "the literature concludes that energy prices drive long-run agricultural price levels and that instability in energy markets is transferred to food markets."

[13] Empirical work on the RFS includes Lade et al. (2015), who estimate the value of the transfer from conventional to biofuel producers resulting from the policy; Yi et al. (2016), who estimate a structural econometric model to analyze the effects of the US ethanol subsidy on the investment, production, entry, and exit decisions of ethanol firms and use the model to simulate the effects of different types and levels of subsidy; and Thome and Lawell (2015), who examine how government policies affect decisions about whether and when to invest in building a new ethanol plant in the Midwestern United States.

[14] For other examples of event study approaches to evaluating impacts of environmental policy on firm profits, see Kahn and Knittel (2006) and Linn (2006, 2010).

[15] See Abbott (2014) for evidence and discussion.

Table 1
Commodity price and welfare impact of subsidy expiration, by stakeholder group.

	Stakeholders	(1) Commodity produced	(2) Range of possible price changes for commodity produced	(3) Change in welfare based on observed price changes per gallon of ethanol
(1)	Ethanol producers	Ethanol	$[-45¢,0]$	$\Delta P_{ethanol} - 0.37\Delta P_{corn}$
(2)	Farmers	Corn	$[-2.7\Delta P_{ethanol},0]$ per bushel of corn	$0.37\Delta P_{corn}$
(3)	Oil refiners	RBOB	$[-5¢,0]$ per gallon of RBOB	$9\Delta P_{RBOB}$
(4)	Blenders	Gasoline	$[0,4.5¢]$ per gallon of finished gasoline	$10\Delta P_{gasoline} - 9\Delta P_{RBOB} - \Delta P_{ethanol} - 45¢$
(5)	Consumers	–	–	$-10\Delta P_{gasoline}$
(6)	Total	–	–	$-45¢$

Notes: Welfare changes are per gallon of ethanol blended and ignore savings to the government. All prices are in $/per gallon (ethanol, RBOB, and gasoline) or bushel (corn). We assume a 1:9 ratio of ethanol to RBOB in each gallon of finished gasoline and 0.37 bushels of corn in each gallon of ethanol (see Eq. (1)).

another way, commodity storage allows buyers and sellers to arbitrage expected future price changes into current prices, and supply and demand need not balance over a period of several months.[16] Our analysis is less informative about long-term incidence, as those effects may not be reflected in short-term prices changes. Alternatively, we could simply interpret our notion of incidence as a decomposition of who lost each cent of the subsidy when it expired, per gallon of ethanol, without interpreting these as welfare effects.

With these assumptions, we can consider what the possible ranges of price changes are for each commodity as a result of removing the subsidy and, ultimately, potential changes in welfare accruing to each stakeholder group. This information is summarized in Table 1 and discussed below.

First, we consider the effect of subsidy removal on ethanol production and further upstream along the agricultural branch in Rows (1) and (2). Subsidy expiration means that each gallon of ethanol blended effectively costs blenders 45¢ more per gallon due to foregone subsidy receipts. If all of the incidence had been passed up the ethanol/agricultural supply chain, blenders' willingness-to-pay (WTP) for ethanol would reduce by that entire amount, and, as a result, the market price of ethanol would decrease by 45¢ per gallon. The other extreme possibility is that none of the incidence had been passed up the ethanol/agricultural branch, in which case the change in the price of ethanol per gallon would be zero. Of course, the true incidence could be somewhere in between these two extreme cases, as demonstrated by the interval in Row (1), Column (2).

Some, if not all, of the incidence passed up the agricultural branch could go beyond ethanol producers to corn farmers, captured in Row (2). Once again, if some of the incidence had been passed up the agricultural supply chain, subsidy expiration means that ethanol producers receive a lower price per gallon of ethanol because of the reduced WTP for ethanol by blenders. If the entire agricultural branch incidence accrues to corn farmers, expiration means that ethanol producers' WTP for corn would decrease by the full amount of the ethanol price decrease. Because each bushel of corn yields 2.7 gallons of ethanol, the resulting price decrease per bushel of corn would be 2.7 times the change in the price of ethanol per gallon. At the opposite extreme, the agricultural branch incidence could accrue entirely to ethanol producers or further downstream. In this case, the change in the corn price resulting from subsidy removal will be zero. Row (2), Column (2) gives the range of price changes per bushel of corn.

Under the assumptions outlined at the beginning of this section, the price changes in ethanol and corn markets correspond directly to welfare changes for corn farmers and ethanol producers. These welfare changes are calculated in Column (3). For corn farmers, the change in welfare due to subsidy expiration is given simply by the change in the price of corn. To calculate the welfare change per gallon of ethanol, the price of corn in bushels needs to be multiplied by a conversion factor of 0.37 bushels per gallon, which is the amount of corn required to produce a gallon of ethanol. For ethanol producers, the change in welfare depends on price changes of both ethanol and corn. Their per-gallon-of-ethanol welfare changes by the ethanol price decrease minus any corresponding decrease in the corn price.

The price and welfare change analysis for oil refiners, reported in Row (3), is analogous to that of corn farmers. After the subsidy is removed, it costs blenders 45¢ more per 10 gallons of gasoline produced since there is 1 gallon of ethanol and 9 gallons of RBOB in every 10 gallons of E10. If refiners were able to extract the entire subsidy, blenders' WTP for RBOB decreases by 45¢ for 9 gallons of RBOB upon expiry, or 5¢ per gallon of RBOB. As a result, the price of RBOB would decrease by a maximum of 5¢ per gallon upon expiration of the subsidy. If none of the subsidy had been passed along to refiners, then the RBOB price would not change with removal of the subsidy. If a portion of the subsidy was passed along, then the price change would be somewhere between zero and -5¢ per gallon of RBOB.

Because we assume that the subsidy incidence would not have been passed further upstream to crude oil producers (due to the presence of a global market for oil), any price decrease in RBOB directly reflects the welfare change for oil refiners resulting from loss of the subsidy. The substantial international integration of markets for refined petroleum products also suggests a strong prior that RBOB prices are set internationally, rather than being influenced by ethanol policy. The implication of that assumption would be zero flow-through of the ethanol subsidy to RBOB refiners. While we look to the evidence rather than imposing that assumption, our results are ultimately consistent with it.

The price and welfare change calculations for gasoline consumers and blenders are given in Rows (4) and (5) of Table 1. Subsidy expiration makes each gallon of ethanol effectively 45¢ more expensive, and ethanol makes up 10% of each gallon of finished gasoline. If the entire subsidy had been passed downstream to consumers, then the price of gasoline would rise by 4.5¢ per gallon upon expiration of the subsidy. If none of it had been passed downstream, then there would be no change in the retail gasoline price. In any event, the welfare change per gallon of ethanol faced by consumers would equal ten times the price change per gallon of finished gasoline.

The welfare change faced by blenders depends on the commodity price changes immediately upstream and downstream of blending. In one extreme, if blenders captured all of the subsidy, there would be no change in any of the commodity price levels. Instead, upon subsidy expiration, blenders' margins would fall by the amount of the subsidy, 45¢ per gallon of ethanol blended. For the other extreme, if we found that the per-gallon price changes for ethanol, RBOB, and gasoline (appropriately weighted) add up to 45¢, this would imply that all of the subsidy had been fully passed upstream or downstream by the blenders.

Table 1 illustrates three fundamental principles of removing a subsidy in the context of a market supply chain. First, prices tend to decrease upstream of the point where the subsidy enters the market and increase downstream upon subsidy removal. Second, assuming that

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[16] Storage capacity is typically one month's supply and stocks are typically at 50% of capacity (U.S. Energy Information Adminstration, 2015a,b).

quantities are fixed in the short run, the overall change in welfare must add up to the full value of the subsidy. Third, Table 1 also demonstrates the difference between economic incidence, which is a calculation of the welfare distribution resulting from a tax or subsidy, and statutory incidence, which is simply an accounting of who physically pays the tax or receives the subsidy. With the conceptual framework established in this section in mind, we proceed by outlining the empirical approach and describing the data.

5. Empirical methods, data, and results

The overall empirical strategy is to use calendar spreads in future commodity prices to estimate the price changes in Table 1. We describe this approach in detail for ethanol and RBOB. For corn and finished wholesale gasoline, we are constrained by data limitations and pursue other approaches.[17] After compiling estimates for changes in the prices of ethanol and RBOB and the blender's margin, we employ a Monte Carlo simulation algorithm to impose the 45¢ constraint implied by the policy, and use the results to construct confidence sets for our incidence estimates.

5.1. Ethanol and RBOB market incidence

The empirical approach for both ethanol and RBOB relies upon the existence of monthly futures contract markets for each commodity. We exploit the design of these contracts to conduct an analysis similar in concept to event studies that typically use spot prices.

Each futures contract is identified by a month–year combination when the contract comes due (the "delivery" month). These contracts begin trading on a daily basis years before the delivery month. As an example, we might observe that the December 2011 futures contract opens for trading in November 2009 and continues to trade until November 30th, 2011. At this point delivery must be completed by December 3rd, 2011. For each commodity, there is a standardized monthly contract with a regular delivery day (e.g., "the 3rd ") and a regular closing day for trading of the contract (e.g., "the last day of the preceding month").

Conceptually, we assume the price of the futures contract at a given point in time reflects the expected spot price of the commodity at the time of maturity.[18] For example, if the contract is set to mature at time T, then the future price at time t is given by the equation

$$F(t, T) = \mathbb{E}_t[S(T)], \tag{2}$$

where F represents a future price, and S represents a spot market price. This is an approximation, as the difference between these two expressions equals a risk premium (Baumeister and Kilian, 2014).[19] Making this approximation, we exploit the combination of this expectation, along with the monthly structure of the futures contract, to examine the subsidy incidence.

Consider a set date for subsidy expiration. In the case of VEETC, the policy was allowed to expire on December 31st, 2011. Ethanol blended into motor fuel before this date received the tax credit, and ethanol blended afterwards did not. If we assume as above that the subsidy incidence manifests in commodity prices, then we should see price differences between the December and January futures contracts to the extent that the subsidy was having an effect on ethanol or RBOB prices. The difference in price is due to the fact that the commodity in December is eligible to receive the subsidy whereas the commodity in January is not. Because the future prices for December and January contracts are being observed at the same point in time prior to these dates, the difference in the future prices is not confounded by changes in market conditions that unfold in actual calendar time.[20] We are also able to look more generally at the pattern of future prices, to see (1) how differences persist into the future beyond January 2012, and (2) at what horizon, prior to the expiration, differences between the December and January contract prices begin to appear. We believe this is a major advantage relative to using spot price changes, which are subject to ongoing incorporation of new market information.

The price difference we use for this identification strategy is known as a one-month calendar spread. For a given point in time t, the one-month calendar spread is the difference in the price of two adjacent futures contracts (with prices denoted by F). If those futures contracts expire on dates T and $T-30$ (about one month difference), then mathematically the calendar spread is given by

$$CS(t, T) = F(t, T+30) - F(t, T), \tag{3}$$

where CS denotes "calendar spread." In the case of the VEETC, the calendar spread of interest is the January 2012 to December 2011 spread (hereafter, Jan12–Dec11). We refer to December's contract as the "leading contract," and January's as the "trailing contract." For RBOB and ethanol, which are produced upstream of the subsidy, we would expect this price spread to be negative as a result of subsidy expiration.

We construct a time series of the Jan12–Dec11 price spread and assess how it evolves over time. We would expect the spread to widen as the market incorporates information that the subsidy is likely to expire. A simple estimate of the subsidy incidence would be the calendar spread of interest on the day the leading contract expires. That is the last day we have simultaneous observations of ethanol prices both before and after the subsidy expiration.

However, the calendar spread is likely influenced by factors other than the subsidy expiration. This introduces potential noise and bias in our measurement, making the simple estimate problematic.[21] We account for this in two steps, both correcting for possible bias and using the noise to estimate the error in our estimate. The first step recognizes that daily variation in the calendar spread is likely unrelated to the subsidy expiration and should be removed. Further, confidence in the expiration of the credit and its consequences should grow over time in a manner that is gradual, but not necessarily linear. This suggests modeling the calendar spread as a quadratic function of days to maturity ($T-t$ in our notation), using the intercept as the estimate of subsidy incidence rather than the last observation, and recognizing the estimated error in the intercept as a measure of uncertainty.

The second step recognizes that data on calendar spreads *other than* the spread of interest provides a control group for the kind of behavior that arises absent the subsidy expiration. Namely, calendar spreads vary for a host of reasons at frequencies of weeks and months. Shortages or gluts at those frequencies that are predicted to end between the leading and trailing contract would lead to positive or negative calendar spreads that persist until the leading contract expires. We construct our control group using calendar spreads for ethanol and RBOB contracts extending several years both prior to and after December 2011. For each leading–trailing combination, we estimate the calendar spread when the leading contract expires, as described above. The mean and variation of these estimated intercepts informs the mean and variance

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[17] See Appendix A for an overview of all data series and sources used in this analysis, and Tables 4 and 5 for detailed regression results.

[18] This assumption is supported by, for example, Chinn and Coibion (2014), who find that energy commodity futures prices are generally unbiased and accurate predictors of subsequent prices.

[19] We focus our analysis on a single-month time frame by comparing adjacent month price differences, which we then compare to other similar one-month spreads. This is effectively a difference-in-difference calculation of future prices over a single month. In order for the risk premia to matter in our calculation, they would need to vary over a period of one month *and* that difference would need to vary across the various one-month spreads that we then compare.

[20] The future price change could be confounded by changes in *expected* market conditions other than the expiration of the VEETC, but we are not aware of any other expected policy or market change at that time.

[21] We thank an anonymous referee for pointing this out and leading us to an improved methodology.

of the incidence as described below.

More precisely, after constructing parallel time series for each calendar spread in our sample, we then estimate the following regression model separately for each calendar spread T:

$$CS_{eth}(t,\ T) = \alpha_0 + \alpha_1(T - t) + \alpha_2(T - t)^2 + \epsilon(t,\ T), \tag{4}$$

where $CS_{eth}(t,T)$ represents a calendar spread for which the leading contract matures on date T, observed on date t, $T - t$ represents days to maturity of the leading contract at time t, and $\epsilon(t,T)$ follows an $AR(1)$ process. To prevent our estimates from picking up effects unrelated to subsidy expiration, we limit our sample to observations from the last 30 days prior to maturity.

For RBOB, we also control for oil prices in the regression. As we demonstrated in Table 1, any price change in RBOB due to VEETC expiration will be *at most* 5¢ per gallon of RBOB. This is a small price change relative to common fluctuations in petroleum markets. In order to gain a more precise estimate, we assume that any incidence accruing to oil refiners did not get passed further upstream in the form of higher crude oil prices. Because crude oil is sold in a global liquids market of which U.S. ethanol is about 1%, it is reasonable to assume that the VEETC would not have any influence on oil prices. This allows us to control for changes in oil prices in the RBOB analysis, thereby removing the main source of RBOB price volatility.

We control for oil price variation by estimating the following model:

$$\begin{aligned} CS_{RBOB}(t,\ T) = \alpha_0 &+ \alpha_1(T - t) + \alpha_2(T - t)^2 + \beta_{0,0}CS_{oil}(t,\ T - 11) \\ &+ \beta_{0,1}CS_{oil}(t - 1,\ T - 11) \\ &+ \beta_{0,2}CS_{oil}(t - 2,\ T - 11) + \beta_{1,0}CS_{oil}(t,\ T + 11) \\ &+ \beta_{1,1}CS_{oil}(t - 1,\ T + 11) + \beta_{1,2}CS_{oil}(t - 2,\ T \\ &\quad + 11) + \epsilon(t,\ T), \end{aligned} \tag{5}$$

Because oil futures contracts mature in the middle of the month prior to the contract month, i.e., around eleven trading days, it is not obvious whether to include the leading oil spread or the trailing spread, where the term "leading" is again meant to express a calendar spread that matures first. Therefore, we include both leading and trailing calendar spreads for Brent crude oil prices as regressors.[22] We also include one- and two-day lags for both types of calendar spreads. We estimate the model separately for each calendar spread in the sample period (i.e., the average daily value of the Jan12–Dec11 calendar spread observed over the entire period during which that calendar spread is traded).

The results of estimating Eqs. (4) and (5) are used to construct preliminary means and variances for ethanol and RBOB incidence (which are in turn used to construct confidence intervals, as described below). The mean estimate for each is defined by the difference between the estimate of the Jan12–Dec11 spread on the day of expiration and the mean of the estimates of all other spreads on the day of expiration, as measured by the constant term in the quadratic functions of $T - t$. Formally, we calculate

$$\widehat{\mu}_{eth} \equiv \widehat{\alpha}_{0,k} - \frac{\sum_{i \neq k} \widehat{\alpha}_{0,i}}{n - 1}, \tag{6}$$

where $\widehat{\alpha}_{0,i}$ represents the estimate of α_0 from Eqs. (4) and (5) for calendar spread i, index k represents the Jan12–Dec11 spread, and n represents the total number of spreads in the sample. The variance for each estimated mean is calculated as the sum of the estimated squared sampling error within and between the estimated calendar spreads, as described above. Formally, we calculate

$$\widehat{\sigma}^2_{eth} \equiv \left(1 + \frac{1}{n - 1}\right)\left(\frac{1}{n}\sum_i se(\widehat{\alpha}_{0,i})^2 + \frac{1}{n - 2}\sum_{i \neq k}\left(\widehat{\alpha}_{0,i} - \frac{\sum_{i \neq k} \widehat{\alpha}_{0,i}}{n - 1}\right)^2\right), \tag{7}$$

where $se(\widehat{\alpha}_{0,i})$ represents the standard error of the estimated parameter $\widehat{\alpha}_{0,i}$. The first term in parenthesis is the contribution associated with the intercept calculation within the sample for each spread. The second term is the contribution associated with variation across spreads. The total in parenthesis is the total variance for each spread intercept. The factor in front adjusts for our difference calculation, which combines a single intercept estimate with the mean of $n - 1$ estimates.

Given our estimation approach, the only data we require are for futures contract prices for ethanol, RBOB, and crude oil. We use daily price data on futures contracts from January 2007 through July 2013.[23] The ethanol futures contracts are traded on the Chicago Mercantile Exchange (CME), while the RBOB and Brent crude oil futures contracts are traded on the New York Mercantile Exchange (NYMEX). All futures price series were accessed via Bloomberg. As noted above, the delivery dates for the futures contracts vary across commodities. For ethanol, the contracts mature on the third trading day of the contract month. Brent contracts mature on the last business day prior to the 15th day of the month prior to the contract month, i.e., the December Brent contract matures in mid-November. RBOB contracts mature on the last day of the month prior to the contract month.

The raw data on ethanol spot prices and futures contract prices around the VEETC expiration is shown graphically in Fig. 2. The figure plots the *forward curves* (solid lines) for August 2011 through April 2012. Each forward curve represents the prices of a set of active futures contracts at a given point in time. For example, the blue line connecting the solid circle markers represents the prices of the August 2011 through April 2012 futures contracts as of August 3rd, 2011. Each monthly forward curve is plotted for the date of expiration of the futures contract for the corresponding month (e.g., August 3rd, 2011 is the date that the August 2011 contract expired). For context, we overlay the spot price of ethanol (dashed line) onto the figure.

First, we note that there is a roughly 30 cent decrease in the spot price over the month of December, which would be one way to estimate the incidence on ethanol. Over the course of that month, it would become increasingly difficult to blend the ethanol in time to qualify for the expiring tax credit, with a typical lag of 2–3 weeks between purchase and blending. Ethanol sold on December 1 would definitely qualify; ethanol sold on December 31 would not. However, many other things might lead to a 30 cent spot market decline over one month; similar changes in realized spot prices can be seen over several one-month periods. Thus our focus on futures prices.

In Fig. 2, we see that, prior to January 2012, the ethanol futures market became increasingly backwardated, meaning that contracts for more distant delivery dates traded at lower prices, as the date of subsidy expiration approached. This is reflected by the overall downward slopes of the five forward curves at the top of the legend. Moreover, this backwardation was especially pronounced around the Jan12–Dec11 contract months.

The two labeled heavy black dots in the figure represent the prices of the December 2011 and January 2012 contracts at the time that the December 2011 contract expired (December 5th, 2011). In noting the vertical distance between the two points, we can see how stark the price difference was between those contracts relative to similar price spreads both before and particularly after that time (e.g., one-month calendar spreads as the leading contract expires). Moreover, comparing the Jan12–Dec11 spread at earlier dates suggests that the subsidy

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[22] When including the leading calendar spread for oil as a regressor, we encounter an additional difficulty with timing. The leading contract of the leading oil spread matures about half a month prior to the leading contract of the RBOB spread. Therefore, if we use the pure calendar spread model, the best we can do is measure the RBOB price change around eleven trading days prior to maturity. Alternatively, we can replace the price of the leading contract of the leading spread with the oil spot price for the last half month. We implement both procedures, finding that there is little difference in the results.

[23] We chose to begin our exploration with 2007 data rather than 2006 (the earliest year for which a market existed for ethanol futures) to avoid noise occurring as a result of MTBE phaseout and participants acclimating to a new market.

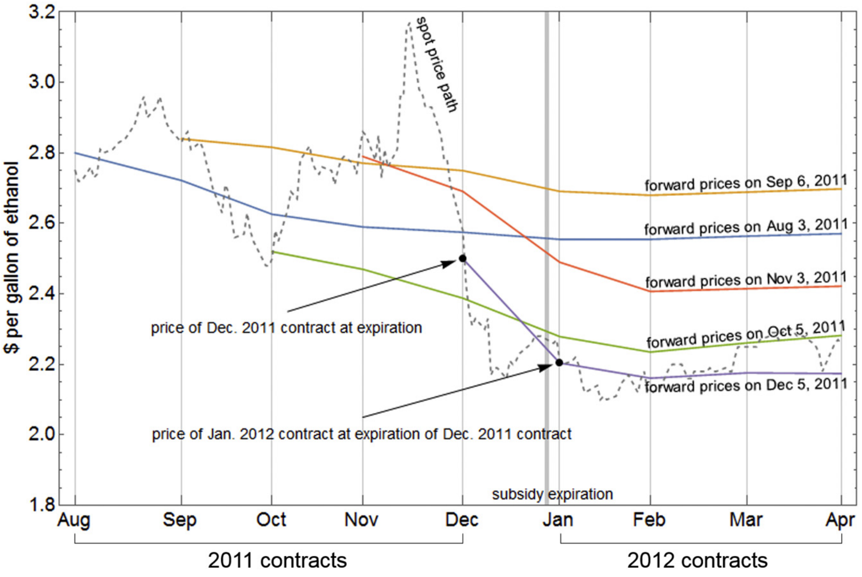

Fig. 2. Ethanol spot prices and forward curves around subsidy expiration, August 2011–April 2012 contracts. (For interpretation of the references to color in this figure, the reader is referred to the web version of this article.)

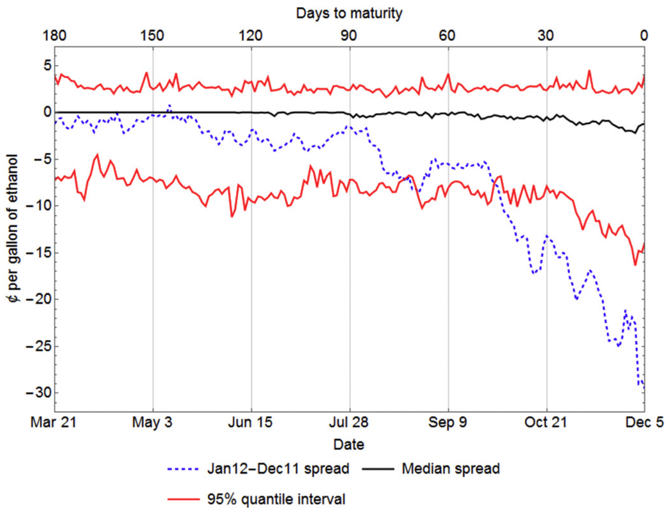

Fig. 3. Ethanol price spread for January 2012–December 2011 versus other one month calendar spreads, conditional on the same number of days to maturity. (For interpretation of the references to color in this figure, the reader is referred to the web version of this article.)

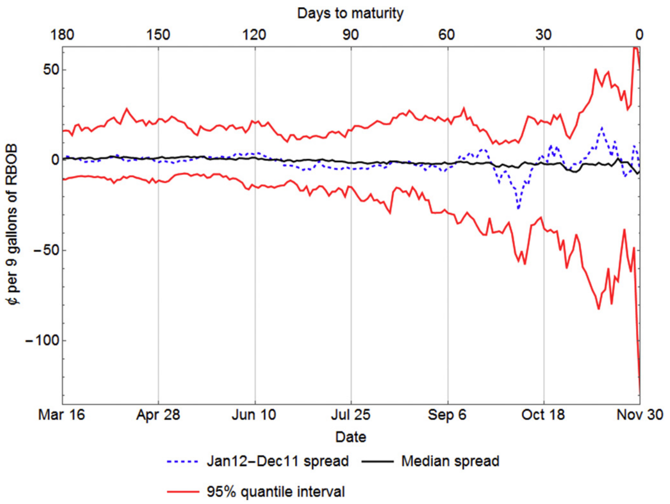

Fig. 4. RBOB price spread for January 2012–December 2011, controlling for oil prices, versus other one month calendar spreads, conditional on the same number of days to maturity. (For interpretation of the references to color in this figure, the reader is referred to the web version of this article.)

expiration might have begun being reflected in the market as early as the beginning of September 2011 and increased as the year progressed. This view is supported by the behavior of spot prices as well. The figure shows that spot prices decreased in September 2011, consistent with the market learning at that time that the subsidy would be removed. In contrast to the behavior in September, the Jan12–Dec11 spread viewed in August 2011 was almost imperceptible.

The notion of a gradually increasing certainty over subsidy expiration is reasonable, especially because of the long-term persistence of the subsidy as well as the last minute extension that had been granted to the VEETC just one year earlier.[24] It could also be the case that the futures market had expected the December 2011 expiration at an earlier time, but gained information over time about the incidence of the subsidy captured by ethanol producers.

While Fig. 2 suggests a reaction in ethanol futures markets to the VEETC expiration that is larger than the four other one-month calendar spreads just prior to maturity of the leading contract, it is hard to turn that into a probabilistic statement. To get a better sense of how significant the size of the Jan12–Dec11 spread was statistically, we calculate the 2.5th, median, and 97.5th quantile of calendar spreads over the 2007–2013 sample, excluding Jan12–Dec11.[25] We group the calendar spreads based on time until the leading contract matures, as described above. The results are plotted in Fig. 3, along with the Jan12–Dec11 spread. The vertical axis represents price spreads, in dollars per gallon of ethanol, while the top horizontal axis represents the number of days until maturity of the leading month contract (since they all mature at different dates) of the price spreads used to construct the quantile interval. The bottom horizontal axis tracks the observed

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[24] For this reason, one could also posit that the effect of the subsidy expiration wasn't fully reflected in the ethanol futures market by December contract maturity. If this is the case, then we are underestimating the benefit of the policy to ethanol producers.

[25] To calculate the quantile time series, we construct separate samples of calendar spreads for each *s* value, order the calendar spreads (excluding Jan12–Dec11) within each group, and calculate the relevant percentiles.

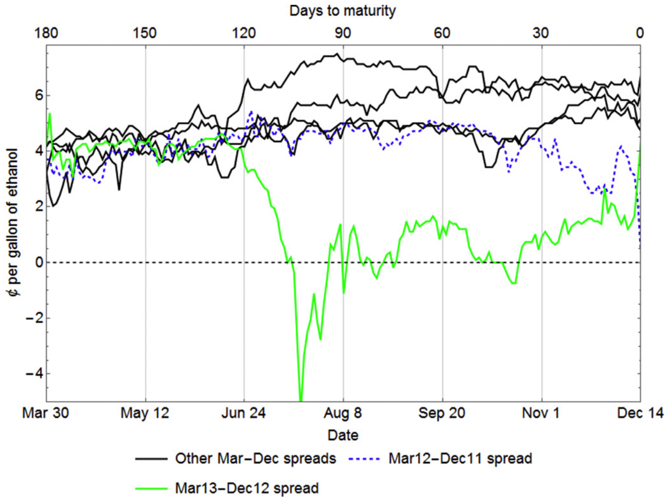

Fig. 5. Corn price spreads for March–December. (For interpretation of the references to color in this figure, the reader is referred to the web version of this article.)

Jan12–Dec11 spread over calendar time.

Excluding the Dec11–Jan12 spread, the ethanol price series appears to exhibit a very slight degree of backwardation, perhaps a penny per month for the median spread, when the leading contract is close to expiration. The median (or 50th percentile), represented by the solid black line in the figure, hovers at 0¢ until around 90 days until maturity, at which point it decreases very slightly and remains slightly negative. The red lines capture the empirical 95th percentile of spreads, and demonstrate that the distribution of spreads is skewed downward (negatively), a feature that appears stronger as the leading contracts approach maturity. The Jan12–Dec11 spread, represented by the blue line, declines steeply as the December delivery date draws near, finishing at about −30¢ per gallon of ethanol, which is well beyond the lower bound of the 95% quantile interval.

The results from estimating Eqs. (4), (6), and (7) generally agree with visual inspection of Fig. 3. We calculate $\hat{\mu}_{eth} = -25.1$¢ and $\hat{\sigma}_{eth} = 5.3$¢.

To investigate whether any incidence was passed up the petroleum branch, we present an analogous illustration for the RBOB market in Fig. 4. However, unlike ethanol, we do not construct the plots directly from the RBOB spreads. Instead, we plot the residuals after controlling for oil price changes. To allow easier comparison of incidence across the various commodities, we also convert the residuals into equivalent cents per gallon of ethanol blended by multiplying the RBOB prices by nine, since there are nine gallons of RBOB for every gallon of ethanol blended.

As a result, the vertical axis in Fig. 4 represents RBOB price spreads (for nine gallons of RBOB or equivalent to one gallon of blended ethanol) after removing the variation in price spreads due to oil price changes. The black line for the median price spread is around zero for all days to maturity. The Jan12–Dec11 spread maintains a price near zero until mid–September 2011, drops in early October, and climbs back up above zero during the month of November. By the last trading day for the December contract, the spread is slightly negative, finishing at about − 7¢. Additionally, the quantile interval depicted by the red lines shows some downward skewness, particularly as maturity of the lead contract approaches.[26]

Although the Jan12–Dec11 spread is negative at maturity, it is mostly positive over the last 30 days and as much as 20¢ higher than the mean of the other spreads, which is the time period over which we estimate Eq. (5). We calculate $\hat{\mu}_{rbob} = 29.6$¢ and $\hat{\sigma}_{eth} = 106.0$¢ using Eqs. (5), (6), and (7). These parametric estimates suggests a larger but even more uncertain positive effect than the figure. Fitting a quadratic over the last 30 days to maturity significantly increases the variability in spread estimates. Moreover, the mean spread at maturity is more negative than the median spread shown in the figure, making $\hat{\mu}_{rbob}$ more positive. In any case, the large variation indicated by the figure and parameter estimates suggest little evidence of an impact of the subsidy on RBOB. Our final estimates change only slightly when we assume the RBOB incidence is zero rather than use these estimates, once we include constraints that the incidence of removing the subsidy is always non-positive and that the total incidence in all markets equals the subsidy.

5.2. Corn market incidence

Given the evidence suggests that a significant portion of the subsidy was passed upstream to ethanol producers, we next investigate whether some of it was passed further upstream to corn farmers. This would be consistent with a Ricardian view that land, as an inelastic resource, capitalizes much of the value of agricultural products (e.g., Mendelsohn et al., 1994), and recent empirical evidence that farms and farmers capture nearly 100% of farm subsidies (Kirwan, 2009). We find some suggestive evidence that this occurred, at least in part. However, because of data limitations due to the nature of corn futures markets, the evidence is more suggestive than conclusive.

As with ethanol, standardized futures contracts exist for corn and are traded through the CME, which we collected via Bloomberg for January 2007 through July 2013. These contracts mature on the business day immediately preceding the 15th day of the contract month. Unlike ethanol and RBOB, however, there are not corn futures contracts for every calendar month. Instead, corn futures contracts exist only for March, May, July, September, and December. This fact, coupled with the highly seasonal nature of agricultural commodity markets, forces us to alter the approach to calculating price changes in the corn market.

The alternative approach is demonstrated in Fig. 5. In lieu of a Jan12–Dec11 spread, which cannot be constructed for the corn market, we base the analysis on the Mar12–Dec11 spread. The rationale for using this spread is the same as before, but this procedure could be more prone to picking up non-VEETC effects than the single month spread. In Fig. 5, we plot the spreads for all March–December spreads from March 2008 to March 2013. We focus only on the March–December spreads due to the existence of highly seasonal effects in corn futures spreads. For example, the typical March–December spread exhibits much different behavior than the typical September–July spread. Because of this more limited set of observations, we look at all of the available series of spreads, rather than summarizing in a quantile interval.

The vertical axis in the figure once again represents the spread in contract prices between adjacent contracts. For the sake of comparison, the prices have been converted to per gallon of ethanol equivalent, assuming the 0.37 bushels per gallon conversion discussed in the context of Eq. (1). For the four earliest contracts, plotted as solid black lines, the spreads exhibit varying degrees of contango (i.e., all spreads are positive), which is typical behavior in grains markets. Because crops are costly to store, a premium, often called the carry, is provided as compensation.[27] When the leading contract is between 150 and 180 days to maturity, the spread tends to be about 4¢ per gallon. The final spread at maturity over this time horizon increases slightly to about 5¢ per gallon (i.e., the average of the Mar08–Dec07, Mar09–Dec08, Mar10–Dec09, and Mar11–Dec10 contracts).

The spread of interest, Mar12–Dec11, is represented by the dashed blue line. It exhibits similar behavior until around 30 days before maturity, at which point it decreases sharply and eventually finishes

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[26] For the day of maturity, this skewness is illustrated by the lower bound on the interval, which is almost three times further away from zero than the upper bound.

[27] For example, see Yoon and Wade Brorsen (2002).

around 0¢ per gallon, or about 5¢ per gallon lower than is typical. The Mar13–Dec12 spread, represented by the solid green line, exhibits atypical behavior as well, trading in an atypically low degree of contango or even backwardation for most of the last 120 days until maturity of the December 2012 contract. The atypical behavior of the Mar13–Dec12 spread can be explained by drought conditions in 2012 that resulted in a short supply of new corn to be sold in December of that year, causing prices for the leading contract to increase. Right before that maturity date, however, the Mar13–Dec12 spread converges rapidly toward a more typical carry premium.

Despite the fact that we have only 4 "typical" corn spreads (not counting the Mar12–Dec11 spread), we apply the approach used in Eqs. (4), (6), and (7). We find $\hat{\mu}_{corn} = -4.9¢$ and $\hat{\sigma}_{corn} = 0.9¢$.

The takeaway from this analysis is that it appears only a portion of the subsidy incidence was being passed upstream from ethanol producers to corn farmers, based on the corn spread for Mar12–Dec11 at maturity being about 5¢ per gallon lower than normal. After rejecting the Mar13–Dec12 spread because of drought conditions in 2012, we have only 4 contracts from which to assess between-spread variation. Among these four, there is (perhaps remarkably) little variation, leading to a relatively precise estimate. Hence, we make the caveat that our approach is inherently missing variation from less frequent extreme events.

5.3. Finished gasoline market incidence

Unlike in the cases of ethanol, RBOB, and corn, there are no standardized futures contracts for finished gasoline. As a result, the preferred approach is not feasible. As an alternative, we turn to finished gasoline spot market prices and blender margins to provide insights.

Having explored all of the upstream incidence, identifying the downstream effect on finished gasoline prices will simultaneously identify the net effect on the blender margin or vice-versa. Given the estimates of ethanol and RBOB price changes, we can see from Table 1 that the blender's welfare effect now depends only on the price change of finished gasoline. We focus on estimating the change in the blender margin because the evidence suggests the blender margin is a stationary time series, while gasoline spot prices are not.

We define the blender margin per gallon of ethanol blended to be equal to 10 times the finished gasoline price, minus the prices per gallon of ethanol and RBOB (weighted by their volumetric contributions to 10 gallons of finished product), plus any subsidy paid to the blender:

$$BM(t) = 10P_{gasoline}(t) - 9P_{RBOB}(t) - P_{ethanol}(t) + s_{ethanol}(t). \qquad (8)$$

Here, $s_{ethanol}(t)$ equals 45¢ prior to a cut-off date (chosen as December 5th, 2011) for collecting the VEETC, and zero afterwards.[28] Comparing this to the blender welfare expression in Table 1, we can see that any change to the blender margin in a window around the expiration of the VEETC subsidy (along with consequent changes in gasoline, RBOB, and ethanol prices) exactly equals the welfare effect per gallon of ethanol.

We compute the blender margin using daily wholesale spot price data on the three commodities from 2011 and 2012. The ethanol and RBOB data are both New York Harbor spot prices acquired from Bloomberg, while the gasoline data are reformulated E10 rack prices in New York City acquired from Oil Price Information Service (OPIS). We chose prices in the same market in order to estimate any effect as precisely as possible, and we chose to work with wholesale prices for the same reason. Retail and wholesale gasoline prices typically follow one another very closely with about a 70¢ average retail margin, which reflects transportation costs, taxes, and mark-ups (Irwin and Good, 2011).[29] If the transport and retail markets are competitive, then any benefit accruing downstream of the subsidy can be assumed to have gone to final fuel consumers. Otherwise, our use of wholesale prices prevents us from disentangling benefits accruing to jobbers (who deliver gasoline from wholesale racks to retail stations) and gasoline retailers versus final consumers. Going forward, we refer to benefits downstream of the blender as accruing to consumers, but they could reflect benefits to retailers to the extent retail markets deviate from pure competition.

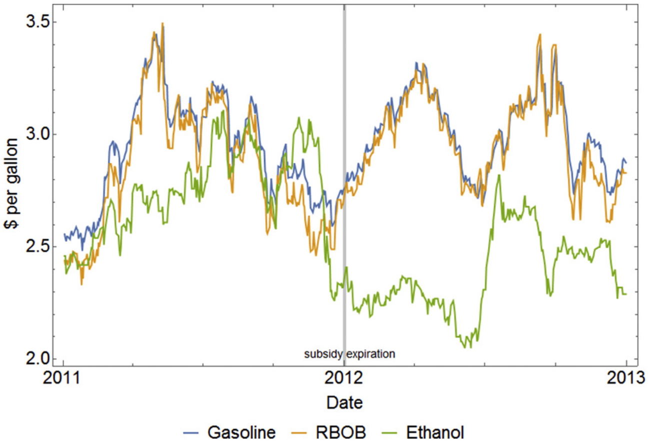

Fig. 6. Daily prices for gasoline (E10), RBOB, and ethanol. (For interpretation of the references to color in this figure, the reader is referred to the web version of this article.)

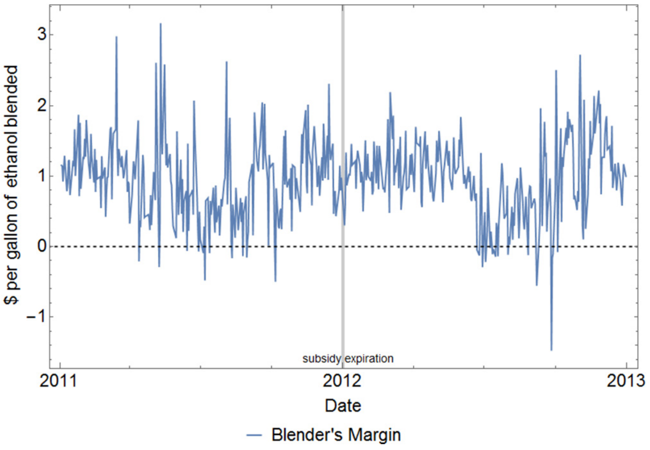

Fig. 7. Daily blender's margin.

The price series over the sample period are plotted in Fig. 6. Ethanol, RBOB, and gasoline prices are identified as the green, orange, and blue lines, respectively. The date of subsidy expiration on December 31st, 2011 is marked by the vertical gray line. Right before this cutoff, ethanol spot prices decline sharply, consistent with the earlier results. As noted earlier, the price of finished gasoline (as well as ethanol and RBOB) evolves according to a random walk.[30] Unsurprisingly, finished gasoline and RBOB prices move very closely together. Meanwhile, a cointegrating regression using the three price series,

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[28] Blenders must have purchased ethanol in advance of December 31st, 2011, in order to blend it with gasoline on or before that date and collect the subsidy. Therefore, the cutoff for defining $s_{ethanol}(t)$ equal to 45¢ will be a date prior to December 31st, 2011. We choose a cutoff of December 5th, 2011, which corresponds to the date of the "pre-expiration" price used in our calendar spread analysis of ethanol prices. It is unclear whether ethanol sold at later dates in December would be blended in time to qualify for the subsidy.

[29] There is an extensive literature on retail gasoline margins. See, e.g., Borenstein (1991), Deltas (2008), and Hosken et al. (2008).

[30] For each commodity, Phillips-Perron tests fail to reject the null hypothesis of a unit root.

Table 2
Estimated commodity welfare impacts, by stakeholder group.

Stakeholders	$\hat{\mu}$	$\hat{\sigma}$	Simul. mean	Simul. 95% CI	Simul. mean	Simul. 95% CI
Corn farmers	4.9	0.9	5.0	[1.3,8.1]	5.0	[1.3,8.1]
Ethanol producers	25.1	5.3	19.8	[8.8,30.8]	19.8	[8.9,30.8]
Oil refiners	−29.6	106.0	2.6	[0.0,21.7]	0	–
Blenders	14.0	11.0	12.3	[0.0,25.6]	12.4	[0,25.6]
Consumers	–	–	5.3	[0.0,23.1]	7.9	[0,24.2]

Notes: All estimates are reported in terms of cents per gallon of ethanol blended and ignore savings to the government. We assume a 1:9 ratio of ethanol to RBOB in each gallon of finished gasoline and 0.37 bushels of corn in each gallon of ethanol. The estimates of $\hat{\mu}$ and $\hat{\sigma}$ for ethanol producers include the incidence for corn farmers as well, which is subtracted out in the simulations.

suggests the existence of one cointegrating vector (based on a formal Johansen test for cointegration) with the following coefficients on the prices: $10P_{gasoline} - 8.9P_{RBOB} - 1.1P_{ethanol}$.[31] Because the estimated cointegrating vector generates coefficients on $P_{ethanol}$ and P_{RBOB} that are close to and statistically indistinguishable from the theoretical relationship in Eq. (8), we simply impose Eq. (8) to define the blender margin.

The constructed blender's margin is plotted in Fig. 7. In line with the aforementioned statistical tests, the figure suggests that the blender's margin series is stationary, and a unit root null is soundly rejected. It also demonstrates that the blender's margin fluctuated substantially during 2011 and 2012, ranging from zero to $3 per gallon of ethanol, with a standard deviation of almost 60¢. It also does not suggest any obvious visible change in the level of the pre- and post-expiration blender's margin.

We use standard autoregressive modeling techniques to form a precise estimate of the change at the time of the VEETC expiration. Specifically, we estimate the following model:

$$BM_t = \varphi_0 + \varphi_s \mathbb{1}\{t > T^*\} + \sum_{i=1}^{P} \varphi_i BM_{t-i} + \epsilon_t, \tag{9}$$

where ϵ_t is white noise and T^* = December 5th, 2011, consistent with the assumed definition of $s_{ethanol}(t)$ above. We are interested in the change in the unconditional mean of the blender's margin resulting from subsidy expiration. Under this model specification, this is estimated by the following transformation of the parameters:

$$\Delta_{bm} = \frac{\hat{\varphi}_s}{1 - \sum_{i=1}^{P} \hat{\varphi}_i}, \tag{10}$$

where Δ_{bm} is the estimated change in the blender's margin resulting from expiration. Under this construction of the blender's margin variable defined by Eq. (8), we will expect to see a change in the blender's margin of between − 45¢ (if the blender was capturing the entire subsidy) and 0¢ (if the entire subsidy was being passed along). To maintain consistency with the earlier analysis focused on the months just before and just after the subsidy expired, we restrict the sample to the six months before and after the expiration breakpoint, *T*. A Box-Jenkins approach to model specification suggests an *AR*-model with $P = 3$. Our estimation results in a point estimate of −14.0¢ with a standard error of 11.0¢ for the change in the blender's margin constant, which is calculated according to Eq. (10).[32] The point estimate suggests that around two-thirds of the subsidy was passed along through price changes, which coincides with the previous estimate of the incidence accruing to the agricultural branch. Taking the previous results at face value, the point estimate suggests that none of the subsidy incidence was passed downstream to gasoline consumers. While the confidence interval on this estimate of the blender margin is quite large, taken together with the other estimates of price changes, it reinforces the view that the majority of the VEETC was being captured by ethanol and/or corn producers, some was captured by blenders, and little if any was being captured by consumers or petroleum refiners.

As a caveat to the results from our preferred specification, other estimation windows yield larger estimates for the change in the blender's margin, all of which are statistically significant at the 95% confidence level. Those estimates, which are presented in Table 5 in Appendix C, range from −39¢ for a 6-month window to −49¢ for a 48-month window, suggesting that virtually all of the subsidy went to blenders. We are skeptical of this conclusion, as our estimates for the change in ethanol prices in the calendar spread analysis provide strong evidence that a significant portion of the subsidy was passed upstream from blenders. As such, we maintain the results from the 12-month window as our preferred estimates, while noting that they may understate the portion of the subsidy that was captured by blenders.

5.4. Combined estimates

In order to generate our final estimates of incidence and the corresponding confidence sets, we apply a simulation algorithm that imposes the condition that incidence estimates must be non-positive (when the subsidy is removed) and must sum to −45¢. The approach is motivated by Mandelkern (2002) who examined the problem of confidence intervals for bounded parameters. Note this is different from the case of (an equality) constrained estimation: in our case, we have a bound or inequality constraint that is not violated at the point estimate (if we assume the true RBOB value is zero), but should influence the confidence sets.[33]

The steps of the algorithm are as follows:

1. Draw from *t*-distributions for ethanol and RBOB and the normal distribution for the blender's margin. Degrees of freedom for the *t*-distribution come from the number of spreads used to compute the between-spread variance.
2. If the value of any draw is positive, set it equal to zero. If the value of any draw is less than −45¢, set it equal to −45¢.
3. If sum of the values in Step 2 is less than −45¢:
   (a) Increase all non-zero values in proportion to their variances until they add up to −45¢.[34]
   (b) If any non-zero values have become positive, set them equal to zero and repeat the previous step.
4. If the sum of the values in step 2 is greater than −45¢, assign the difference between the sum of the final values and −45¢ as the incidence that accrued to gasoline retailers/consumers.
5. In the last step, we divide the ethanol incidence between corn and

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[31] In order to precisely estimate the cointegrating relationship, we use price data from 2007 through 2013. The 95% confidence intervals for the coefficients on $P_{ethanol}$ and P_{RBOB} contain 1 (CI: [0.82,1.32]) and 9 (CI: [8.76,9.12]), respectively.

[32] See Table 5 in Appendix C for the full set of estimated parameters.

[33] Our approach is most similar to the "Classical" approach in Mandelkern. He did not address the problem of multiple variables and bounds.

[34] See Appendix B for details.

ethanol refiners. We pair each ethanol draw them with independent draws from a *t*-distribution for corn. As with ethanol and RBOB, the mean and variance comes from the estimation procedure described in Section 5.1 and the degrees of freedom are determined by the number of spreads used to compute the between-spread variance.

(a) If the value of the corn draw is positive it is set equal to zero.
(b) If the value of the corn draw is less (i.e., more negative) than the ethanol draw, it is set equal to the ethanol draw. The ethanol refiner incidence is zero for this draw.
(c) If the value of the corn draw is more than the ethanol draw, the ethanol refiner incidence equals the ethanol draw minus the corn draw.

We implement this algorithm for 500 draws from each distribution.

The results from applying the simulation algorithm are presented in Table 2. Columns 2 and 3 summarize the distributional parameters obtained from our estimation procedures. The last four columns contain the mean and 95% confidence intervals of incidence for each stakeholder group. Columns 4 and 5 use the RBOB estimates from Section 5.1; columns 6 and 7 assume the RBOB price effect is zero.

First, we note that whether we assume the RBOB price effect is zero or not has little consequences for our final results, affecting only whether roughly 2¢ goes to oil refiners or consumers. Therefore, we focus on the unconstrained results in columns 4 and 5. Here, we find that ethanol producers likely benefited most from the subsidy at the time it expired, but our confidence intervals for all commodities are fairly wide. The mean estimate for ethanol producers is 19.8¢, and the top end of the confidence interval is 30.8¢. The mean estimates for incidence per gallon of ethanol blended are very small for oil refiners (2.6¢) and consumers (5.3¢), but somewhat larger for blenders (12.3¢). However, in all three cases, the 95% confidence interval contains 0¢, while also including values of 20¢ or more.

6. Conclusion

At the time of its expiration, there was considerable debate about who was benefiting from the VEETC. This paper examines this question through a detailed, empirical analysis of price changes at the time the subsidy expired, in an event-study framework. Where possible, we used calendar spreads of futures prices, giving us a relatively clean indication of how the market expected prices to change for upstream commodities. Since futures price data was not available for measuring downstream incidence on gasoline prices, we instead directly estimated the blender's margin using spot price data, and assessed consumer impacts as the residual.

We found compelling evidence that, at the time the VEETC expired, an estimated 20¢ of the subsidy was passed up the agriculture chain to ethanol producers, with a lower bound of 9¢. Moreover, we found suggestive evidence that a small portion of the subsidy (around 5¢ per gallon of ethanol blended) was further passed upstream to corn farmers, though the data is more limited. Our direct estimate of the blender's take is 12¢ per gallon, with a confidence interval that includes zero. We find a point estimate for the consumer incidence of 5¢ per gallon, and find a (noisy) estimate of little incidence on refineries (3¢). This matches our prior that gasoline blendstock prices are largely, if not completely, independent of ethanol policy, being determined in internationally integrated product markets.

These results are consistent with previous work based on analytic and simulation modeling that generally argued ethanol producers benefited the most from VEETC, with some pass-through to corn farmers (De Gorter and Just, 2008; Taheripour and Tyner, 2007; Gardner, 2007; Kruse et al., 2007; McPhail and Babcock, 2008). It also provides partial support for Babcock (2008), who attributes most subsidy incidence to blenders. Our results match up closely to Abbott (2014), who found a similar 2:1 incidence split between ethanol producers and blenders. Unlike these prior studies, however, we have empirically estimated the incidence based on the VEETC elimination rather than simulating the policy with assumed elasticities. The approach introduces a new methodology for assessing the impact of policy and other market changes through futures contracts.

There are at least two important caveats to our results. First, our estimates are identified off of a relatively short time series around a single event. Second, we have measured the incidence at the time the subsidy expired in December 2011, and our technique emphasizes the response over a period of months. The degree to which our results hold over longer periods of time, or at different points in time, is unclear. For example, the subsidy may have played a large role in corn markets when it was introduced, but other forces were at work by the time it expired. This touches on the larger question of the role of biofuels policy and food prices, which we have not sought to address (see, e.g., Roberts and Schlenker, 2013).

Regardless of these caveats, however, the findings are relevant both for understanding the financial incidence of one of the largest energy subsidies in US history, as well as the market structure underpinning an industry that continues to be subject to substantial policy intervention.

Acknowledgments

We are grateful to the Bipartisan Policy Center for funding support.

Appendix A. Data sources

Table 3 provides an overview of the data sources used for this study. Additional details on how the data were used can be found in Section 5.

Table 3
Summary of data sources.

Commodity	Series type	Exchange/location	Source	Time horizon
Ethanol	Futures contract	CME	Bloomberg	January 2007–July 2013 (all months)
RBOB	Futures contract	NYMEX	Bloomberg	January 2007–July 2013 (all months)
Brent	Futures contract	NYMEX	Bloomberg	January 2007–July 2013 (all months)
Corn	Futures contract	NYMEX	Bloomberg	December 2007–March 2013 (December and March only)
Ethanol	Spot price	New York Harbor	Bloomberg	January 2011–December 2012
RBOB	Spot price	New York Harbor	Bloomberg	January 2011–December 2012
E10	Spot price	New York City	OPIS	January 2011–December 2012

Notes: All series represent daily prices.

Appendix B. Simulation algorithm details

In step 3 of our simulation algorithm, we increase the incidence values in proportion to their variances in order to enforce the constraint that they sum to −45¢. The optimization program underlying this step is the following:

$$\underset{\Delta_{eth},\Delta_{rbob},\Delta_{bm}}{\text{minimize}} \quad \frac{\Delta_{eth}^2}{\widehat{\sigma}_{eth}^2}+\frac{\Delta_{rbob}^2}{\widehat{\sigma}_{rbob}^2}+\frac{\Delta_{bm}^2}{\widehat{\sigma}_{bm}^2}$$

$$\text{subject to} \quad x_{eth}+\Delta_{eth}+x_{rbob}+\Delta_{rbob}+x_{bm}+\Delta_{bm}=45,$$

where x_i and Δ_i represent the current value and subsequent change in that value for commodity i. The solution for the change in the value of ethanol is

$$\Delta_{eth}=\frac{\widehat{\sigma}_{eth}^2}{\widehat{\sigma}_{eth}^2+\widehat{\sigma}_{rbob}^2+\widehat{\sigma}_{bm}^2}(-45-x_{eth}-x_{rbob}-x_{bm});$$

the solutions for the other commodities are analogous.

Appendix C. Regression estimates

Table 4 summarizes the results of estimating Eq. (4) for both ethanol and corn and Eq. (5) (RBOB), and Table 5 summarizes the results of estimating Eq. (9). For the regressions on calendar spreads, we present the estimates from the regression on the spread of interest in one column and the average of the estimates (both point and standard error) in another. For the blender's margin regressions, we present estimates for a variety of window lengths, including the change in blender's margin parameter defined in Eq. (10).

Table 4
Calendar spread regression results summary.

Commodity	Parameter	Spread of interest	Average of other spreads
Ethanol	α_0	− 0.283 (0.015)	− 0.031 (0.009)
	α_1	0.007 (0.002)	0.000 (0.001)
	$\alpha_2 \times 100$	− 0.006 (0.008)	0.001 (0.005)
RBOB	α_0	0.101 (0.065)	− 0.195 (0.199)
	α_1	− 0.004 (0.007)	0.014 (0.012)
	$\alpha_2 \times 100$	− 0.004 (0.022)	− 0.029 (0.034)
	$\beta_{0,0}$	0.461 (0.792)	0.132 (0.995)
	$\beta_{0,1}$	− 0.875 (0.767)	0.380 (1.108)
	$\beta_{0,2}$	0.196 (0.765)	0.221 (1.150)
	$\beta_{1,0}$	1.610 (1.946)	4.523 (7.666)
	$\beta_{1,1}$	3.581 (2.399)	− 2.387 (8.280)
	$\beta_{1,2}$	0.803 (2.375)	− 2.064 (8.029)
Corn	α_0	0.007 (0.010)	0.056 (0.001)
	α_1	0.003 (0.001)	0.000 (0.000)
	$\alpha_2 \times 100$	− 0.006 (0.004)	− 0.001 (0.001)

Notes: Standard errors are in parentheses. All regressions estimated on 30 observations. For legibility, all α_2 point estimates and standard errors have been multiplied by 100.

Table 5
Blender's margin regression results summary.

Parameter	Window length 6-Month	12-Month	24-Month	48-Month
φ_0	0.833 (0.177)	0.655 (0.110)	0.553 (0.080)	0.411 (0.048)
φ_1	0.219 (0.091)	0.234 (0.063)	0.328 (0.044)	0.363 (0.031)
φ_2	0.063 (0.092)	0.094 (0.064)	0.032 (0.046)	0.092 (0.033)
φ_3	0.150 (0.089)	0.153 (0.063)	0.241 (0.044)	0.242 (0.031)
φ_s	− 0.221 (0.088)	− 0.073 (0.058)	− 0.174 (0.051)	− 0.147 (0.032)
Δ_{bm}	− 0.389 (0.138)	− 0.140 (0.110)	− 0.437 (0.115)	− 0.485 (0.094)
N	123	251	499	995

Notes: All values are in dollars. Standard errors are in parentheses.

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