AgEcon SEARCH
RESEARCH IN AGRICULTURAL & APPLIED ECONOMICS

The World's Largest Open Access Agricultural & Applied Economics Digital Library

This document is discoverable and free to researchers across the globe due to the work of AgEcon Search.

Help ensure our sustainability.

Give to AgEcon Search

AgEcon Search
http://ageconsearch.umn.edu
aesearch@umn.edu

*Papers downloaded from **AgEcon Search** may be used for non-commercial purposes and personal study only. No other use, including posting to another Internet site, is permitted without permission from the copyright owner (not AgEcon Search), or as allowed under the provisions of Fair Use, U.S. Copyright Act, Title 17 U.S.C.*

Pricing RINs and Corn in a Competitive Storage Model

May 2014

Wei Zhou
Graduate Assistant
Department of Economics
Iowa State University
wzhou815@iastate.edu

Bruce Babcock
Cargill Chair of Energy Economics and
Director, Biobased Industry Center
Professor of Economics
Iowa State University
babcock@iastate.edu

Selected Paper prepared for presentation at the Agricultural & Applied Economics Association's 2014 AAEA Annual Meeting, Minneapolis, MN, July 27-29, 2014.

Copyright 2014 by Wei Zhou, Bruce Babcock. All rights reserved. Readers may make verbatim copies of this document for non-commercial purposes by any means, provided that this copyright notice appears on all such copies.

Pricing RINs and corn in a Competitive Storage Model

Wei Zhou and Bruce Babcock

August, 2014

Abstract

A rational expectations competitive storage model for U.S. corn and RIN (Renewable Identification Numbers) markets is built to study the impacts of different ethanol policy scenarios. The model considers corn use for ethanol, storage and all other uses in each period, accounting for two random variables: oil prices and corn yields. Borrowing and banking provisions of the Renewable Fuels Standard (RFS) mandate are also integrated into the model. We use the model to provide estimates of the impact on corn prices, corn plantings and ethanol production under two ethanol mandate scenarios for six marketing years from 2014/15. The first scenario is one in which corn ethanol mandates stay the same as required in the RFS and additional E85 stations are introduced that allow for compliance with higher mandates. The second scenario is one in which no investment occurs and the Environmental Protection Agency reduces the mandate to 13 billion gallons. We find that corn prices drop about 6 percent from reduced mandates or about 26 cents per bushel, while RIN prices drop from around 54 cents to nearly zero. The results suggest that meeting the more broad policy objectives of energy policy and not the price of corn or RINs should determine the level of ethanol mandates.

1 Introduction

The impact of increasing biofuel consumption has been the subject of intense study over the last few years because of the concern that policies that support biofuels may have unintended impacts on impact food prices (World Bank), greenhouse gas emissions (Searchinger et. al (2008)), or fuel prices (CBO). Biofuel mandates in the Renewable Fuels Standard (RFS) is the primary policy that supports biofuel consumption in the United States so attention has recently focused on the impact of these mandates on biofuel production. The compliance mechanism for the RFS is that fuel producers and importers must obtain sufficient Renewable Identification Numbers (RINs) to show that they have met their biofuel obligations. RINs are produced when biofuels are produced. Their 38-digits facilitate traceability of each biofuel batch. Obligated parties obtain RINs either by buying biofuel from producers or by buying RINs in the market. Optimizing firms will choose to buy RINs if the price of RINs is less than their net cost of buying and blending biofuels that have the RINs attached. The net cost of buying and blending biofuels is the difference between the market price of the biofuel and its value in the fuel market. In theory, the price of RINs in the market will reflect this net cost. When RFS mandates push biofuel beyond the level that market forces alone would support, then the price of RINs will increase. RIN prices will approach zero when mandates are lower than the quantity that market forces support. Thus RIN prices provide a market measure of the impact of the RFS on biofuel consumption and production as well as providing a measure of marginal compliance costs. To lower the cost of complying with biofuel mandates the Environmental Protection Agency (EPA) allows RINs to be banked or borrowed. Thus the price of RINs will not only reflect current net costs of buying and blending biofuels but also anticipated future net costs. Rubin (1996) developed temporal arbitrage conditions for tradeable environmental permits that can be banked or borrowed. McPhail (2010) applied these conditions to the RIN market and solved the optimal conditions for how many RINs to store based on no-arbitrage conditions. However, she ignores the 20% borrowing and banking constraints and to simplify the problem assumed that ethanol mandates disappear

in the future so that two-year ahead RIN price distributions can be more easily estimated. The other model that has been used to project impacts of RFS mandates include Thompson, Meyer and Westhoff (2008, 2009a, 2009b) who use the FAPRI-MU model. The model in these papers did not incorporate borrowing and banking of RINs. Thompson, Meyer and Westhoff (2011) model RIN banking as a decreasing function of the current RIN price. They generate a dynamic price path for RIN prices but storage in their model depends only on the current RIN price rather than expected future RIN prices. Thus the model cannot be characterized.

The contribution of this paper is estimation of the future impact of RFS ethanol mandates under two scenarios. The first scenario assumes that EPA allows mandates to increase to 15 billion gallons, which is the cap on mandates that can be met with corn ethanol. The second scenario assumes that EPA keeps mandates at approximately 10 percent of US gasoline consumption. The impacts are estimated with a new competitive storage model of RINs and corn. The source of uncertainty in the future prices of corn is variable growing conditions which leads to supply volatility. The source of uncertainty in RIN prices is cost variability caused by variable corn prices as well as demand variability caused by uncertain future gasoline prices. The model is solved to allow estimation of corn and price distributions through the 2019 crop year using USDA projections of corn demand along with trend yield adjustments. Results indicate rather modest impacts on corn prices but large impacts on RIN price distributions.

RFS Compliance

With borrowing and banking provisions, a generated RIN is valid for two years. RINs expire after their valid life to prevent hoarding of RINs. RFS required that more than 80% of the mandated volume in a certain year will be met by RINs generated in the same year. That is, a maximum of 20% of the mandate can come from the RINs generated in the previous year. If the previous year's RINs are more than the maximum 20% limit, then the extra RINs expire. When a shock happens like the drought condition in 2012, it could be that the

obligated parties may run a deficit of RIN stocks. If this condition happens, the obligated party is required to not have a deficit greater than 20% of the next year's mandate. If deficit happens in one year, the next year's mandate will include the deficit. With RIN borrowing and banking, RINs generated in excess of the mandate could have a value for meeting the next year's mandate.

The policy for RIN use in our paper is slightly different from reality. RFS requires that RIN borrowing is not allowed in consecutive two years. For simplicity, we assume that RINs can be borrowed or banked up to 20% of the next year's mandate for each year. Thus the policy used in this paper is a little bit more flexible compared to reality.

2 The Model

In this simplified competitive markets model, a representative farmer makes an acreage decision each period. Harvested corn is used for feed, food, export, ethanol, and storage. A representative corn stock holder decides how much to store for the future according to a no-arbitrage condition. We assume that there is a representative ethanol producer who is both a blender and an obligated party[1]. In each period, They need to decide how much more ethanol they need to produce in order to meet a mandate in each period considering current and future costs of meeting the mandate, as well as the fact that they can borrow and bank RINs[2]. Corn is consumed by a representative consumer according to the corn

[1] As defined in RFS2, obligated parties are any refineries producing gasoline or diesel fuel within the 48 contiguous states or Hawaii, or any importer that imports gasoline or diesel fuel into the 48 contiguous states or Hawaii. Blenders, who simply buy ethanol and gasoline and blend ethanol into gasoline, are not obligated parties under the RFS. However, some blenders also own oil refineries such as BP and ConocoPhilips and so are considered obligated parties. The mandate for each obligated party is determined as a percentage of the total gasoline they sell in the United States.

[2] Here RINs are negative mandates. RIN market exists when there are heterogeneous ethanol producers whose marginal compliance costs are different. If there is only one producer who aggregately produce ethanol

demand function $D_c(p_{ct})$, where p_{ct} is the corn price at time t. The demand function is decreasing in price. US ethanol demand including both blender's demand for ethanol in E10 and consumer's demand for E85 is taken from Pouliot and Babcock (2014) [NEED THE NAME OF THE PAPER]. Total U.S. ethanol disappears according to an ethanol usage curve $D_e(p^d_{et}, p_{gt})$, where p^d_{et} and p_{gt} are the ethanol price and exogenous gasoline price at which an amount $D_e(p^d_{et}, p_{gt})$ of ethanol is used. Exogenous gasoline price is the ethanol usage curve shifter. The details of the representative farmer, corn storer and ethanol producer's problems are as follows.

Farmer

The farmer bases current year's planting decisions on next year's post-harvest expected price as shown in equation (1). A_{t+1} is acreage harvested in $t+1$. $A(\cdot)$ is a concave function of $E_t(p_{ct+1})$, i.e., $A'(\cdot) > 0$ and $A''(\cdot) < 0$.

$$A_{t+1} = A(E_t(p_{ct+1})) \tag{1}$$

Corn Storer

Equilibrium storage satisfies the following no-arbitrage condition

$$\beta E_t(p_{ct+1}) = p_{ct} + SC_t(x_{t+1}), \tag{2}$$

and meet the total mandate, there is no RIN market. In this case, the producer can borrow or bank negative mandate aggregately. Here in the paper we still call it RIN and RINs borrowing and banking to avoid confusion. RINs are similar to emission permits. For heterogeneous agents, they borrow, bank and trade emission permits. Aggregately, a social planner bank and borrow emission.

where x_{t+1} is the beginning corn stock in time $t+1$, which is also the storage decision made in time t, per bushel storage cost of crop i is denoted by SC_t. The per bushel storage cost includes a marginal convenience yield which goes to negative infinity when stock level approaches zero. The disccount factor β equals $\frac{1}{1+r}$ where r is the interest rate. Corn storage is determined by equating expected gains from holding corn to the next period and the cost of holding it. The expected revenue from holding one bushel of corn to the next period is the discounted expected price of corn. The cost of holding one bushel of corn is the per bushel corn price at time t plus the storage cost. If there is positive economic profit from holding corn, firms and individuals will store it. With more corn stored for $t+1$, total corn consumption decreases in t and total corn supply increases in $t+1$. The current corn price goes up and the expected corn price goes down. When expected gains equals the cost, the incentive to store corn disappears and a no-arbitrage condition is reached. When stock level approaches zero, marginal storage cost goes to negative infinity. Thus, the expected gain can never be less than the cost of holding one unit of stock. This specification of marginal storage cost eliminates stock-out conditions.

Ethanol Producer

The maximization problem for heterogeneous agents with different compliance costs is analyzed in McPhail (2010). As proved by Rubin (1996), when trade is allowed, heterogeneous agents will collectively behave as one facing a mandate who efficiently produce ethanol to minimize total life time costs of meeting the mandate. The ethanol producer's problem is similar to Schennach (2000) and McPhail (2010).

A representative ethanol producer minimizes extra cost of meeting the mandate in each period, $c_t(e_t - \varepsilon_t)$, where $c_t(\cdot)$ is the extra cost function which is the difference between production cost with and without any policy constraints, $c_t^{'}(\cdot) > 0$ and $c_t^{''}(\cdot) > 0$. ε_t is the optimal ethanol production without ethanol mandate. The decision variable e_t is total

ethanol produced in time t. $c_t(\cdot)$ is also called compliance cost function. The blender can borrow or bank RINs up to 20% of the next period's total mandate. Let B_t be the beginning stock of RINs and m_t be the mandate in each period t. The ethanol produer minimizes life time compliance cost:

$$\min_{e_t,\forall t} \sum_{t=0}^{\infty} \beta^t E_0(c_t(e_t - \varepsilon_t)) \tag{3}$$

$$s.t. \qquad B_{t+1} = min(B_t + e_t - m_t, 0.2m_{t+1}) \tag{4}$$

$$B_t + e_t - m_t \geqslant -0.2m_{t+1} \tag{5}$$

where $0.2m_{t+1}$ is the upper bound of banked RINs and $-0.2m_{t+1}$ is the lower bound of borrowed RINs. Equation (4) says that the carryover B_{t+1} cannot exceed the maximum carryover allowed at time t. Available RINs stock is the sum of RIN stock and RINs generated less the actual mandate, $B_t + e_t - m_t$. If available RINs stock is not greater than the banking limit, $B_t + e_t - m_t$ will be banked. If available RINs stock exceeds the banking limit, only $0.2m_{t+1}$ can be used in the next period and the rest of the available RINs will expire. Borrowing constraint (5) says that carryover RIN stock should be greater than -0.2 of next period's mandate. RIN stock is a state variable in ethanol producer's problem.

Let

$$V_t(B_t, T) = \min_{e_t,\forall t} \sum_{t=T}^{\infty} \beta^t E_0(c_t(e_t - \varepsilon_t)). \tag{6}$$

The Bellman equation for solving the problem with borrowing and banking constraints is

$$V_t(B_t,\, t) = \min_{e_t} c_t(e_t - \varepsilon_t) + \beta E_t V_{t+1}(min(B_t + e_t - m_t, 0.2m_{t+1}),\, t+1) + \lambda_t(-0.2m_{t+1} - (B_t + e_t - m_t)), \tag{7}$$

where λ_t is Karush-Kuhn-Tucker (K.K.T) multiplier. The K.K.T. conditions are:

$$e_t:\ c_t^{'}(e_t - \varepsilon_t) + \beta \frac{\partial E_t V_{t+1}(min(B_t + e_t - m_t,\, 0.2m_{t+1}),\, t+1)}{\partial e_t} - \lambda_t \geqslant 0,\ \frac{\partial V_t(B_t,\, t)}{\partial e_t} \cdot e_t = 0, \tag{8}$$

$$\lambda_t: \ -0.2m_{t+1} - (B_t + e_t - m_t) \leqslant 0, \ (-0.2m_{t+1} - (B_t + e_t - m_t)) \cdot \lambda_t = 0, \ \lambda_t \geqslant 0. \tag{9}$$

The envelope condition is

$$\frac{\partial V_t(B_t,\, t)}{\partial B_t} = \beta \frac{\partial E_t V_{t+1}(min(B_t + e_t - m_t, 0.2m_{t+1}),\, t+1)}{\partial B_t} - \lambda_t. \tag{10}$$

Without RINs borrowing and banking, the ethanol producer has to produce at least the mandated level in each period. After introducing borrowing and banking provisions, the ethanol producer can produce less than or more than the mandated level to minimize the total cost of meeting the obligated volume for all time periods. (8) means that if total ethanol production is not zero then the first part $\frac{\partial V_t(B_t,t)}{\partial e_t} = 0$. Ethanol produced, e_t cannot be zero because at least 80% of the mandate has to be met by RINs generated in this period. Thus the K.K.T condition with respect to e_t (8) becomes

$$e_t: \ c_t^{'}(e_t - \varepsilon_t) + \beta \frac{\partial E_t V_{t+1}(min(B_t + e_t - m_t, 0.2m_{t+1}),\, t+1)}{\partial e_t} - \lambda_t = 0. \tag{11}$$

If the borrowing and banking constraints are not binding, then marginal cost of the borrowing constraint equals zero ($\lambda_t = 0$) and all available RINs will be banked $B_{t+1} = B_t + e_t - m_t$. Equation (11) becomes

$$c_t^{'}(e_t - \varepsilon_t) = -\beta \frac{\partial E_t V_{t+1}(min(B_t + e_t - m_t, 0.2m_{t+1}),\, t+1)}{\partial e_t}, \tag{12}$$

and together with equation (10), we have the marginal compliance cost in time t equals the discounted expected marginal compliance cost in the next period:

$$c_t^{'}(e_t - \varepsilon_t) = \beta E_t(c_{t+1}^{'}(e_{t+1} - \varepsilon_{t+1})). \tag{13}$$

The relationship between marginal compliance cost in t and expected marginal compliance cost in $t + n$ can be derived from equation (13),

$$c_t^{'}(e_t - \varepsilon_t) = \beta^n E_t(c_{t+n}^{'}(e_{t+n} - \varepsilon_{t+n})). \tag{14}$$

Equation (14) says that the expected marginal compliance cost increases at interest rate. If the expected marginal compliance cost increases at a rate greater than interest rate, ethanol producer would have an incentive to bank RINs. With more ethanol produced and more RINs banked, current marginal compliance cost increases and expected marginal cost decreases. No more RINs will be banked until current marginal compliance cost equals the discounted expected marginal compliance cost. If the expected marginal compliance cost grows less than interest rate, ethanol producer will borrow RINs from future, resulting in a decrease in current marginal compliance cost and a rise in expected marginal compliance cost. An equilibrium is achieved when current marginal compliance cost is equal to the discounted expected marginal compliance cost.

If the maximum banking limit is reached, λ_t is zero, $min(B_t + e_t - m_t, 0.2m_{t+1}) = 0.2m_{t+1}$, and (11) becomes

$$c_t^{'}(e_t - \varepsilon_t) = -\beta \frac{\partial E_t V_{t+1}(min(B_t + e_t - m_t, 0.2m_{t+1}),\, t+1)}{\partial e_t} = \beta \frac{\partial E_t V_{t+1}(0.2m_{t+1})}{\partial e_t} = 0. \tag{15}$$

Marginal extra cost is zero only if no extra ethanol needed to be produced, thus we have

$$e_t = \varepsilon_t. \tag{16}$$

In this case, available RIN stock could be greater than the amount banked. Some extra RIN stock is of no use. Thus RIN price can be bid to zero. The optimal condition for ethanol production requires that the marginal compliance cost of meeting the mandate is zero. As shown by (16), ethanol produced is the same as if there is no mandate and no

banking and borrowing of RINs.

When the borrowing constraint is binding at time t , $e_t - (m_t - B_t) = -0.2m_{t+1}$, $\lambda_t > 0$. Then we have

$$c_t^{'}(e_t - \varepsilon_t) = \beta E_t(c_{t+1}^{'}(e_{t+1} - \varepsilon_{t+1})) + \lambda_t. \tag{17}$$

Equation (17) says that the expected marginal compliance cost grows less than the rate of interest, the ethanol producer would have an incentive to borrow negative mandate from future. However there is a physical constraint restricting the maximum borrowing, resulting in a binding borrowing constraint.

From the discussions of the constraints, we know that the expected marginal cost grows with the interest rate whenever the constraints on borrowing and banking are not binding. The marginal cost grows lower than interest rate when the borrowing constraint binds. Marginal cost is zero when the negative mandate banking constraint binds.

Marginal compliance cost specification

The expected RIN price is the marginal extra cost of production and we assume that the marginal extra cost for meeting the mandate is defined as the difference between marginal cost of producing ethanol and marginal benefit of using ethanol (McPhail (2010)). The marginal cost of producing an extra gallon of ethanol equals the feedstock cost plus a constant conversion cost. Corn is assumed to be the feedstock. Let Y_e be the net corn use for producing a gallon of ethanol accounting for byproducts produced per bushel of corn processed in ethanol production[3]. Per gallon conversion cost is assumed to be a constant c_e. Assume that the technology for producing ethanol from corn is constant for all time periods, thus Y_e and c_e do not change for all t. Thus $\frac{p_{ct}}{Y_e} + c_e$ is the marginal cost of ethanol production.

[3]The details of modeling the net corn production for ethanol can be found in Lapan and Moschini (2012) page 227.

With more corn devoted to produce ethanol, corn price rises and the marginal production cost increases. This specification connects the ethanol market with the corn market. The marginal benefit of blending ethanol equals the ethanol price p^d_{et} along the ethanol usage curve. RIN price equals $\frac{p_{ct}}{Y_e} + c_e - p^d_{et}$.

Comparing RIN storage and corn storage

We treat RIN as a storable commodity. Just as storing stabilizes corn prices under yield uncertainty, RIN storage serves the same function, helping to stabilize ethanol prices and corn prices under an ethanol mandate in a stochastic world. The carryover of corn is determined by the no-arbitrage equation that compares the value of storing one unit in this period and the value of consuming one unit in this period. Without borrowing and banking constraints, the negative rollover is determined by the no-arbitrage condition that equates the marginal cost of meeting the mandate in this period to the discounted value of expected cost of meeting the mandate in the next period. The difference between the use of corn storage and RIN storage is that corn carry-over can be consumed but the RIN storage cannot be consumed as ethanol in the next period. RIN stock has an impact on actual mandate, it plays a role in determining the ethanol production. If the ethanol production is greater than actual mandate, total ethanol production will still be consumed in ethanol market equilibrium and the extra generated RINs will be stored for the next period.

Market Equilibrium

The total supply of corn at time t is determined by $TS_t = A_t y_t + x_t$, where A_t is the acreage harvested at time t which is decided by farmers in aggregate in time $t-1$: $A_t = A(E_{t-1}(p_t))$, where y_t is the corn yield at time t. Total corn demand is the sum of feed demand $D_c(p_{ct})$, corn for ethanol $\frac{e_t}{Y_e}$ and storage x_{t+1}. Equilibrium conditions are sequences of quantities $\{e_t,\ D_{ct},\ x_{t+1},\ A_{t+1}\}_{t=0}^{\infty}$ and prices $\{p_{ct},\ p_{et}\}_{t=0}^{\infty}$ such that (i) the quantities solve the arbitrage conditions for different agents given the sequence of prices, (ii) the corn market clearing condition is met as shown by equation (18), (iii) and the ethanol market clears

through equation (19).

Corn market:

$$\forall t,\ A(E_{t-1}(p_{ct}))y_t + x_t = D_c(p_{ct}) + \frac{e_t}{Y_e} + x_{t+1} \tag{18}$$

Ethanol market:

$$e_t = D_e(p^d_{et},\, p_{gt}) \tag{19}$$

3 Calibration

Ethanol usage curve

The ethanol demand curve is taken from Pouliot and Babcock (2014). Their total ethanol usage curve equals the summation of ethanol demanded in E10 by blenders and ethanol demanded in E85 by consumers. There is little data for U.S. ethanol demand beyond the blend wall. So Pouliot and Babcock (2014) use Brazilian data to estimate the consumers willingness to pay for E85, making the assumption that US consumer preference for E85 is similar to Brazilian preference for ethanol.

Both the ethanol demand in E10 and E85 depend on the gasoline price. Ethanol in E10 complements gasoline, whereas ethanol in E85 substitutes for gasoline. Suppose the ethanol demand function of E10 and E85 is given by $Q^{10}_e = D^{10}_e(p_{et}, p_{gt})$, $Q^{85}_e = D^{85}_e(p^r_{85t}, p^r_{gt})$, where p_{gt}, p_{et}, p^r_{85t} and p^r_{gt} are the wholesale gasoline price, wholesale ethanol price, retail E85 price and retail gasoline price in time t. Horizontal summation of the two inverse demand curves gives rise to the total inverse demand of ethanol. Details of the functional forms is provided as follows.

To allow the model to be solved at different gasoline prices, both the ethanol demand in E10 and E85 are approximated using piecewise linear functions:

$$Q_e^{10} = \begin{cases} 13 & 0 < \frac{p_{et}}{p_{gt}} < 0.686777 \\ 14.2178 - 1.7731\frac{p_{et}}{p_{gt}} & 0.686777 < \frac{p_{et}}{p_{gt}} \leqslant 1.074941 \\ 18.5193 - 5.7748\frac{p_{et}}{p_{gt}} & 1.074941 \leqslant \frac{p_{et}}{p_{gt}} \leqslant 1.145516 \\ 11.9042 & \frac{p_{et}}{p_{gt}} = 1.145516 \end{cases} \tag{20}$$

The maximum ethanol demanded in E10 is 13 billion gallons to reflect the blend wall.

Let x be the ratio of retail E85 price to retail gasoline price, $x = \frac{p^r_{85t}}{p^r_{gt}}$. With the current fleet of flex vehicle and new E85 stations, ethanol demand in E85 as a function of price ratio with no new E85 stations is as follows.

$$Q_e^{85} = \begin{cases} 1.7 - 0.85x & 0.409 \leqslant x < 0.62 \\ 3.3810 - 3.55x & 0.62 \leqslant x < 0.88 \\ 1.2268 - 1.11x & 0.88 \leqslant x < 1.08 \end{cases} \tag{21}$$

With 2500 new E85 stations, ethanol demand in E85 is:

$$Q_e^{85} = \begin{cases} 3.22 - 1.5283x & 0.409 \leqslant x < 0.688 \\ 7.308 - 7.47x & 0.688 \leqslant x < 0.9188 \\ 2.4482 - 2.1808x & 0.9188 \leqslant x < 1.0864 \end{cases} \tag{22}$$

Ethanol demand in E85 with 5000 new E85 stations is:

$$Q_e^{85} = \begin{cases} 4.4633 - 1.6667x & 0.409 \leqslant x < 0.65 \\ 10.2960 - 10.64x & 0.65 \leqslant x < 0.90 \\ 3.7042 - 3.3158x & 0.90 \leqslant x < 1.09 \end{cases} \tag{23}$$

The demand for E85 is quite limited when the price of E85, adjusted on a cost per mile basis, is higher than E10. But demand becomes quite elastic when E85 prices become

competitive with E10. Eventually demand becomes quite inelastic due to limits on the number of stations that sell E85. The range of E85 quantities where demand is elastic increases if additional E85 fueling stations become available because the bottleneck limiting demand for E85 is access to fueling stations not the number of flex vehicles. In this analysis, it is assumed that E85 contains 75 percent ethanol, the wholesale E85 price is the weighted average price of ethanol and gasoline, retail E85 ethanol price is \$0.75 per gallon higher than wholesale price and retail gasoline price is \$0.75 per gallon higher than the wholesale gasoline price. (source?)

Thus the price ratio x can also be stated as $\frac{0.75p_{gt}+0.25p_{et}+0.75}{0.75+p_{gt}}$. This value can be substituted into (21), (22), (23). Adding the quantity of ethanol in E10 and E85 using (20), (21), (22), (23). Then we get the inverse ethanol usage function $e_t = D_e(p^d_{et}, p_{gt})$ for each investment with each wholesale gasoline price. The inverse ethanol usage function is $p^d_{et} = D_e^{-1}(e_t, p_{gt})$.

Wholesale gasoline price

Wholesale gasoline prices are assumed to be log-normally distributed. Mean wholesale gasoline price in 2014/15 is set to be \$2.68/gallon which is the average of RBOB gasoline futures prices from September 2014 to August 2015 in August 13th 2014. The values of RBOB gasoline futures prices are taken from CME Group. The RBOB future gasoline price is falling in the following years and we assume the mean value for 2015/16 is \$2.60/gallon and is \$2.50/gallon for all years in the future. The standard deviation is assumed to be 20% of the mean price.

Mandate

The RFS operates on a calendar-year basis while our model operates on a marketing year basis. So we assume that the marketing year mandate is one-third of one year and two-thirds of the next year. Thus the present ethanol mandates (in 10 billion gallons) 2014/15 is 1.48 and fixed at 1.5 for all years after 2014/15.

RIN stock

The potential carry in of RINs in 2014 is estimated to be 0.997 billion gallons when 2013 yearly mandate is set to be 13.8 billion gallons (Paulson (2014)). Because the marketing year mandate for 2012/13 is 13.6 billion gallons, the carry-in RIN in 2013/14 is assumed to be 0.2 more than Paulson's estimate. Then the beginning RIN stock is set to be 1.2 billion gallons in 2013/14. According to WASDE report in August 2014, 5075 million bushels of corn are devoted to ethanol production and a bushel of corn yields 2.8 gallons of ethanol. Ethanol yield from corn is taken from monthly profitability of ethanol by Iowa State University[4]. Thus the generated ethanol production is 5075*2.8=14.21 billion gallons. The 2013/14 mandate is 14.2 billion gallons. The carryover stock is then calculated as the potential carry-in in 2013/14 plus the generation less the 2013/14 mandate. Carryover stock is 1.2+14.21-14.2=1.408 billion gallons. The beginning stock in 2014/15 is assumed to be 0.1408 10 billion gallons.

Non-ethanol demand

In this study, we use a constant elasticity non-ethanol, non-storage demand function.

$$p_c = a_1 D_c^{a_2}$$

When producing ethanol from corn, a valuable by-product called DDGS (dry distillers grains plus solubles) is also produced. DDGS is a close substitute for corn in livestock feed. If the by-product's price is proportional to corn, then it is legitimate to assume that less corn can be used for producing the same amount of ethanol (Lapan and Moschini (2012)). Here, we assume that the price of DDGS is 91% of the price of corn (Anderson, Anderson and Sawyer (2010)). 56 lbs of corn (1 bushel) that is processed into ethanol production will produce 17 lbs of DDGS. The net corn used for producing 2.8 gallons of ethanol is calculated as $1 - 0.91 * 17/56$. That is, the yield of one bushel of corn is $\frac{2.8}{1-0.91*17/56} = 3.87$ gallons of ethanol. It is assumed that the corn feed demand elasticity is fixed at -0.44 (Adjemian

[4]http://www.extension.iastate.edu/agdm/refirst.html

and Smith (2012)). D_c includes all non-ethanol use except corn storage. The value of a_1 in 2014/15 is calibrated using the average received corn price by farmers and the non-ethanol, non-storage quantity demanded in August 2014 WASDE report. The non-ethanol use for corn is calculated by subtracting the net corn use for ethanol from the total use of corn (Total corn use(without storage) - corn use for ethanol *(1-0.91*17/56) = non-ethanol use). The positions of demand curves from 2015/16 to 2019/20 are based on USDA's long term agriculture projections in February 2014.[5]From 2012/13 to 2015/16, the values of a_1 are different. a_1 is assumed to be constant after 2015/16.

Corn yield

Corn yield is assumed to be beta-distributed and has a linear trend. US corn yields from 1970 to 2013 reported by National Agricultural Statistics Service (NASS) of the U.S. Department of Agriculture are used to estimate the trend. Then we scaled up all the yield realizations from 1970-2013 to 2013 trend yield levels. Detrended yield data is used for estimating the parameters of a beta distribution that represents corn yield distribution during 2013/14 marketing year. The estimated corn yield is assumed to have an upper bound $y_u = 200$ bushels per acre, lower bound $y_l = 90$ bushels per acre. The beta distribution in 2013/14 is $beta(7.3766, 4.7497)$. According to the corn yield trend line, the per acre mean yield value increases by approximately two bushels per year. Thus we assume that the whole corn yield distribution shifts out two bushels per acre until 2019/20. After 2019/20, assume that corn yield distribution remains the same as in 2019/20. The calibrated mean yield values are documented in table 6. Corn yield in 2014 is set to be 167.4 bushels per acre accordint to August WASDE 2014. Corn yields are impacted mainly by weather, so we assume that corn yields are independent of gasoline prices.

Other Variable Cost

Per gallon ethanol conversion cost (c_e) is assumed to be constant. This cost includes

[5]USDA long term projection 2014 can be found here
http://usda.mannlib.cornell.edu/MannUsda/viewStaticPage.do?url=http://usda.mannlib.cornell.edu/usda/ers/94005/./2

the cost of natural gas used in the production process and variable costs. We calculate the non-corn production cost using the Monthly Profitability of Ethanol Production calculator (Mallory et. al. (2012)). The variable costs consists of chemical costs, electricity, maintenance, etc. The total non-corn production cost is fixed at 50 cents per gallon.

Harvested Acres

Farmers make planting decisions according to the expected corn price. We assume that harvested acres has a constant elasticity functional form as

$$A = \delta_1 E(p_c)^{\delta_2}. \tag{24}$$

The elasticity of harvested acres is assumed to be 0.2. This supply elasticity is roughly consistent with that of Roberts and Schlenker (2010) which is 0.14. δ_1 is determined by the expected price for 2013/14 and the harvested acres in 2013/14. The per bushel expected price is represented by the average marketing year's December futures price in 2013 from September 1st 2012 to August 31st 2013. The expected price in 2013/14 is \$5.68 per bushel. The harvested acres is 0.877 100 million acres. We have $\delta_1 = 0.62$. We use harvested acres in August WASDE 2014 to be the real harvested acres in 2014. After 2014, the acreage decision follows (24).

Storage Cost and Convenience Yield

The storage cost per unit includes per unit observed cost and per unit unobserved cost. The observed part of the storage cost (OSC) is a constant physical per unit storage cost paid by the storer. We assume that the observed per bushel storage cost is 3 cents per bushel per month (Peterson and Tomek (2010)). The yearly observed storage cost is thus \$0.36 per bushel, $OSC_t = 0.36$. One component of unobserved storage cost is the opportunity cost that increases with stock level when stock levels are large. This is because holding more stock of one crop decreases the opportunity of holding other more profitable crops (Paul (1970)). The other unobserved storage cost is the marginal convenience yield.

The unobserved storage cost should be increasing with stock level and it is negative when stock level s_t is small and positive when stock level is high. Rui and Miranda (1995) uses a logarithmic function to achieve it. $USC_t = \eta_1 + \eta_2 log(s_{it+1})$ where η_1 and η_2 are two parameters needed to be calibrated. We calibrate this USC_t to two points. One point has low ending stock and the other has abundant ending stock in recent years. The chosen low ending stock point is 2012/13. Both 2008/09 and 2009/10 have high ending stocks. Thus we use the average of the stock level and the average of unobserved storage cost in those two years as the other point. We can get unobserved storage cost from the storage no-arbitrage condition: $USC_t = \beta E_t(p_{t+1}) - p_t - OSC_t$. We collect our data including current price p_t, expected price $E_t(p_{t+1})$ in 2008/09, 2009/10 and 2012/13. Use average price received by the farmer in each marketing year from USDA NASS for the current year price. The average of December corn futures price from September 1st to August 31st is used as the yearly expected price. The discount factor, β, is defined as $\frac{1}{1+r}$ where r is the interest rate. We use the return for 1-year treasury constant maturities as risk free interest rate. We have $\eta_1 = -1.65$, $\eta_2 = -2.8926$. It is also assumed that the per bushel storage cost goes to infinity when approaching the storage capacity 0.4 10 billion bushels. Thus we have

$$USC_t = \begin{cases} -1.65 - 2.8926 log(s_{t+1}) & 0 < s_{t+1} < 0.4 \\ \infty & s_{t+1} \geqslant 0.4 \end{cases}.$$

4 Solution Methods

Corn stock and RIN stock are two state variables in our model. The model solutions are expected corn price and expected ethanol price functions of two state variables and they need to meet three conditions: (1) optimal harvested acres by the farmer, (2) corn storage condition, (3) RIN storage conditions. The collocation method is used to solve the problem. This method is applied to solve agricultural commodity markets with storage by Miranda (1997), Peterson and Tomek (2005) and Gouel (2013). Expected prices of corn and ethanol are first approximated as linear combinations of cubic spline functions of corn stock and RIN stock. Second, collocation nodes are chosen. The collocation method replaces infinite

dimensional problem with finite dimensional problem. The approximate solution is solved when the conditions (1), (2) and (3) are satisfied at only certain points. The certain given points are collocation nodes. Two shocks (corn yield and gasoline prices) are discretized using Gaussian quadrature method. In the third step, we need to solve for the coefficients of the approximated expected prices which allow optimal harvested acreage, corn storage, RIN storage satisfy conditions (1), (2) and (3). Function iteration is used to solve the coefficients. First, we guess the values for the unknown coefficients. Second, for each collocation node and quadrature node, acreage harvested is a known function of approximated expected corn price. Given this harvested acreage, solve the corn storage and RIN storage no-arbitrage conditions. Third, we compare the approximated expected prices and the expected prices generated by the model with our coefficients guesses. Finally, we update the coefficients until the expected prices are well approximated. The details are provided below.

In our model, we assume for simplicity that non-ethanol demand functions, distributions of corn yield and gasoline prices remain the same and no new E85 stations will be built from 2019/20. Thus the corn and RIN storage are stationary from 2019/20. Before 2019/20, the world is assumed to be changing in each period. The yield distribution shifts out by two bushels per acre in each period. Non-ethanol demand also changes. We first solve a stationary world after 2018/19, then solve backwards to the present.

Solve a stationary world

Collocation method is used to replace the infinite dimensional functional problem to a finite dimensional nonlinear equation problem (Judd 1998). Using collocation method, the unknown function P is approximated using a linear combination of unknown functions ϕ_1, ϕ_2,... , ϕ_n, called the basis functions. If there is only one dimension

$$P(x) \approx \sum_{j=1}^{n} c_j \phi_j(x) \tag{25}$$

The coefficients c_1, c_2,... , c_n are determined by letting the approximation satisfy functional equations at n finite points x_1, x_2,... , x_n chosen in the space of x, $[\underline{x}, \bar{x}]$. All possible values of x should be in $[\underline{x}, \bar{x}]$. The n points are the collocation nodes.

To apply the method to our two dimensional problem. The expected prices of corn and ethanol (EP_c, EP_e) can be represented as two dimensional polynomials of given degrees of approximation. The approximation of expected corn prices and ethanol prices functions at each collocation nodes are

$$EP_k(x_i, B_i) = \sum_{j_1=1}^{n_1} \sum_{j_2=1}^{n_2} c_{kj_1j_2} \phi_{j_1}(x_i) \phi_{j_2}(B_i) \tag{26}$$

$$k = c, e, \ j_1 = 1, 2, ...n_1, \ j_2 = 1, 2, ..., n_2$$

The steps used to solve for these functions are as follows:

(0) Initial Step:

Select the degrees of approximation in each dimension n_i, for $i = 1, 2$; select the cubic spline basis functions ϕ_1,..., $\phi_{n_1 n_2}$; select the collocation nodes x_i, B_i, for $i = 1, 2, ...n_1 n_2$, guess the initial values of $c_{cj_1j_2}$,$c_{ej_1j_2}$, $j_1 = 1, ..., n_1$, $j_2 = 1, ..., n_2$, where n_1, n_2 are the selected degrees of approximation in each dimension. We use $n_1 = 30$, $n_2 = 10$ to show the results. Then we determine the state spaces for each state variable. Let x lie in the interval [0, 0.4] in units of 10 billion bushels as the unit and B is chosen in $[-0.3, 0.3]$ with 10 billion gallons as the unit. n_i spline collocation points are chosen to be evenly distributed in each dimension.

Gaussian quadrature is used to replace the continuous yield and gasoline price distributions by l_1-point and l_2-point discrete distributions. The discrete yield values are y_1, y_2, ... , y_{l_1} with the associated probabilities w_{k_1} for $k_1 = 1, 2, ..., l_1$. The values p_{g1}, p_{g2}, ...

, p_{gl_2} are assumed to be the discrete demand shocks and w_{k_2} with $k_2 = 1, 2, ..., l_2$ are the corresponding probabilities. We pick 8 quadrature nodes for both the beta distribution and log-normal distribution. The Matlab codes given in Miranda and Fackler's book are used to generate quadrature nodes and the corresponding probabilities.

(1) Solution Step:

Get the total supply ($A_{ik_1k_2}$) for each collocation node (i) and Gaussian quadrature node (k_1, k_2). The acreage harvested in t can be written as $A_{ik_1k_2} = A(\sum_{j_1=1}^{n_1}\sum_{j_2=1}^{n_2} c_{cj_1j_2}\phi_{j_1}(x_i)\phi_{j_2}(B_i))$, so the total supply at each collocation node (x_i, B_i) given y_{k_1} and p_{gk_2} is

$$TS_{ik_1k_2} = x_i + A_{ik_1k_2}y_{k_1}. \tag{27}$$

Given the total supply, solve the corn storage arbitrage condition and RIN storage arbitrage conditions described in (28), (29) and (30) to get corn storage ($x_{ik_1k_2}$) and quantity of ethanol ($e_{ik_1k_2}$) at each collocation node i for $i = 1, 2, ..., n_1n_2$ and each gaussian quadrature node $k_1 = 1, 2, ..., l_1$, $k_2 = 1, 2, ..., l_2$.

$$\beta EP_c(x_{ik_1k_2}, B_{ik_1k_2}) - p_c(TS_{ik_1k_2} - x_{ik_1k_2} - \frac{e_{ik_1k_2}}{Y_e}) - SC(x_{ik_1k_2}) = 0. \tag{28}$$

Let

$$\begin{aligned} F = &\frac{1}{Y_e}p_c(TS_{ik_1k_2} - x_{ik_1k_2} - \frac{e_{ik_1k_2}}{Y_e}) + ce - p_e^d(e_{ik_1k_2}, p_{gk_2}) \\ &-\beta[\frac{1}{Y_e}E(P_c(x_{ik_1k_2}, B_{ik_1k_2})) + ce - E(P_e(x_{ik_1k_2}, B_{ik_1k_2}))) \end{aligned}$$

with $B_{ik_1k_2} = min(B_i + e_{ik_1k_2} - m, 0.2m)$,

$$\begin{aligned} e_{ik_1k_2} &= -0.2m + m - B_i,\ F > 0 \\ -0.2m + m - B_i \leqslant e_{ik_1k_2} &\leqslant 0.2m + m - B_i,\ F = 0 \\ e_{ik_1k_2} &= 0.2m + m - B_i,\ F < 0. \end{aligned} \tag{29}$$

The nonlinear equation system (28) to (29) can be solved using $PATHSolver$[6]. Whenever the ethanol consumption binds by $e_{ik_1k_2} = 0.2m + m - B_i$, we need to solve equations (28) together with equation (30) for the unknowns $x_{ik_1k_2}$, $e_{ik_1k_2}$,

$$\frac{1}{Y_e} p_c(TS_{ik_1k_2} - x_{ik_1k_2} - \frac{e_{ik_1k_2}}{Y_e}) + ce - p_e^{d-1}(e_{ik_1k_2}, p_{gk_2}) = 0. \tag{30}$$

(30) says that if the banking constraint binds, we assume that the ethanol production is the same as there is no borrowing and banking limit and only the maximum level of banked RIN stock will not be carried to the next period.

(2) Update Step:

update the coefficients $\hat{c}_{cj_1j_2}$,$\hat{c}_{ej_1j_2}$ that solve the equation system (31), (32):

$$\sum_{j_1=0}^{n_1}\sum_{j_2=0}^{n_2} \hat{c}_{cj_1j_2}\phi_{j_1}(x_i)\phi_{j_2}(B_i) = \sum_{k1=1}^{l_1}\sum_{k2=1}^{l_2} w_{k_1}w_{k_2}p_c(TS_{ik_1k_2} - x_{ik_1k_2} - \frac{e_{ik_1k_2}}{Y_e})\, i = 1, ..., n_1n_2 \tag{31}$$

$$\sum_{j_1=0}^{n_1}\sum_{j_2=0}^{n_2} \hat{c}_{ej_1j_2}\phi_{j_1}(x_i)\phi_{j_2}(B_i) = \sum_{k1=1}^{l_1}\sum_{k2=1}^{l_2} w_{k_1}w_{k_2}p_e^{d-1}(e_{ik_1k_2}, p_{gk_2})\, i = 1, ..., n_1n_2 \tag{32}$$

(3) Convergence Check:

If $\mid \hat{c}_{cjj_2} - c_{cj_1j_2} \mid < \epsilon$ and $\mid \hat{c}_{ej_1j_2} - c_{ej_1j_2} \mid < \epsilon$ for all j_1, j_2 and some convergence tolerance ϵ, set $\hat{c}_{cj_1j_2} = c_{cj_1j_2}$ and $\hat{c}_{ej_1j_2} = c_{ej_1j_2}$; otherwise set $c_{cj_1j_2} = \hat{c}_{cj_1j_2}$ and $c_{ej_1j_2} = \hat{c}_{ej_1j_2}$ for all j_1, j_2 and return to step (1).

Solve nonstationary world

Let T=2019/20. In the changing world before 2019/20, we solve for approximated

[6]Path solver for matlab can be downloaded from http://pages.cs.wisc.edu/~ferris/path.html.

expected price functions in $T-1$ when taking $T's$ expected price forms as given. After solving approximated expected price functions in $T-1$, the coefficients for approximated expected prices can be solved backwards in $T-2$, $T-3$, etc. in the same way.

5 Results

In this section, we simulate distributions of prices of corn, ethanol and RIN under yield and gasoline price uncertainty from 2014/15 to 2019/20 under two scenarios.

In 2014/15, we assume corn yield and acreage are known. We generate 5000 gasoline prices in 2014/15. 5000 sequences of corn yields together with gasoline prices are drawn from 2015/16. Each corn yield and gasoline price are drawn separately from the beta distribution and log normal distribution in the given time period. The nth sequence of the uncertain values or the nth state of world could be written as $((y_{14/15}, p^n_{g14/15}), \ldots, (y^n_{19/20}, p^n_{g19/20}))$. The probability for the happening of nth sequence is 1/5000.

Given the beginning corn stock ($x_{14/15}$), beginning RIN stock ($B_{14/15}$), acreage harvested ($A_{14/15}$) in 2014/15. If we are in the nth state of world in 2014/15, we can solve for storage decision in 2014/15 ($x_{15/16}$), harvest decision in next year ($A_{15/16}$), beginning RIN stocks in the next period ($B_{15/16}$), quantity of ethanol ($e_{14/15}$) and corn feed consumption ($TS_{14/15} - \frac{e_{14/15}}{Y_e} - x_{14/15}$). Thus all prices are obtained in 2014/15. Starting from all known values of 2014/15 and if we are in the nth state of the world in 2015/16, first we need to know the values of all state variables. The beginning corn stock in 2015/16 is $x_{15/16}$ and the beginning RIN stock is $B_{15/16}$. Then we solve for all values interested in 2015/16 when nth state happens and all prices are known for 2015/16. The same method is used for solving the prices in 2016/17. After solving each sequence, we will get distributions of prices in each period.

Table 1 shows the average model solution for the scenario in which EPA lets the ethanol mandate increase to 14.4 billion gallons in 2014 and 15 billion gallons in 2015. There is not a single model solution because the model is solved for a wide range of corn yields and gasoline

prices. Because this model is solved on a marketing year basis, the mandates that are imposed on the model solutions are 14.8 billion gallons for the 2014/15 marketing year, and 15 billion gallons thereafter. To allow these mandates to be met, 2,500 additional stations that sell E85 are installed in the 2014/15 marketing year and another 2,500 additional stations are built in the following marketing year.

The results show that the increased ethanol mandates can be met with the 2,500 additional stations in the first two marketing yeaers through a combination of expanded ethanol consumption and production and a drawdown in the number of banked RINs. The first-year drawdown of banked RINs is about 0.44 billion RINs to meet the 14.8 billion gallon mandate. Thus about 14.36 billion gallons of ethanol are actually consumed. Thereafter, ethanol production and consumption are much more closely aligned, with the average size of the RIN bank staying around zero in the following periods. Average corn prices rise modestly through the projection period. This modest rise hides the actual volatility in the model solutions caused by yield variability. Harvested corn acreage falls from its high mark of 83.8 million acres in 2014, stabilizing at an average level of 82.5 million acres. Average RIN prices are slightly below 55 cents per gallon which implies that ethanol mandates push average ethanol consumption higher than what market demand would dictate in the absence of mandates. This level of RIN prices would likely incentivize additional investment in stations that sell E85 (or E15) which would then results in lower RIN prices.

Average model solutions with reduced mandates and no investment in E85 stations are shown in Table 2. Corn prices and production are modestly lower due to decreased demand for ethanol. Average RIN prices are close to zero which implies that the 13 billion gallon ethanol mandate is largely irrelevant to ethanol production and consumption levels. Because the average price of RINs is so low, the aveage bank of RINs grows and is used to buffer the effects of short corn crops. At the end of the projection period the bank of RINs grows to about 2 billion on average.

The impact of reduced mandates can be measured by comparing the Table 2 results

Table 1: Average Model Solutions with Increased Mandates*

	14/15	15/16	16/17	17/18	18/19	19/20
Ethanol Mandate	14.8	15	15	15	15	15
New E85 Stations	2,500	2500	0	0	0	0
Harvested Acreage	83.80	82.14	82.30	82.47	82.70	82.91
Corn Production	1.40	1.32	1.34	1.36	1.38	1.40
Corn Price	3.86	4.05	4.12	4.18	4.22	4.28
Ending Corn Stocks	1.58	1.53	1.52	1.52	1.53	1.49
Ethanol Demand Price	0.96	1.00	1.02	1.03	1.05	1.06
Ethanol Production	14.36	15.08	15.00	14.97	14.96	14.95
RIN Price	0.5412	0.5436	0.5449	0.5452	0.5452	0.5437
Beginning RIN Stock	1.408	0.969	1.051	1.018	1.003	0.968

*Units are billion gallons for ethanol mandate, ethanol production, and beginning RIN stock; million acres for harvested acreage $ per bushel for corn prices, $ per gallon for ethanol price and RIN price; and billion bushels for ending corn stocks and corn production.

Table 2: Table 2. Average Model Solutions with Reduced Mandates*

	14/15	15/16	16/17	17/18	18/19	19/20
Ethanol Mandate	13.00	13.00	13.00	13.00	13.00	13.00
New E85 Stations	0.00	0.00	0.00	0.00	0.00	0.00
Harvested Acreage	83.80	81.06	81.25	81.43	81.68	81.91
Corn Production	1.40	1.31	1.32	1.34	1.36	1.38
Corn Price	3.61	3.80	3.87	3.92	3.97	4.02
Ending Corn Stocks	1.58	1.52	1.51	1.52	1.52	1.48
Ethanol Demand Price	1.42	1.48	1.49	1.51	1.52	1.53
Ethanol Production	13.20	13.37	13.27	13.25	13.24	13.23
RIN Price	0.0113	0.0063	0.0064	0.0071	0.0069	0.0083
Beginning RIN Stock	1.408	1.603	1.927	2.026	2.061	2.066

*Units are billion gallons for ethanol mandate, ethanol production, and beginning RIN stock; million acres for harvested acreage $ per bushel for corn prices, $ per gallon for ethanol price and RIN price; and billion bushels for ending corn stocks and corn production.

with the Table 1 results. Both the absolute difference in average results and the percent difference are shown in Table 3. Corn prices drop about 6 percent from reduced mandates or about 25 cents per bushel. Corn production drops by about 17 million bushels which is between 1.2 and 1.3 percent. Ethanol production drops by about 11.5 percent from reduced mandates. Corn prices would decrease even more from this drop in demand except that the decrease in corn supply from lower planted acreage boosts average prices a bit.

There are two ways of viewing these results. The rather modest decrease in corn prices from relaxing the mandates could be viewed as evidence that the agricultural crop sector will not be too badly hurt from a reduction in mandates. An alternative view is that a reduction in mandates would not be a panacea for livestock organizations or anti-hunger groups who want to see corn prices decrease by even more than they have in the last six months. The very low RIN prices in Table 2 also suggest that corn prices would not move any lower even if mandates were eliminated, because the mandate is not increasing the production of ethanol. This result hinges on the assumption that oil companies would continue to find it profitable to blend inexpensive ethanol with low-octane gasoline to create 87 regular gasoline. In either case, it is difficult to argue that a change in corn prices provides an over-riding justification for either reducing mandates or letting them grow because the impacts of a reduction are modest.

Before concluding it is useful to consider how a reduction in mandates would affect the distribution of corn prices and RIN prices. One justification for lower mandates is that mandates can exacerbate corn price spikes caused by short crops. Figure 1 shows the distribution of corn prices for the 2017/18 marketing year for the two scenarios considered. The distribution with the increased mandate is shifted to the right, which represents a higher average corn price, and it is slightly flatter, which indicates a bit more price variability. The increase in price variability is not greater because of the role that RIN and corn stocks play in buffering the effects of low corn yields. Corn stocks are drawn down in low yield years as are RIN buffer stocks. Due to the ability to borrow RINs from future years, the RIN stock

Table 3: Table 3. Impact of Reduced Ethanol Mandates*

	14/15	15/16	16/17	17/18	18/19	19/20
Corn Production	0	-0.017415	-0.01711815	-0.01713816	-0.01702584	-0.01689
	0.00%	-1.31%	-1.28%	-1.26%	-1.23%	-1.21%
Corn Price	-0.2557	-0.2545	-0.2573	-0.257	-0.2536	-0.2521
	-6.62%	-6.28%	-6.24%	-6.15%	-6.01%	-5.90%
Ending Corn Stocks	-0.008	-0.009	-0.008	-0.008	-0.008	-0.009
	-0.51%	-0.59%	-0.53%	-0.53%	-0.52%	-0.60%
Ethanol Demand Price	0.4624	0.4712	0.4717	0.4715	0.4726	0.4701
	48.17%	46.93%	46.20%	45.59%	45.22%	44.30%
Ethanol Production	-1.166	-1.714	-1.731	-1.72	-1.72	-1.719
	-8.12%	-11.36%	-11.54%	-11.49%	-11.50%	-11.50%
RIN Price	-0.5299	-0.5373	-0.5385	-0.5381	-0.5383	-0.5354
	-97.91%	-98.84%	-98.83%	-98.70%	-98.73%	-98.47%
Beginning RIN Stock	0	0.634	0.876	1.008	1.058	1.098

*Units are billion gallons for ethanol production and beginning RIN stock; million acres for harvested acreage $ per bushel for corn prices, $ per gallon for ethanol price and RIN price; and billion bushels for ending corn stocks and corn production.

can actually turn negative, further buffering the effects of low corn yields.

Figure 2 shows the two distributions of RIN price solutions in 2017/18. The distribution with reduced mandates shows that 90 percent of the RIN price solutions are less than one cent. This represents a return to the situation that mostly prevailed between 2008 and 2011 when RIN prices were quite low. If mandates are increased and if 5,000 new E85 stations are built, then about 95 percent of RIN price solutions are between 50 and 80 cents.

6 Policy Implications

The price of corn has fallen dramatically in 2013. For example, the average price received by corn farmers in March was $7.13 per bushel. The average price received in October was $4.49 per bushel, a drop of 37 percent. Corn prices have not been this low since October of 2010. Barring another short crop in 2014, corn prices are unlikely to return to recent high levels and could drop further if growing season weather is favorable. In contrast

Figure 1: Figure 1. Distributions of Corn Prices in 2015/16

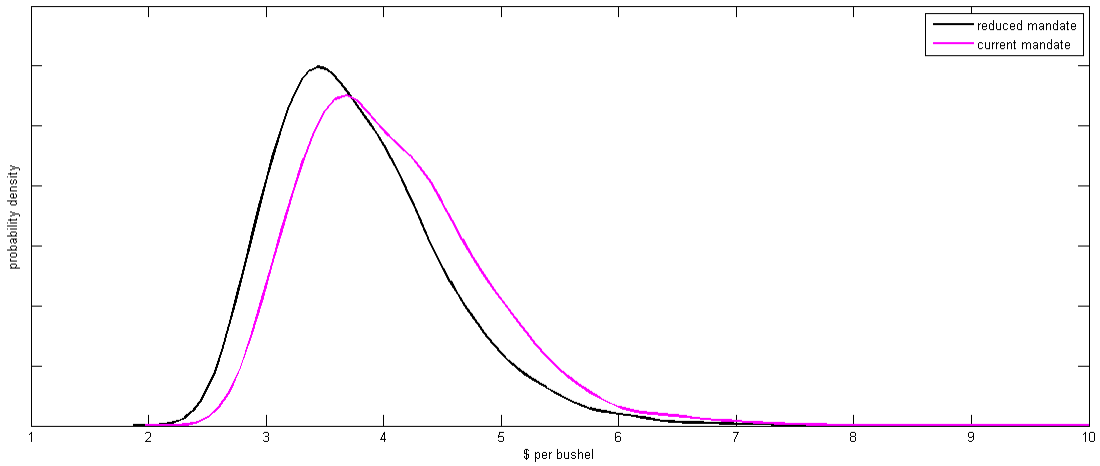
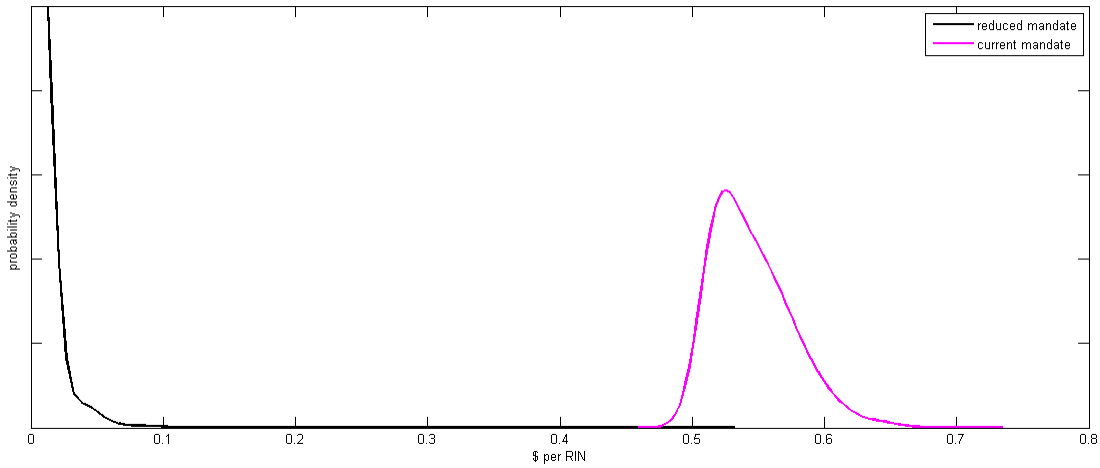


Table 4: Figure 2. Distributions of RIN Prices in 2015/16



to the large swings we have seen in corn prices, the results presented here indicate that EPA's mandate decisions for 2014 and 2015 will impact corn prices by about 8 cents per bushel. The impacts of corn prices for 2015 and 2016 is about 22 cents, or by between 5 and 6 percent. This relatively modest impact suggests that whether ethanol mandates should be reduced to levels that can be easily met with 10 percent blends or increased above those levels should be determined by factors other than the impact on corn prices.

An EPA decision to reduce ethanol mandates in 2014 and 2015 would send a strong signal to car companies to reduce the production of flex vehicles, and to investors to not invest in high-ethanol-blend fueling stations or in next-generation plants that convert cellulosic material to ethanol. It likely also sends a negative signal to investors in biofuel plants that can convert cellulosic material to non-ethanol biofuels, such as synthetic diesel or gasoline. It might not seem that an EPA decision to decrease support for ethanol would imply a decrease in support for these "drop-in" fuels because they can be easily integrated into existing fuel channels. But the cost of constructing plants that can produce drop in fuels is high. High investment costs imply high risk. A reduction in public policy support for ethanol would only increase the perceived risk that in the future EPA would also reduce its support for other biofuels.

Two stated objectives of the RFS are to reduce greenhouse gas emissions and to reduce petroleum imports. Economists are nearly unanimous that the best way to cut emissions is with a carbon tax because the cost of reducing emissions is minimized when a tax is applied equally to all emission sources. Similarly, the most efficient way or reducing oil imports is to tax imports. But politicians rarely agree with economists' prescriptions so second-best policy instruments such as the RFS that only apply to liquid transportation fuels to meet policy objectives are utilized.

RFS mandates stimulate biofuel production which substitutes for petroleum, a large part of which is imported. And almost all the growth in future mandates are for advanced biofuels which lower greenhouse gas emissions much more than conventional biofuels. Thus

the RFS, however inefficiently, will meet its stated objectives.

The question facing EPA and Congress is whether the costs of maintaining support for biofuels through the RFS are too high for the benefits that are obtained. If the costs are too great or if a more efficient policy is available, then this should be communicated as quickly as possible. The sooner that a decision to withdraw support for biofuels is made, the better, as this will allow investment dollars to be redirected to more profitable enterprises. However, if a withdrawal of support for biofuels is not forthcoming, then an EPA decision to set mandates at levels that can be easily met sends exactly the wrong signal to investors because without investment, increased consumption of biofuels will never occur. This policy consideration should be of upmost importance, not the price of corn.

References

[1] Anderson, David, John D. Anderson, and Jason Sawyer. "Impact of the ethanol boom on livestock and dairy industries: What are they going to eat?." Journal of Agricultural and Applied Economics 40.2 (2008): 573-579.

[2] Gouel, C. (2013). "Comparing numerical methods for solving the competitive storage model." Computational Economics, 41(2), 267-295

[3] Judd, K. L. (1998). Numerical methods in economics. MIT press.

[4] Lapan, H., Moschini, G., (2012). "Second-best biofuel policies and the welfare effects of quantity mandates and subsidies." Journal of Environmental Economics and Management 63, 224-241.

[5] Mallory, Irwin, S. , Hayes, D.J. (2012). "How market efficiency and the theory of storage link corn and ethanol markets." Energy Economics, 34(6), 2157-2166.

[6] McPhail, L. M. (2010). "Impacts of renewable fuel regulation and production on agriculture, energy, and welfare." Graduate Theses and Dissertations. Paper 11268. http://lib.dr.iastate.edu/etd/11268.

[7] Miranda, M.J. (1997). "Numerical Strategies for Solving the Nonlinear Rational Expectations Commodity Market Model,Computational Economics." Volume 11, Issue 1-2, 71-87.

[8] Miranda, M. J. and P. L. Fackler. (2002). "Applied Computational Economics and Finance." Cambridge, Mass. : MIT Press.

[9] Paul, A. B. (1970). The pricing of binspace—a contribution to the theory of storage. American Journal of Agricultural Economics, 52(1), 1-12.

[11] Paulson, N.,(2014). "RIN Stock Update." Farm doc Daily, http://farmdocdaily.illinois.edu/2014/04/rin-stock-update-1.html.

[12] Peterson, H. H., Tomek, W. G., (2005). “How much of commodity price behavior can a rational expectations storage model explain?” Agricultural Economics, 33, 289-303.

[13] Pouliot and Babcock (2014).

[14] Roberts, M. J., and W. Schlenker. (2013). "Identifying Supply and Demand Elasticities of Agricultural Commodities: Implications for the US Ethanol Mandate." American Economic Review, 103(6): 2265-95.

[15] Rubin, J. D. (1996). A model of intertemporal emission trading, banking, and borrowing. Journal of Environmental Economics and Management, 31(3), 269-286.

[16] Rui, X., and M. J. Miranda. (1995). “Commodity Storage and Interseasonal Price Dynamics.” Proceedings of the NCR-134 Conference on Applied Commodity Price Analysis, Forecasting, and Market Risk Management. Chicago, IL. [http://www.farmdoc.uiuc.edu/nccc134].

[17] Searchinger, T., Heimlich, R., Houghton, R. A., Dong, F., Elobeid, A., Fabiosa, J.,... & Yu, T. H. (2008). Use of US croplands for biofuels increases greenhouse gases through emissions from land-use change. Science, 319(5867), 1238-1240.

[18] Schennach, S. M. (2000). The economics of pollution permit banking in the context of Title IV of the 1990 Clean Air Act Amendments. Journal of Environmental Economics and Management, 40(3), 189-210.

[19] Thompson, W., S. Meyer, and P. Westhoff. (2009a). “How does Petroleum Price and Corn Yield Volatility Affect Ethanol Markets with and without an Ethanol Use Mandate?” Energy Policy, 37(2).

[20] Thompson, W., S. Meyer, and P. Westhoff. (2009b). “Renewable Identification Number Markets: Draft Baseline Table.” FAPRI-MU Report #07-09.

[21] Thompson, W., S. Meyer, and P. Westhoff. (2011). "What to Conclude About Biofuel Mandates from Evolving Prices for Renewable Identification Numbers?" American J. of Agricultural Economics, 93(2),481-487.

[22] US Department of Agriculture. "USDA Agricultural Projections to 2022." Office of the Chief Economist, World Agricultural Outlook Board. Long-term Projections Report OCE-2013-1.

Appendix

Table 5: Parameter values in 2014/15

parameter	value	source or explanation
ethanol yield	2.8	Monthly Profitability of Ethanol Production by Iowa State University
DDGS yield	17/56	
DDGS price	91% of corn price	Anderson, Anderson and Saweyer(2008)
other ethanol production cost c_e	50 cents	Monthly Profitability of Ethanol Production by Iowa State University
constant storage cost per bushel per year within capacity	36 cents	Peterson and Tomek(2005)
beginning corn stock	0.1181 10 million bushels	May 2014 WASDE Report
beginning RIN stock	0.1408 10 billion gallon	Calculated
non-ethanol demand elasticity	-0.44	Adjemian and Smith (2012)
supply elasticity	0.2	Roberts and Schlenker (2012) Increased a little bit
supply factor	0.62	Chicago board of trade
gasoline price distribution	log normal(0.9185,0.2722)	fit yield data from USDA from 1970 to 2012

Table 6: Parameters in other years

parameters	14/15	15/16	16/17	17/18	18/19	19/20	Source
demand factor(α_1)	3.95	3.45	3.62	3.81	4.07	4.36	USDA
mean yield	165.3	160.94	162.94	164.94	166.94	168.94	trend line value except 14/15
mean gasoline price	2.68	2.6	2.5	2.5	2.5	2.5	RBOB gasoline