Conditional Suspension of the US Ethanol Mandate using Threshold Price inside a Competitive Storage Model

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Abstract

In 2012, EPA turned down request to suspend the US ethanol mandate on the ground that doing so would not result in lower corn prices. Given that ethanol production accounts for more than 40 percent of the US annual corn harvest together with current trend of extreme weather events, it is likely that a similar request will resurface in the future. We therefore use a competitive storage model to investigate how a waiver of the US ethanol mandate, conditional on high corn price, might affect corn prices and consume welfares. It is found that although waiving the mandate when the price was at the level in 2012 would only result in moderate decrease of long run corn prices, the price volatility reductions are much larger. In addition, if the US corn yield in 2013 is as low as it was in 2012, suspending 20 percent of the mandate in 2012 will result in a price drop of 18 percent in 2013, higher than EPA's estimate of less than 1 percent. Associated with lower corn price is a gain of 7.69 billion dollars in US consumer welfares.

1 Introduction

In 2012, amid the record high corn price caused by the worst drought in the US in at least 25 years, a temporary suspension of the Renewable Fuel Standard (RFS) program was under consideration. Proponents of the RFS suspension argued that because ethanol production under RFS takes up 40 percent of the country corn harvest, waiving RFS will provide the market with some relief from high grain prices brought on by the drought which will help the livestock industry and food consumers, especially those in the developing countries. The US Environmental Protection Agency (EPA), the agency in charge of implementing RFS, however, concluded that RFS is not causing severe economic harm and denied the waiver request.

Although EPA did not consider the immediate circumstances severe enough to suspend the mandate, EPAs consideration of it suggests that under different more severe circumstances the standard might be waived in the future. Under guidelines of the RFS, Congress stipulated that a waiver of the mandate could be granted if it "would severely harm the economy or environment of a State, a region, or the United States." If prices rose and grain inventories declined further, and perhaps if there was less carry-over of RFS credits from earlier years, social benefits of a temporary suspension might quell hunger and possibly civil unrest in some parts of the world. If market speculators anticipate that such a conditional suspension is possible, then those expectations could feed back and affect storage and prices even in absence of storage.

In light of these observations, we use a competitive storage model to investigate how a suspension of RFS, conditional on a threshold corn price, might affect corn storage and pricing. Specifically, we consider a policy scenario in which EPA would have a safety valve: a critical corn price, anticipated in advance, above which they would suspend the mandate. It is important to examine this policy because little research has been done on the impact of waiving RFS on corn price, especially given that the market knows about the temporary nature of the RFS waiver. Such a policy, which may already be implicit in the RFS, may go some ways toward reducing unintended consequences of the RFS on world food prices and hunger. Further, the model may facilitate research into the best level to set the threshold.

Temporary suspension of RFS results in a corn consumption demand that has a flat spot. If price falls below the threshold, consumption demand equals to corn demand with RFS. If the price level is at or above the threshold price, consumption demand is lower and equals demand without RFS. Therefore, at the threshold price, consumption demand has a flat spot with length equals to the size of ethanol production being temporarily suspended.

We analyse and compare the impact of both expected and unexpected RFS suspensions on corn price and storage using modified versions of the competitive storage model taking the kinked consumption demand curve into account. When the mandate waiver is anticipated, because the shape of the demand curve is known, we use stochastic dynamic programming to solve the storage model using the kinked consumption demand curve. If the mandate waiver is not anticipated, because the market knows about the temporary nature of the consumption demand shift, storage demand will not shift completely back to the environment with lower consumption demand. We therefore solve the storage model in two steps. First, we solve the infinite-horizon storage model, given the consumption demand with RFS. Using solutions of the model with RFS, we then use backward induction to solve the storage model when consumption demand is temporary shifted back, replacing the higher consumption demand function with the kinked consumption demand curve.

The nature of the RFS waiver greatly affect corn storage. If RFS is suspended unexpectedly, more is stored every time consumption is cut back temporarily. If the shift in ethanol production is anticipated, because of the known lower demand which limit price increase, less is stored to maintain the storage arbitrage relation. An expected RFS suspension, therefore, will always accumulate less inventory which results in higher price volatility relative to an unexpected suspension of the mandate.

The US corn yield distribution is constructed using corn yield data between 1950 and 2012 from USDA. Corn demand and supply elasticity, taken from Roberts and Schlenker (2010), are -0.31 and 0.14, respectively. Other parameters of the storage model are calibrated so that simulated price data using a 10,000 random yield draw has the mean value equals to observed corn price of 2012. In addition, the standard deviation of the simulated price also matches closely with observed price standard deviation between 2005 and 2012, the period after RFS has been enacted.

Because there is demand for ethanol even in the absence of RFS, the policy only accounts for a fraction of the total ethanol being produced every year. In our baseline analysis, we assume in the event that RFS is waived, demand shifts back by the size of the amount of the Renewable Identification Numbers (RINs) available in 2012.[1] The threshold corn price is set at 7.2 dollars/bushel, the price level observed in 2012.

We simulated 10,000 time paths of price and quantity data for the three storage models: without RFS suspension, with expected RFS suspension, and with unexpected RFS suspension. Data from the later two are then compared with that of the first one. For the baseline analysis, we found that suspending RFS expected and unexpectedly lower mean corn price in the long run by 5 and 4 percent respectively. In addition, price volatility decreases by 46 and 63 percent, in the same order.

Keeping the threshold price fixed at 7.2 dollars/bushel and varying the size of the demand shift, we found that the more demand shifts in, the lower mean price and price volatility are relative to the case of no RFS suspension. Yet, the differences in mean prices are relatively small. If half of the ethanol mandated for 2012 is waived, an expected RFS suspension results in only a mean price reduction of 8.3 percent in the long run. The same number of an unexpected RFS suspension is even smaller at 5.5 percent. However, suspending the mandate expectedly and unexpectedly yields 68 and 70 percent lower price volatility, consequentially.

Holding the demand shift fixed and allowing the threshold price to vary, we found that the higher the threshold price, the lower price differences waiving RFS makes. If the threshold price is set 40 percent higher than observed 2012 price at 10 dollars/bushel, waiving the RFS makes no significant change for mean price in the long run. Price volatility drops by 20 and 21 percent for expected and unexpected ethanol suspension, in that order.

We next calculate welfare gains from a RFS waiver. Across scenarios, suspending RFS yields consumer surplus gains in the range of 0.52 to 2.94 billion dollars. Associated with the changes in consumer surplus are the reductions of ethanol production, declining from 24 to 296 million gallons. For the baseline analysis, on average, consumer welfare increases by 1.53 billion dollars while ethanol production lowers by 116 million gallons.

[1]Under the US ethanol mandate, ethanol producers or importers are required to generate RINs in proportion to the amount of ethanol they produce or import. Gasoline producers are then will need to acquire these RINs every time they blend ethanol into gasoline. Finally, gasoline producers will submit RINs to EPA as a proof of compliance with the mandate. RINs can be traded and bankable. As of 2012, it was estimated that gasoline producers have an excess 2.4 to 2.6 billion gallons of RINs that they can use in future years (Paulson and Meyer (2012)).

Assuming that corn yield in 2013 equals to those in each of the years: 2012, 2011, and 2010, corn price in 2013 is simulated using different levels of demand shifts. We found that if corn yield in 2013 equals to the level in 2012, corn price with full RFS in 2013 will be at 8.77 dollars/bushel, a 22 percent increase relative to the previous year. Under the scenario that all the available RINs are used, corn price will be 18 percent lower. Compared to previous studies, Tyner et al. (2012) found that the price reduction for this scenario is only 7 percent. Babcock (2012)'s results, however, suggested that price decrease by 20 percent for the same specifications. Our result in this case, thus, lies in between these only known studies on the topic. Nevertheless, if RFS was waived and demand shifted in by 40 percent of the 2012 mandate, our analysis suggests a price reduction of 20 percent, lower than estimates from the two previous studies.

If the 2013 corn yield turns out to be at the same levels as in 2011 and 2010, corn price will be at 7.11 dollars/bushel and 6.95 dollars/bushel, respectively. Because of better yield outcomes, RFS suspension will only lower corn prices by moderate amounts. However, even for the smallest demand shift and the best yield outcome considered in our analysis, suspending RFS yields a 2.2 percent corn price reduction, higher than EPA's estimate of less than 1 percent.

The gains in consumer surplus associated with the price reductions, resulting from RFS suspension in 2012, range from 0.94 to 11.34 billion dollars. For the case of a 20 percent mandate reduction, assuming that corn yield in 2013 equals to the observed 2012 level, granting a RFS waiver results in a consumer welfare gain of 7.69 billion dollars.

2 US Ethanol Mandate Suspension

Under the Energy Independence Act of 2007, gasoline producers are required to blend 15 billion gallons of corn ethanol into the US gasoline supply by 2015. Because ethanol production takes up to 40 percent of the country total corn crop, the US ethanol mandate is considered by many as one of the main driving factors behind the recent increase in food prices (Roberts and Schlenker (2010), Hausman et al. (2012), Childs and Kiawu (2009), Piesse and Thirtle (2009), Mitchell (2008)).

In view of the adverse impacts of ethanol production on corn price, in 2012, amid the record drought in the US in at least twenty five years, governors of several states as well as many firms and associations in the agricultural sector petitioned EPA to temporarily halt the ethanol mandate.[2] In response, on August 30, 2012, EPA provided notice of the waiver

[2]Detailed information about the drought as well as its impacts on the US farms and food sectors can be found at: `www.ers.usda.gov/topics/in-the-news/us-drought-2012-farm-and-food-impacts`. Ac-

requests and invited public comment on issues relevant to making a decision on the matter. By October 11, 2012, nearly 30,000 comments were submitted.[3]

In November of 2012, the EPA, however, did not grant the request because they could not find evidence that the ethanol mandate "would severely harm the economy or environment of a State, a region, or the United States." Out of 500 scenarios that they considered, 89 % of the time RFS would make no harm at all. Even for the 11% of scenarios where waiving RFS would have an impact on the corn and other markets, the average impact on corn prices is only 7 cents a bushel, less than an 1 percent change in corn prices.

Contradict EPA's results, the only two quantitative studies on the impact of RFS suspension on corn prices have different answers. Babcock (2012) found that temporarily suspending RFS could lower corn price by 20 to 26 percent. Tyner et al. (2012) suggested that a partial waiver of the US ethanol mandate could drop corn prices by anywhere from 7 to 23 percent depending on the size of the waiver itself.

As pointed out by Abu-Sneneh et al. (2012), different results on impacts of waiving RFS rooted in different views about the shape of the ethanol demand curves without RFS.[4] Abu-Sneneh et al. (2012) argued that, accounting for energy content of ethanol and gasoline, the 2012 corn price shifted the ethanol supply to the more elastic part of the ethanol demand curve (Figure 1). Because of that, without the ethanol mandate, less ethanol will be demanded hence corn price will go down. EPA, on the other hand, found the equilibrium quantity of ethanol to be at the inelastic part of the ethanol demand curve and very close to the amount of ethanol mandated for 2013. In other words, even in the absence of the mandate, the US market still demands the amount of ethanol equals to that under RFS. Therefore, suspending RFS will not help relieve corn price. While it is uncertain at the moment which side of the debate on waiving RFS is right, their analyses both suggested that EPA should suspend the ethanol mandate if corn price was high enough to shift the ethanol supply curve to the elastic part of the ethanol demand curve.

While the RFS waiver request has been denied by EPA this time, given the current increasing trend of weather temperature as well as the fact that a significant portion of the US corn production will continued to be withdrawn for ethanol production in the next 10 years, it is likely that another waiver request will resurface in the future. We therefore investigate the impacts of suspending RFS on the corn market, given that corn price gets

cessed April 28, 2013.

[3]For detailed information on requests for a waiver of the US ethanol mandate, please refer to: `www.epa.gov/otaq/fuels/renewablefuels/notices.htm`. Accessed April 28, 2013.

[4]In the US, federal regulation mandates a cap on the volume of ethanol permitted in a gallon of gasoline at 10 percent. Therefore, the ethanol demand curve is very inelastic at the quantity equals to 10 percent of total gas consumption. The demand curve gets more elastic as gasoline contains less than 10 percent of ethanol.

past a threshold level using a competitive storage model.

3 The Model

Storage has been shown to play an integral role on the behaviour of commodity market equilibria (Gustafson (1958), Scheinkman and Schechtman (1983), Williams and Wright (1991), Deaton and Laroque (1992, 1995, 1996), and Cafiero et al. (2011)). Storers, motivated by inter-temporal arbitrage, act to stabilize consumption, production and prices by accumulating inventories in times of abundance and depleting them in times of shortage. Storage allows transitory shocks to demand or supply to be buffered by inventory adjustments, thereby reducing price volatility relative to what it would be without storage. The introduction of storage, therefore, would change the way prices evolve over time compared with the dynamic of prices for non-storable commodities. Recognizing this fact mandates that storage should be endogenously modelled inside the traditional supply and demand system.

We first introduce the storage model similar to the one found in Cafiero et al. (2011), replacing their *i.i.d.* supply assumption with an elastic supply curve. Because the implicit condition for a waiver of the mandate is that price should be high, we next modify the competitive storage model to account for the policy scenario in which EPA would have a safety valve: a critical corn price, above which they would suspend the mandate. We consider two cases: (1) the market knows about the threshold price in advance and (2) EPA waive the ethanol mandate unexpectedly as prices get past the threshold price.

3.1 The storage model

There are three agents in the market: storer, producer, and consumer. They are all price takers and risk neutral. The agents are rational and form their expectation about future prices and profits based on all information currently available.

The storer maximize his expected future profit π from carrying inventories one period ahead into the future:

$$E_t(\pi^x_{t+1}) = \left[\frac{1-d}{1+r}E_t(p_{t+1}) - p_t\right] x_t - kx_t, \quad (1)$$

where r is the social discount rate, d is the decay rate of products stored for one period, and

k is the constant marginal storage cost of storing one unit of inventory x_t.[5] [6] $E_t(p_{t+1})$ is the expected future price in period $t+1$ formed at time t and p_t is the price at time t.

Similarly, in anticipation of expected future price, a forward looking producer will make planting decision in period t, l_t, to maximize his profit π subject to production cost:

$$E_t(\pi^l_{t+1}) = \frac{E_t(p_{t+1}l_t y_{t+1})}{1+r} - \Phi(l_t), \tag{2}$$

with $\Phi(l_t)$ as the cost of planting land l_t and y_{t+1} is the realized yield in period $t+1$. Assuming constant elasticity of demand, the consumption demand takes the form:

$$c_t = \alpha_d p_t^{\beta_d}, \tag{3}$$

where β_d is the demand elasticity and α_d being the constant term.

Taking the first order conditions of Equation 1 and Equation 2 with respect to storage and land respectively, allow for the non-negativity of storage, yield:

$$l_t = \alpha_s E_t(p_{t+1}y_{t+1})^{\beta_s} \tag{4}$$

and

$$\left\{ \begin{array}{c} p_t + k = \frac{1-d}{1+r}E_t(p_{t+1}), \text{ when } x_t > 0; \\ p_t + k \geq \frac{1-d}{1+r}E_t(p_{t+1}), \text{ when } x_t = 0 \end{array} \right\}, \tag{5}$$

where β_s is the supply elasticity and α_s is the constant term.[7]

Finally, for any time period t, the amount of commodity currently available, amount on hand- z_t, at the beginning of the period equals either unspoiled inventories carried over from the last period plus the new harvest or consumption this period plus storage this period:

$$\begin{aligned} z_t &= (1-d)x_{t-1} + l_{t-1}y_t. \\ &= x_t + c_t, \end{aligned} \tag{6}$$

Equation 5 says that, in the presence of storage (i.e. $x > 0$), the discounted expected

[5]As shown later in Table 1, for the purpose of parameter calibration, we allow storage cost to be negative. This suggests the existence of *convenience yields*—an apparent ancillary benefit to storers for holding inventories. In earlier literature, convenience yields have been used to explain holding of inventories during times of *contango*, which are times current spot prices exceed futures prices. Positive inventories during contango might alternatively be explained by risk premiums, option values and/or transactions costs associated with delivery of commodities from storage locations to futures market locations.

[6]Drawing on past studies, Cafiero et al. (2011) argues that marginal storage costs may in fact be constant over time.

[7]Production cost takes the form: $\Phi(l_t) = \frac{a_s(\frac{l}{a_s})^{1/b_s+1}}{(1+r)(1/b_s+1)}$.

future price next period cannot exceed the spot price this period by more than the marginal storage cost. Otherwise, storers can arbitrage by storing more goods in the current period, reducing current consumption and increasing current price. When current price increases, the gap between current price and discounted expected future price will fall until it equals marginal storage cost. Similarly, the discounted expected future price cannot be smaller than the current price plus storage cost. If the current price plus storage cost is greater than discounted expected future price, storers will store less goods, increasing current consumption which will drive down the gap between current price and discounted expected future price until they equal.

A key feature of the model is the non-negativity of inventories. Zero storage implies $c_t = z_t$, all of the amount on hand in the current period is consumed. In this case price is given by the inverse demand function, $p_t = F(z_t)$. This will be optimal if anticipated future prices are too low relative to the present to cover the marginal cost of storage. Equation 5 can also be re-written as:

$$p_t = max\left\{\beta E_t(p_{t+1}) - k, F(z_t)\right\}, \tag{7}$$

where $\frac{1-d}{1+r}$ is replaced by β for simplification.

Equations (5) and (7) indicate the market demand function will not be smooth. When z_t is sufficiently low, all of the amount on hand z_t will be consumed in the current period and p_t will be high. However, as z_t increases and p_t declines, some of z_t will be stored. At the point where the first unit of commodity is stored, the market demand function has a non-smooth "kink." In other words, there exists a cut-off price below which there will be positive storage and market demand is the sum of consumption demand and storage demand.

Solving the storage model is complicated due to the non-negativity of storage which creates the aforementioned "kink" on the market demand and because there is feedback between storage and prices. The amount of commodities stored this period depends on current commodities availability and on expected prices in future periods. Expected future prices and commodities availability depend, in turn, on storage in future periods and the last period. Because of the dependence of current storage on future and past storage, solving for equilibrium requires stochastic dynamic programming. In addition, it is necessary to use numerical methods because even with dynamic programming, only in a few cases can the equilibrium be solved analytically. We follow the numerical method initiated by Gustafson (1958) and later adapted by Deaton and Laroque (1992, 1995, 1996), and Cafiero et al. (2011). This approach approximates the control variable price p as a function of the state variable amount on hand z.

The price as a function of available supply z_t can be written as $p_t = p(z_t)$. Equation 7 is now:

$$p_t(z_t) = max\left\{\beta E_t(p_{t+1}(z_{t+1})) - k, F(z_t)\right\},$$
$$p_t(z_t) = max\left\{\beta E_t p_{t+1}(l_t y_{t+1} + (1-d)x_t) - k, F(z_t)\right\},$$

where

$$x_t = z_t - c_t$$
$$x_t = z_t - F^{-1}(p(z_t)). \tag{8}$$

Scheinkman and Schechtman (1983) proved that there exist a unique rational expectation equilibrium.

$$p_t(z_t) = p(z_t)$$

The expected future price in this model requires integration over all values of the random harvest y_t. This integration process is not easy given the unknown nonlinear form of the price function $p_t(z_t)$. In order to further simplify the model, the standard normal harvest process y_t is discretized into N points so that Equation 7 is expressed as:

$$p(z_t) = max\left\{\beta \sum_{n=1}^{N} p(l_t y_{t+1}^n + (1-d)(z_t - F^{-1}(p(z_t))) \times Pr(y_{t+1}^n) - k, F(z_t)\right\}, \tag{9}$$

where $Pr(y_{t+1}^n)$ is the probability for each of the possible harvest y^n and $\sum_{n=1}^{N} Pr(y_{t+1}^n) = 1$.[8]

The land equation, Equation 4, is rewritten as:

$$l_t = \alpha_s \left(\sum_{n=1}^{N} \left[p_{t+1}(y_{t+1}^n l_t + (1-d)x_t) y_{t+1}^n\right] \times Pr(y_{t+1}^n)\right)^{\beta_s}. \tag{10}$$

Knowing parameters of demand, supply, and storage arbitrage equations, solving for the price as a function of amount on hand as in Equation 9 follow an iterative process as follow:

1. Select a set of grid points for the amount on hand z. The amount on hand are bounded by some upper and lower bound values $[\underline{z},\ \overline{z}]$ that should be set to include all possible values of amount on hand.

[8] The discretization process is done using the *CompEcon Toolbox for Matlab* by Miranda and Fackler (2002).

2. Guess the initial parameters of the function $p_t(z_t)$ using linear spline.

3. Use the initial parameters to find price p on the left hand side of Equation 9.

4. Compute storage x_t using Equation 8.

5. Using x_t, find l_t using Equation 10

6. With x_t and l_t found, compute price p_t using the right hand side of Equation 9.

7. If the price function replicates itself, stop the iteration process. Otherwise, get the parameters from this step and use it to approximate price on the left hand side, as in step 3. Repeat until prices from step 3 and 6 equal each other.

3.2 The storage model with threshold price

Waving the ethanol mandate temporarily results in a corn consumption demand that has a flat spot. If price falls below the threshold, consumption demand equals to corn demand with RFS. If the price level is at or above the threshold price, consumption demand is lower and equals demand without RFS. Therefore, at the threshold price, consumption demand has a flat spot with length equals to the size of ethanol production being temporarily suspended. Impacts of expected and unexpected ethanol mandate suspensions on corn price and consumer welfares, conditional on a threshold corn price, are analyzed using a modified version of the competitive storage model which incorporates this strange, kinked demand curve.

If the RFS suspension is anticipated, the storage model will be solved using the same standard approach outlined earlier. However, instead of a normal downward sloping consumption demand, the model uses a consumption demand curve with a flat spot on it. If the RFS suspension comes unexpectedly, because the market knows about the temporary nature of the demand shift, the storage demand function will not move completely to the lower demand environment. We first solve for the infinite-horizon storage model assuming full implementation of RFS. The solution characterizes a terminal condition over the range of feasible prices, storage, consumption, and land use in the market without RFS suspension. We then solve backward for a year using the kinked consumption demand curve when RFS is temporarily suspended.

The formal description of the solution is as follows.

Recall $F(z_t)$ as the inverse of the downward sloping consumption demand curve. Denote the inverse of the kinked consumption demand curve as $G(z_t)$. The consumption demand curve takes the form:

$$G^{-1}(p_t) = \begin{cases} F_l^{-1}(p_t) & \text{if } p \geq \bar{p} \\ F_h^{-1}(p_t) & \text{otherwise,} \end{cases} \tag{11}$$

where $\bar{p}$ is the threshold price. $F_l^{-1}(p_t)$ and $F_h^{-1}(p_t)$ are consumption demands with and without ethanol mandate suspension respectively. In addition, $F_h^{-1}(p_t) - F_l^{-1}(p_t) = \Delta_d$ for all p_t, with Δ_d is the size of the demand shift. When RFS suspension is anticipated, the equilibrium price function is found by solving the following two equations using the same iterative process described earlier:

$$p(z_t) = max\left\{\beta\sum_{n=1}^{N} p(l_t y_{t+1}^n + (1-d)(z_t - G^{-1}(p(z_t))) \times Pr(y_{t+1}^n) - k, G(z_t)\right\}, \tag{12}$$

$$l_t = \alpha_s\left(\sum_{n=1}^{N}\left[p_{t+1}(y_{t+1}^n l_t + (1-d)x_t)y_{t+1}^n\right] \times Pr(y_{t+1}^n)\right)^{\beta_s}. \tag{13}$$

When the ethanol mandate is suspended temporarily and unexpectedly, it does not shift the total market demand back to the original no-RFS curve. Only consumption demand shifts back. Storage demand will take into account the fact that suspension is temporary. Thus, the new total market demand will be in between the two demands with and without RFS.

Denote l and h as the low (with RFS suspension) and high (without RFS suspension) demand environments, respectively. The unique equilibrium price function with RFS, $p_h(z_h)$, is found by solving Equation 12 and Equation 13 where consumption demand takes the normal downward sloping form of $F(z_h)$ in place of $G(z_t)$. The total market demand price function when RFS is unexpectedly and temporarily halted can be found by solving:

$$p_l(z_l) = max\left\{\beta\sum_{n=1}^{N} p_h(y_l^n l_l + (1-d)(z_l - G^{-1}(p(z_l))) \times Pr(y_l^n) - k, G(z_l)\right\}, \tag{14}$$

$$l_l = \alpha_s\left(\sum_{n=1}^{N}\left[p_h(y_l^n l_l + (1-d)(z_l - G^{-1}(p(z_l)))y_l^n\right] \times Pr(y_l^n)\right)^{\beta_s}. \tag{15}$$

Solution for $p_l(z_l)$ is found using the following iterative procedure:

1. Pick starting values for land.

2. Solve for $p_l(z_l)$ using Equation 14 and land starting values.

3. Solve for inventory: $x_l = z_l - G^{-1}(p(z_l))$.

4. Use x_l in Equation 15 to find l_l
5. If land value replicates itself, stop and use it to solve for $p_l(z_l)$ as in Equation 14. Otherwise, keep iterating steps 2-5.

Using the three price equilibrium functions $p_t(z_t)$, $p_l(z_l)$, and $p_h(z_h)$, we can then simulate data using the same yield distribution (the only random component of the models) to find the impacts on price and price volatility resulting from either expected or unexpected RFS suspension.

Because of the constant elasticity form of demand, consumer surplus equals infinity. Instead of calculating the surplus, we focus on the change in consumer surplus resulting from a change of price when the mandate is waived. In addition, as consumption demand in the analysis is explicitly the sum of food demand and ethanol demand, we assume that the ethanol demand portion of the aggregate demand is perfectly inelastic and calculate the food consumption demand as:

$$D^{-1}(p_t) = F^{-1}(p_t) - \Delta_e, \tag{16}$$

where $D^{-1}(p_t)$ is the food consumption demand and Δ_e is the size of the ethanol mandated for 2012. The change in consumer surplus is calculated using:

$$CSDIFF = \int_{p_0}^{p_s} D^{-1}(p_t)dp, \tag{17}$$

where p_0 and p_s are the prices with and without a RFS waiver, respectively.

4 Data and Parameter Calibrations

US corn yield and price data are publicly available from the US Department of Agriculture website.[9] Because collected data has trend while data generated by the storage model is stationary, a quadratic trend is removed for the purpose of parameter calibration.[10] The upper panel of Figure 2 shows US annual corn yield from 1950-2012. As can be seen, there is an upward trend of corn productivity, increasing from 38 bushels/acre in 1950 to 165 bushels/acre in 2009 before dropping down to 123.4 bushels/acre in 2012. After removing the quadratic time trend, it is clearly show that US corn yield in 2012 was one of the lowest

[9] www.nass.usda.gov/Quick_Stats/

[10] We regress log values of yield and price data on a quadratic time trend and obtain fitted and residual values. We then convert these values back to levels and multiply the proportional residual by the trend value in 2012

in the last 60 years. Not surprisingly, the significant yield drops are either in the drought years of 1983, 1988, and 2012 or during the 1993 floods.

The lower panel of Figure 2 depicts the annual price that US farmers received in the last 60 years. In general, price has trending down, decreasing from 14 dollars/bushel in 1950 to 2.4 dollars/bushel in 2005. After 2005, however, the downward trend of corn price reversed until reaching 7.2 dollars in 2012, an unprecedented increase of three folds in just 7 years. Some possible explanations for the spike of corn price are the introduction of the US ethanol mandate in 2005, weather anomalies in the US as well as other major food producers and exporters, high oil prices, and demand growth from emerging economies (particularly China and India).

Table 1 summarizes parameters used in our baseline analysis. We use -0.31 and 0.14 as demand and supply elasticities for corn respectively, following the results found in Roberts and Schlenker (2010). Decay rate is set at 0.01 and interest rate equals 0.02. The values for amount on hand range from 4 billion bushels to 20 billion bushels.[11] Mean and SD of corn yield, after removing a quadratic time trend from US corn yield between 1950 and 2012, equals 171 bushels and 16.15 bushels, respectively.

The constant terms of demand and supply and storage cost are calibrated so that using a generated 10,000 time period of crop yield with mean and SD specified above, the mean and CV of simulated price equals 7.2 dollars/bushel and 0.14, appropriately. While 7.2 dollars/bushel is the corn price in 2012, 0.14 is the CV of detrended price between 2005 and 2012, the period after RFS was enacted.[12]

As the ethanol mandate was requested to be waived last year, we set the threshold price, the price above which demand will be suspended, to be equal to the corn price in 2012 at 7.2 dollars/bushel. Also, as noted by Paulson and Meyer (2012), it is estimated that 2.4-2.6 billion gallons of RINs were currently available in 2012. Using a conversion rate of 2.8, this translates into roughly 0.85 billion bushels of corn.[13] We use 0.85 billion bushels as the size of the baseline demand shift. To put this number in perspective, 0.85 billion bushels of corn equals 18 percent of the ethanol mandated in 2012.

[11]Because of the flat spot on the consumption demand curve which makes demand very non-linear near the threshold price, the majority of the amount on hand grid points are arranged to be where consumption demand is flat to assure model convergence as well as speeding up computing time. Out of 110 points of amount on hand ranging from 4 to 20 considered in this paper, 70 of them lie in the flat spot of the consumption demand curve.

[12]Note that because of the non-linearity of the storage demand function, we need to vary 3 parameters, constant terms of demand and supply and storage cost, to match the two moments of observed price.

[13]2.8 gallons of ethanol can be produced using 1 bushel of corn.

5 Results

5.1 Storage model solutions and baseline analysis

Figure 3 shows solutions of different storage models considered in the paper. As described earlier, the consumption demand function has a flat spot equals to the size of the demand shift at the threshold price of 7.2 dollars/bushel. When there is no suspension in the model, the total market demand is similar to an ordinary market demand function with a "kink" happens at the stock-out price. When the RFS suspension is expected, the market demand lies to the farthest left because both consumption demand and stock demand are shifted to the environment with less ethanol production. For an unexpected RFS suspension, because the market knows about the temporary nature of the demand shift, the storage demand function does not move completely to the lower demand environment, only the consumption demand function does. Because of this, the market demand with an unexpected demand shift is higher than the market demand with an expected RFS waiver. The flat spot on the market demand functions indicates that, when prices get to the threshold price, there is a trade-off between consumption and storage. Because of the shift in consumption, storage will increase by the same amount of the demand shift which equals to 0.85 billion bushels as shown in this figure.

Next, we draw 11,000 random corn yield observations assuming $y \sim \mathcal{N}(147,\ 16.15^2)$ with 147 and 16.15 are mean and standard deviation of the detrended yield values between 1950 an 2012. Assuming baseline threshold price and demand shift, we simulated three hypothetical price and storage time-series for three scenarios: no RFS suspension, expected RFS suspension, and unexpected RFS suspension. We use a starting value with no storage so that in period one, the amount on hand equal to the harvest. Given the amount on hand, we subsequently find price, consumption, production, land, and inventories in the first period using the appropriate market demand functions. Then, with inventories from the first period and yield in the second period, we can find all the other variables in the second period, and continue this way until getting to the final period. In order to avoid bias associated with the selection of starting value, the first 1000 observations are discarded. Summary of the remaining 10,000 time series are given in Figure 4.

It is shown on Figure 4 that on average, suspending RFS only lower mean prices by small amounts. If the mandate is waived unexpectedly, mean price will be lowered by 4 percent compared with the case of no RFS suspension. In a similar magnitude, an expected waiver of the ethanol mandate results in a 5 percent drop of mean corn price relative to when there is no change in ethanol production.

One noteworthy feature of Figure 4 is that while storage decreases by 30 percent when the ethanol mandate wavier is expected, it increases by 18 percent if the mandate is suspended unexpectedly. Storage is higher for the case of unexpected RFS suspension because there is an accumulation of storage at the threshold price due to the drop of consumption. If the RFS waiver is expected, however, as the lower demand curve that limit price increase is known in advance, less is stored to maintain the arbitrage relation. Storage, therefore, is lower on average.

Because the case of expected ethanol suspension has lower storage which acts as buffers to weather shocks, there will be more price swings which result in higher price volatility relative to the case of unexpected RFS suspension. On average, price standard deviations for the cases of expected and unexpected RFS suspensions decrease 46 and 63 percent compared to when there is no RFS waiver, respectively.

5.2 Different threshold prices and demand shifts

It is of more interest to find answers to questions such as: keeping the threshold price at 7.2 dollars/bushel, how much consumption need to be suspended in order for the long run price to be lowered by 5 percent? And if the consumption demand can only shift in 10 percent, how high should we set the threshold price so that the average long run price will be reduced by 5 percent? We, therefore, consider two additional scenarios. The first one is to keep the threshold price fixed at 7.2 dollars/bushel and allow the size of the demand shift to vary. The second one is to have different threshold prices, keeping the demand shift at 0.85 billion bushels.[14]

Figure 5 shows simulated corn price and storage data, given that the threshold price is held fixed at 7.2 dollars/bushel. The size of the demand shift varies from 8 to more than 50 percent of the ethanol mandated for 2012. In general, suspending the RFS results in lower mean prices and price standard deviations. In addition, the higher the size of the demand shift, the bigger drop in price and price standard deviation regardless of the nature of the mandate waiver.

Unexpectedly suspend RFS always results in the lowest price volatility because of the

[14]For some special cases, such as when the threshold price is set too close to the stock-out price of the model without RFS, the model with expected ethanol suspension does not converge even after organizing the grid of amount on hand to include the two end points of the flat section of the consumption demand curve. Instead of one equilibrium price function, the model results in two slightly different price functions with the biggest difference in prices being smaller than 0.1. Because of the insignificant difference between these two price functions, instead of diving into the non-converge problem which likely involves tedious numerical technique precision improvements, we take the average of the two to arrive at the final solution of the storage model. Also note that because the special non-converge cases happen when either the threshold price is set too low or the demand shift is too small, like suspending the mandate at the corn price of 7.2 dollar/bushel with only a 1 percent demand shift, none of these scenarios are considered for analysis in this section.

build-up of inventories as explained earlier. It also creates the biggest price drops when the demand shift is smaller than 15 percent of the 2012 mandate. However, if the demand shift is greater than 15 percent of the mandate, an expected mandate waiver will yield lower mean prices. This relationship between the mean prices of expected and unexpected ethanol suspension can be explained looking at the changes in storage.

For an expected RFS suspension, holding threshold price constant and varying the demand shifts, there are two components that affects storage. On the one hand, storers/speculators know that demand may be reduced, limiting potential price increase, and thus less is stored to maintain the arbitrage condition. On the other hand, storage increase every time price gets past the threshold price due to a suspension of demand. Therefore, as can be seen on Figure 5, storage can be either increasing or decreasing as the size of the demand shift gets bigger. If the RFS waiver is not anticipated, however, storage will always increase as a result of consumption being suspended. Therefore, for this case, storage increases as the demand shift gets bigger.

Figure 6 shows simulated corn price and storage data with different threshold prices, given that corn consumption only shift back 0.85 billion bushels or 18 percent of the ethanol mandated for 2012. In general, the higher the threshold price, the smaller the price differences between suspending and not suspending RFS. If the threshold price is set to be at 10 dollar/bushel, suspending RFS reduces mean price by only 1.3 percent in the long run.

It can also be seen on Figure 6 that, as the threshold price is set higher, storage increases for the case of expected RFS waiver but decreases for the case of unexpected demand shift. Keeping everything else constant, a higher threshold price results in a lower probability of demand being suspended. Because storage increases every time consumption demand is unexpectedly suspended, a higher threshold price means that less inventory is accumulated in this case. If the RFS wavier is anticipated, however, because the known demand shift that limits price increase happens less often, more will be stored.

5.3 Welfare calculations

Table 2 shows the changes in mean consumer surpluses (CS) and ethanol production under various scenarios of threshold prices and demand shifts.[15] In general, waiving RFS results in gains in CS and lower ethanol productions. For the baseline scenario, on average, CS increases by 1.53 billion dollars while ethanol production lowers by 116 million gallons.

For the same threshold price, the higher the demand shift, the bigger the gain in CS. If the demand shift equals 50 percent of the ethanol mandated for 2012, given that the shift

[15] Consumer here refers to non-ethanol consumption. It equals total corn consumption minus corn devoted to ethanol production mandated for 2012 (4.7 billion corn bushels).

is anticipated, CS increases by 2.92 billion dollars and ethanol production decreases by 296 million gallons.

For the same level of demand shift, the higher the threshold price, the lower the change in CS. For the threshold price of 8.7 dollar/bushel, in the long run, the average change in CS when demand shifts in unexpectedly is only 0.52 billion dollar. Ethanol production, therefore, only decreases by a moderate amount of 23.98 million gallons.

5.4 Simulated 2013 prices

EPA's decision to deny the waiver request in 2012, of course, did not base on the long run analysis of price. EPA's interest, as well as those of the public, was to see how much price could be lowered in 2013 if the mandate was temporarily suspended for a year. We therefore simulated 2013 corn price by first picking the level of amount on hand, in the storage model with RFS, that yield the price observed in 2012 at 7.2 dollars/bushel. We then use the three consumption demand functions: no RFS suspension, expected RFS suspension, and unexpected RFS suspension to calculate the respective consumptions and storages in 2012. Assuming a 2013 yield value, we proceed to compute the new amount on hand in 2013. With these 2013 amount on hands, using the appropriate market demand functions, we simulate different scenario of prices in 2013.

Table 3 shows price in 2013 if the mandate was suspended in 2012 at the price of 7.2 dollar/bushel. Yield in 2013 is assumed to be equal to those of previous years: 2012, 2011, and 2010. The demand shift takes values from 10 to 50 percent of the ethanol mandated in 2012. Generally, expected RFS suspension yields higher price reduction relative to unexpected RFS suspension. Yet, the difference is small, ranging from 2 to 5 percent points. Across all scenarios, price decrease from 2.3 to 22 percent when RFS is suspended unexpectedly.

Assuming that the crop yield in 2013 will be at the same level as in 2012, the model predicts a price of 8.77 dollar/bushel when there is no ethanol suspension. Reducing ethanol production unexpectedly by 20 percent of the amount mandated in 2012 results in a price drop of 18 percent, from 8.77 to 7.19 dollars/bushel. Compared with previous studies, Tyner et al. (2012), under a "stronger drought" scenario, found corn prices only lower by 7 percent for roughly the same level of demand shift. In contrast, Babcock (2012) found the price drop to be much higher at 20 percent. However, it should be noted that Babcock (2012) results was conducted later in 2012 relative to Tyner et al. (2012), using the latest drought information and other assumptions about gasoline price and crop yields. The former, therefore, is better suited for the purpose of comparison with this study. Increasing the size of the demand shift to 40 percent in this study results in a price reduction of 20 percent, lower than estimates from the two previous studies.[16]

If the 2013 corn yield turns out to be at the same levels as in 2011 and 2010, corn price will be at 7.11 dollars/bushel and 6.95 dollars/bushel, respectively. Because of better yield outcomes, suspending the mandate lowers corn price by moderate amounts. Even for a demand shift equals to 50 percent of the 2012 mandate, assuming 2013 yield equals to 2011 yield, waving RFS unexpectedly in 2012 results in only a 10 percent price reduction.

The gains in CS associated with the price reductions are shown in Table 4. Across scenarios, US consumer gains from 0 to 11.3 billion dollars as a result of suspending RFS. For the case of a 20 percent mandate reduction, assuming that corn yield in 2013 equals to the observed 2012 level, granting RFS waiver results in a CS gain of 7.69 billion dollars.

6 Conclusion

In 2012, amid the record high corn price caused by the worst drought in the US in at least 25 years, a temporary suspension of the RFS program was under consideration. The EPA, the agency in charge of implementing RFS, however, denied the waiver request because they could not find evidence that RFS is causing economic harms. Although the RFS waiver request was not granted, given current increasing trend of extreme weather events together with the fact that 40 percent of the US corn production are used in ethanol production, it is likely that another request might soon resurface.

In light of this observation, we use a competitive storage model to investigate how suspending RFS both expectedly and unexpectedly, conditional on a threshold corn price, might affect corn storage and pricing as well as consumer welfares. Parameters of the storage model are selected so that the mean price and price volatility in equilibrium match closely with observed 2012 price and price standard deviation between 2005 and 2012.

Assuming a threshold price of 7.2 dollars/bushel and a demand shift the size of available RINs in 2012, we found that suspending RFS expected and unexpectedly lower mean corn price in the long run by 5 and 4 percent respectively. In addition, price volatility decreases by 46 and 63 percent, in the same order. Associated with the reduction of price when RFS suspension is not anticipated, consumer welfare increases by 1.53 billion dollars while ethanol production lowers by 116 million gallons.

We found that for the same threshold price, suspending RFS results in lower price and price volatility in the long run as the size of the demand shift increases. In addition, the for same demand shift, the higher the threshold price, the smaller the difference in price and

[16] Babcock (2012) found the price drop to be from 20 to 26 percent. Tyner et al. (2012), for roughly the same level of demands shift of 40 percent, suggested that corn price will be 23 percent lower.

price volatility relative to when there is no RFS suspension.

Assuming that the corn yield in 2013 will be the same as it was in 2012, we found that suspending RFS unexpectedly in 2012 yields a 18 percent price reduction in 2013, given that all of RINs available in 2012 are used. Together with the lower price is a 7.69 billion dollar gain in consumer welfare. If the 2013 corn yield turns out to be higher, the impacts of waiving RFS on corn prices and consumer welfares will be smaller.

This paper, however, is not without caveats. First, all results are sensitive to parameters of the storage model, especially demand and supply elasticities. If demand is less elastic, suspending RFS will yield higher price difference, thus bigger gains in consumer welfares. Likewise, a more responsive supply will limit price reductions thus temper changes in consumer surplus. However, as the true values of demand and supply elasticities are unknown, using the most updated estimates on corn demand and supply elasticities is the best one could do.

Second, this paper assumes the size of the demand shift, a critical component in evaluating the impact of RFS suspension. By looking closely at the ethanol demand curve which comprises of ethanol price, gasoline price, available RINs, and ethanol production capacity, future studies can pinpoint how much demand shifts in and be able to figure out the impact of suspending RFS more directly.

Lastly, results in this paper focus squarely on the US domestic market. Being the world's largest producer and exporter of corn, waving RFS can go a long way in reducing world food prices and hunger. The gains in consumer surplus estimated in this paper, therefore, are at the lower end of the benefits from a RFS waiver.

Table 1: Model parameters

Parameters	**Values**
Demand elasticity	-0.31
Supply elasticity	0.14
Lowest amount on hand (billion bushels)	4
Higher amount on hand (billion bushels)	20
Decay rate	0.01
Interest rate	0.02
Storage cost ($/bushel)	-0.06
Constant term of demand	18.21
Constant term of supply	0.02
Mean yield (bushels)	171.94
SD yield (bushels)	16.15
Mean price ($/bushel)	7.2
CV price	0.14
Threshold price ($/bushel)	7.2
Demand shift (billion bushels)	0.85

Table 2: Average changes in CS and ethanol production (10,000 time period)

Percent mandate waived	Expected suspension		Unexpected suspension	
	Δ CS (billion dollars)	Δ Ethanol production (million gallons)	Δ CS (billion dollars)	Δ Ethanol production (million gallons)
	Threshold price is set at $7.2/bushel			
10	1.05	-91.45	1.19	-89.51
20	1.95	-181.91	1.62	-123.39
30	2.42	-234.53	1.78	-142.07
40	2.71	-270.22	1.89	-157.57
50	2.92	-296.35	1.99	-173.05
Threshold price	**Demand shift equals 0.85 billion bushels**			
6.7	2.70	-259.97	2.84	-282.80
7.2	1.72	-156.32	1.53	-116.59
7.7	1.13	-100.75	0.91	-47.35
8.2	0.77	-68.34	0.67	-29.73
8.7	0.56	-48.29	0.52	-23.98

Note: Table shows the average changes of consumer surplus and ethanol production over different scenarios of ethanol suspension compared with no ethanol suspension. The first half of the table assumes a threshold price of 7.2 dollars/bushel with different sizes of the demand shift, expressed in term of the ethanol mandate in 2012. A demand shift equals to the amount of RINs available in 2012 is assumed for the second half of the table. Threshold price varies from 6.7 dollars/bushel to 8.7 dollars/bushel.

Table 3: Simulated 2013 corn prices under different assumptions of corn yield in 2013 (dollars/bushel)

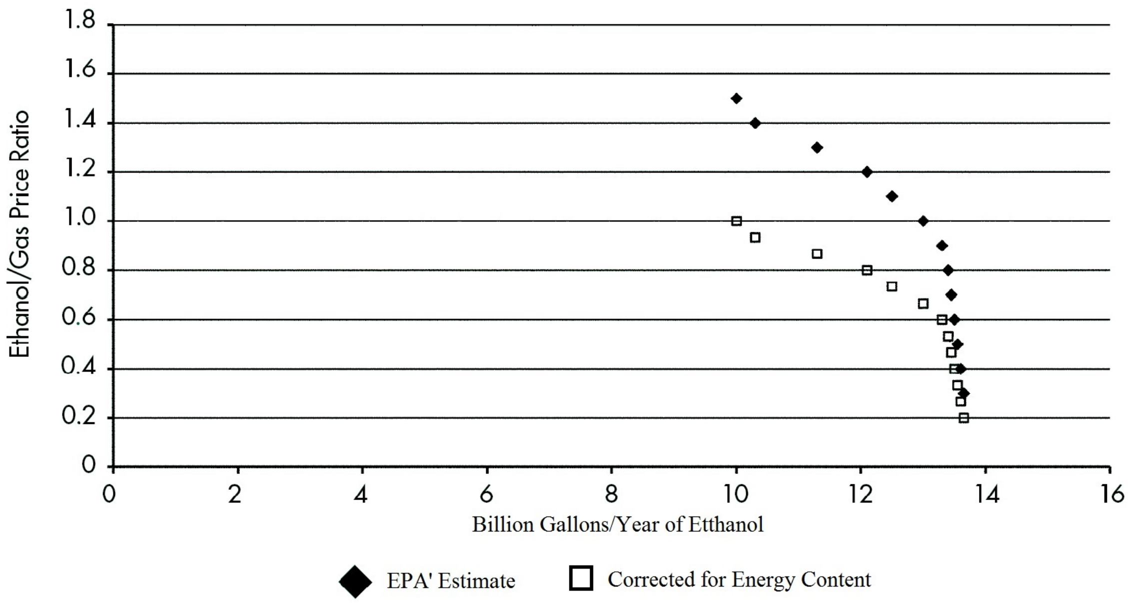
Percent mandate	**2012 yield**			**2011 yield**			**2010 yield**		
waived	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)
0	8.77			7.11			6.95		
10		7.21	7.51		6.7	6.93		6.6	6.79
		(17.79)	(14.37)		(5.77)	(2.53)		(5.04)	(2.30)
20		7.03	7.19		6.5	6.78		6.41	6.66
		(19.84)	(18.02)		(8.58)	(4.64)		(7.77)	(4.17)
30		6.75	7.17		6.37	6.64		6.3	6.54
		(23.03)	(18.24)		(10.41)	(6.61)		(9.35)	(5.90)
40		6.61	7.02		6.28	6.53		6.21	6.44
		(24.63)	(19.95)		(11.67)	(8.16)		(10.65)	(7.34)
50		6.5	6.85		6.2	6.42		6.13	6.35
		(25.88)	(21.89)		(12.80)	(9.70)		(11.80)	(8.63)

Note: Table shows simulated corn prices in 2013 assuming that corn yield in 2013 will be the same as 2012, 2011, and 2010. Scenarios (1)-(3): 1- No mandate waiver, 2- expected waiver, 3- unexpected waiver. The threshold price is set at 7.2 dollars/bushel. The demand shifts are shown in term of percentage of ethanol mandated in 2012. The numbers in parenthesis are the percent drops of price compared with the case when there is no RFS suspension.

Table 4: Simulated consumer surplus gains under different assumptions of corn yield in 2013 (billion dollars)

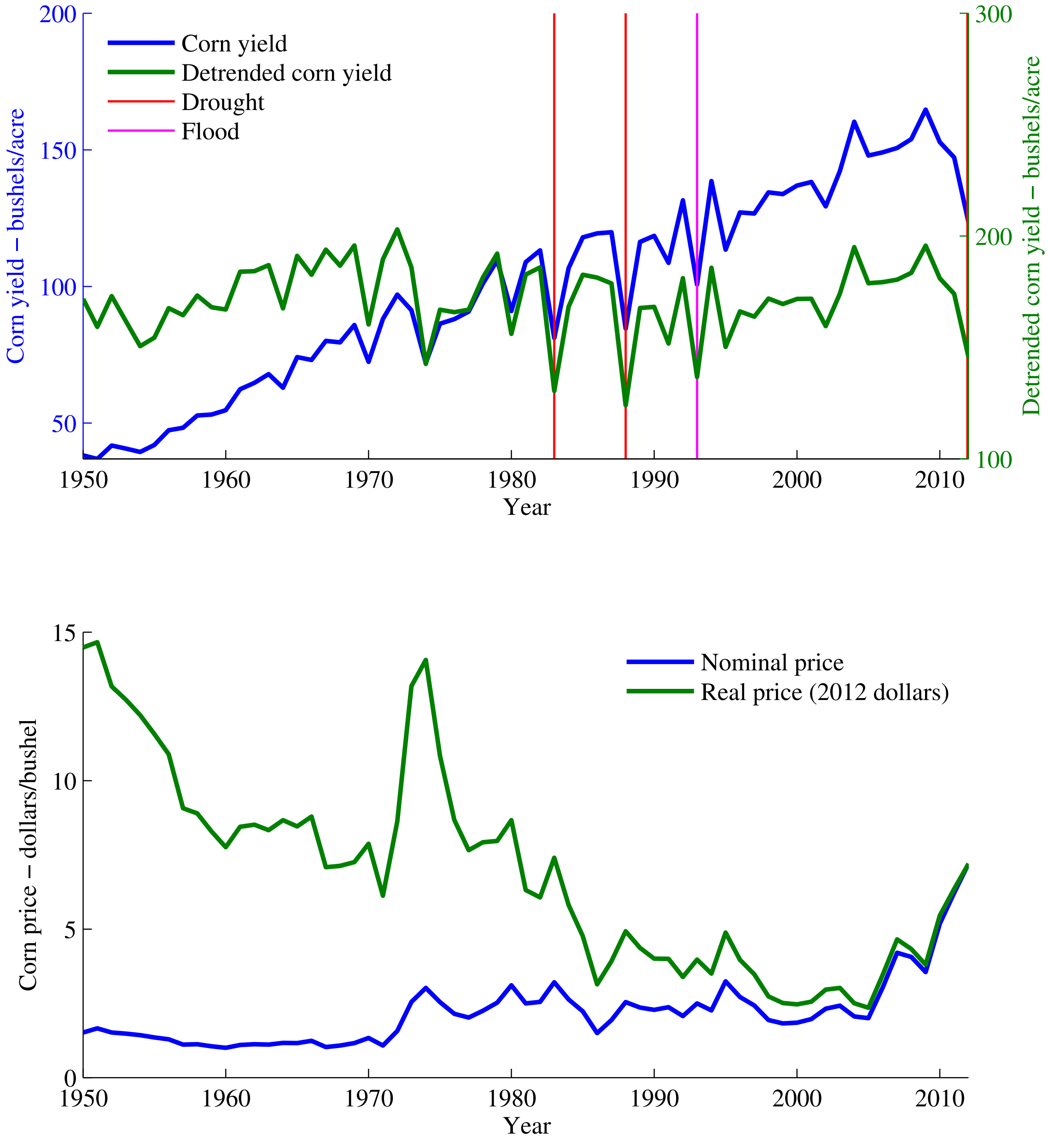
Percent	**2012 yield**		**2011 yield**		**2010 yield**	
mandate waived	Expected suspension	Unexpected suspension	Expected suspension	Unexpected suspension	Expected suspension	Unexpected suspension
10	7.59	6.06	2.16	0.94	1.88	0.81
20	8.53	7.69	3.29	1.76	2.90	1.54
30	9.99	7.81	3.96	2.49	3.52	2.17
40	10.75	8.57	4.50	3.12	4.02	2.74
50	11.34	9.48	4.95	3.68	4.44	3.25

Note: Table shows simulated consumer surplus gains in 2013 assuming that corn yield in 2013 will be the same as 2012, 2011, and 2010. The threshold price is set at 7.2 dollars/bushel. The demand shifts are shown in term of percentage of ethanol mandated in 2012.



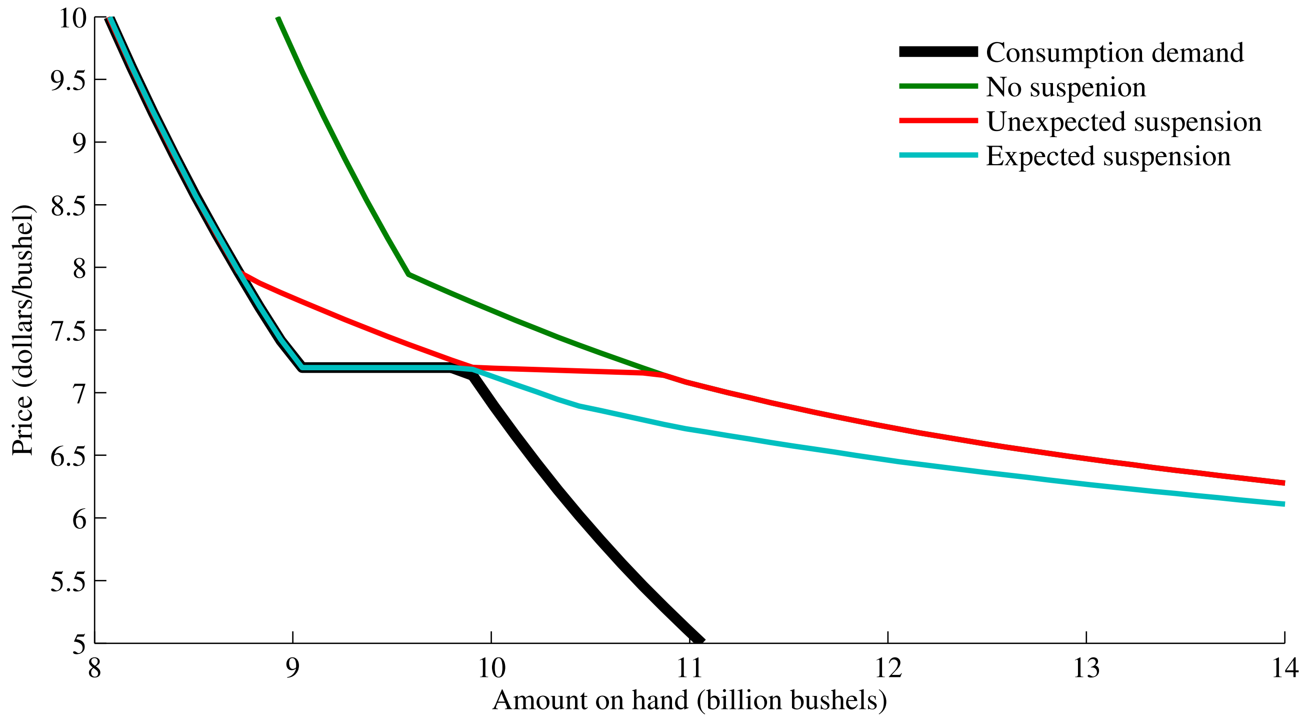
Source: Reproduce from Abu-Sneneh et al. (2012).

Figure 1: Estimated ethanol demand curve without RFS for 2012 and 2013



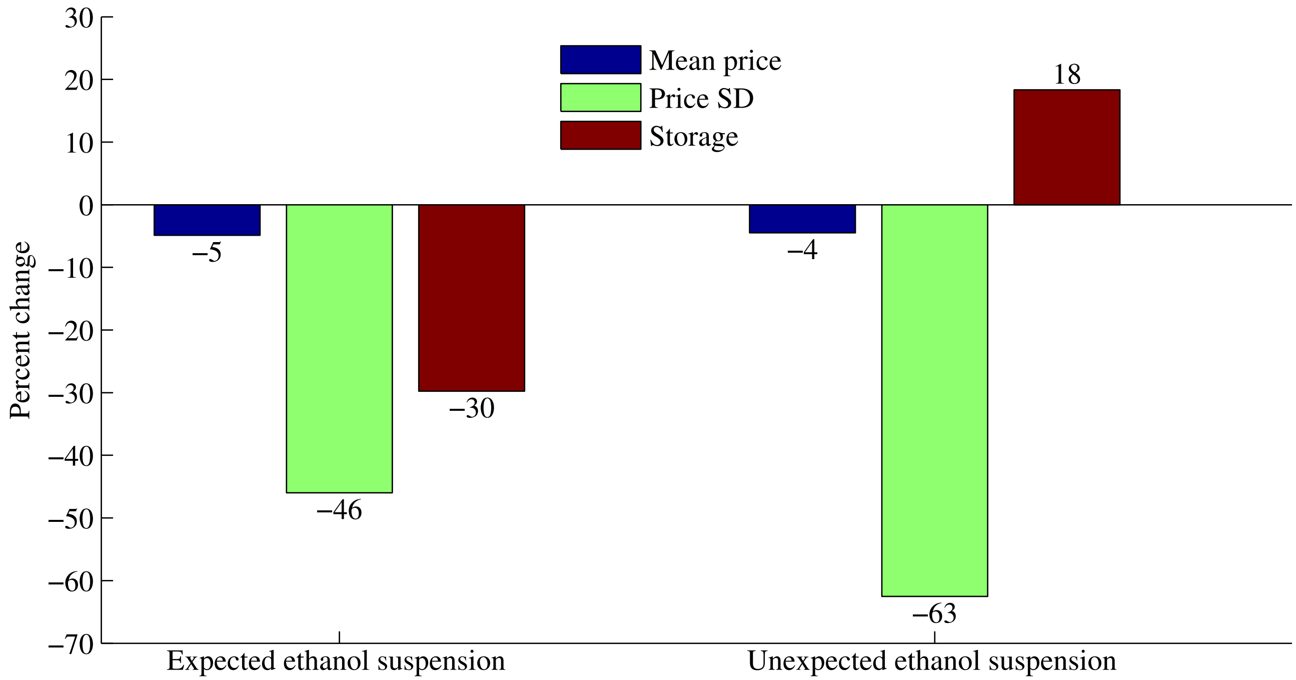
Source: USDA - National Agricultural Statistic Service.

Figure 2: Corn data on price and yield



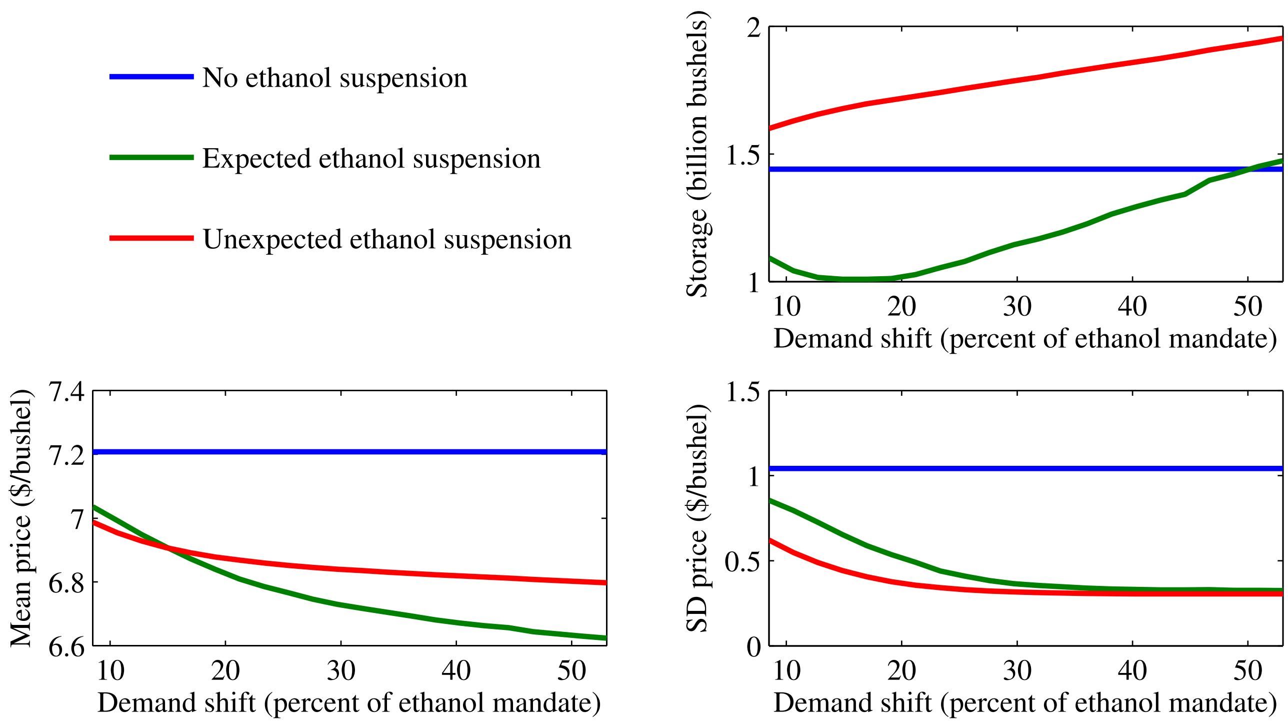
Note: Models' parameters are specified in Table 1

Figure 3: Solutions of the storage models



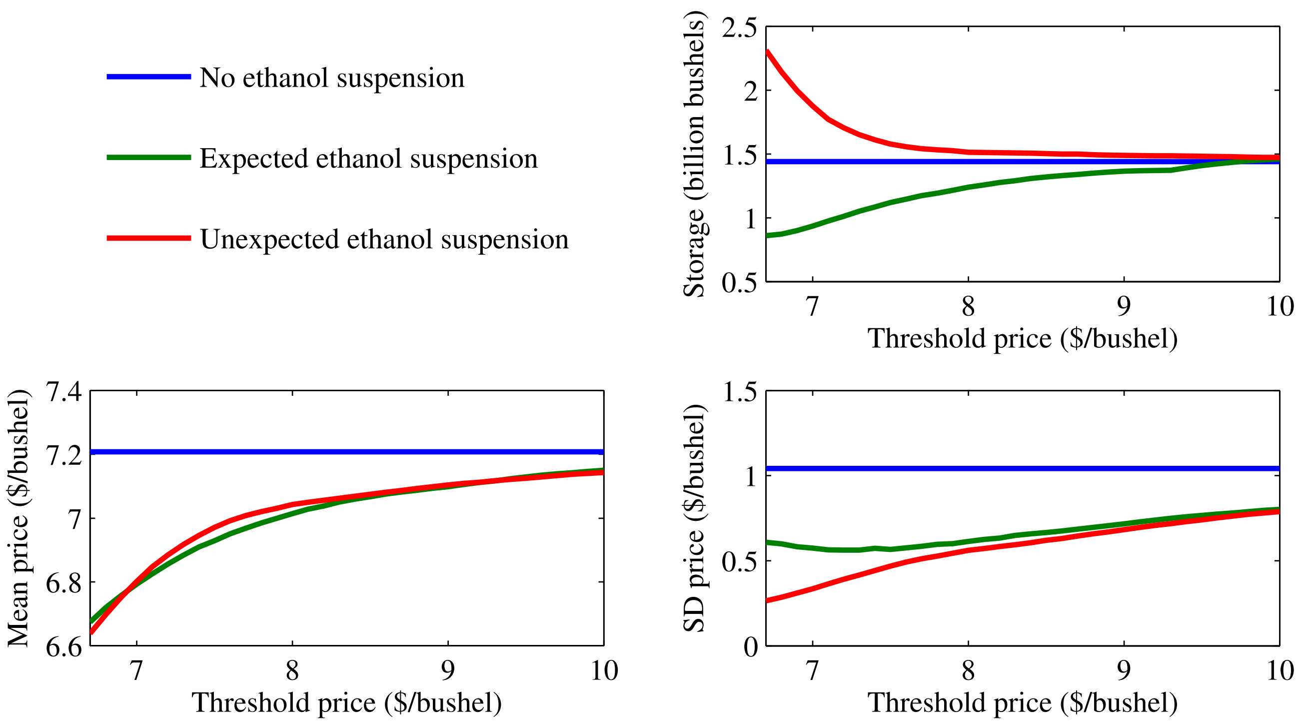
Note: Threshold price is set to be 7.2 dollars/bushel and the demand shift is assumed to be 0.85 billion bushels.

Figure 4: Impacts of ethanol suspension on food prices and storage (10,000 time period)



Note: Threshold price is set to be 7.2 dollars/bushel. The demand shift is shown as percentage of the ethanol production mandated in 2012.

Figure 5: Impacts of ethanol suspension over different sizes of the demand shift (10,000 time period)



Note: Demand shift is held constant at 0.85 billion bushels.

Figure 6: Impacts of ethanol suspension over different threshold prices (10,000 time period)

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