NCCC-134
APPLIED COMMODITY PRICE ANALYSIS, FORECASTING AND MARKET RISK MANAGEMENT

RIN Risks: Using Supply and Demand Behavior to Assess Risk in the Markets for Renewable Identification Numbers used for Renewable Fuel Standard Compliance

by
Dustin J. Donahue, Seth Meyer,
and Wyatt Thompson

Suggested citation format:

Donahue, D. J., Seth Meyer, and Wyatt Thompson. 2010. "RIN Risks: Using Supply and Demand Behavior to Assess Risk in the Markets for Renewable Identification Numbers used for Renewable Fuel Standard Compliance." Proceedings of the NCCC-134 Conference on Applied Commodity Price Analysis, Forecasting, and Market Risk Management. St. Louis, MO. [http://www.farmdoc.illinois.edu/nccc134].

RIN Risks: Using Supply and Demand Behavior to Assess Risk in the Markets for Renewable Identification Numbers used for Renewable Fuel Standard Compliance

Dustin J. Donahue,

Seth Meyer,

and

Wyatt Thompson[1]

Paper presented at the NCCC-134 Conference on Applied Commodity Price Analysis, Forecasting, and Market Risk Management
St. Louis, Missouri, April 19-20, 2010

[1] Dustin J. Donahue is a graduate student at the University of Missouri and a National Needs Fellow (Agricultural and Food Research Initiative, US Department of Agriculture grant 2008-38420-18747); Seth Meyer and Wyatt Thompson are on the faculty at the University of Missouri and members of the Food and Agricultural Policy Research Institute (FAPRI-MU). This research is based on work funded in part by (1) the Environmental Protection Agency (subcontract agreement 412-45-07 of USDA Agreement 58-0111-6-006); (2) Economic Research Service, USDA, (Cooperative Agreement 58-3000-8-0125); and (3) the US Department of Energy (Grant DE-FG02-07ER64504). We thank Pat Westhoff for reviewing a draft of this manuscript. Views expressed here and all errors are the authors' own.

RIN Risks: Using Supply and Demand Behavior to Assess Risk in the Markets for Renewable Identification Numbers used for Renewable Fuel Standard Compliance

Congress has mandated that more biofuels be used over the next decade. To ensure compliance with the mandate, RINs are used to track biofuels that fuel blenders mix into motor fuels for domestic consumption. RINs may be traded, and the prices of RINs are affected by the ability of blenders and biofuel producers to comply with the mandate. There are four components to the mandate, one of which relates specifically to cellulosic biofuels, and the EPA has the authority to waive any or all components of the mandate.

The purpose of this paper is to gain insight into the interactions between cellulosic biofuel technology and the mandate. To achieve this, the prices of RINs are simulated through the use of an economic model under scenarios varying both levels of technology and the enforcement or waiver of the cellulosic component. If the non-cellulosic components of the mandate are not waived, RIN markets are found to contain the effects that might otherwise be transmitted to crops markets. Higher levels of cellulosic biofuel technology are found to increase compliance costs in the presence of a mandate waiver but lower compliance costs if the mandate is not waived.

Keywords: RINs, biofuel, mandate, cellulosic, switchgrass, corn stover, EPA waiver, energy policy

Introduction

Biofuels, while by no means a new idea, have only recently come to the forefront of U.S. energy policy. Biofuels are derived from the fermentation of plants or plant by-products (in the case of ethanol) or by extrusion of the naturally occurring oils within the plants (in the case of soy-based biodiesel). Corn has been used as the crop of choice for serving U.S. ethanol needs for at least several decades. However, ethanol use has increased in its capacity as an octane booster in gasoline and, beyond that, to substituting directly for gasoline. Ethanol refiners' demand for corn has grown, and competition between the different uses (food, cattle feed, and fuel) has helped cause the price of corn to increase (Abbott, Hurt, and Tyner, 2009). The current practice of using traditional agricultural commodities for biofuel production also creates a new avenue for volatility in energy prices to affect agricultural commodity prices (Thompson, Meyer, and Westhoff, 2009). To weaken the ties between these markets, alternative feedstocks have been sought to provide the U.S. with a dedicated energy crop. Several sources have been explored, corn stover and switchgrass among them. However, the information available concerning large-scale production of these alternative crops, such as price and yield, is limited. In addition, there is uncertainty in how changes in technology will reduce the costs associated with producing ethanol from these different sources. These uncertainties make forecasting available feedstocks difficult. However, a mandate is already in place requiring the creation and blending of certain amounts of biofuel over the course of the next decade.

Under the Energy Independence and Security Act of 2007, the use of at least 36 billion gallons (b.g.) of biofuel by 2022 has been mandated, of which no more than 15 b.g. can come from corn-based ethanol, with the remainder comprised of advanced biofuels (PL 110–140, sec. 202). Advanced biofuels are likely to include sugar-based ethanol from Brazil, but are scheduled to include a growing proportion of cellulosic biofuels and at least 1 b.g. of bio-based diesel (*ibid*). This use mandate is imposed on fuel blenders who buy input fuels and mix them for resale to retail outlets.

Renewable Identification Numbers (RINs), implemented by and reported to the Environmental Protection Agency (EPA), will be used to ensure this mandate is met. RINs are 38-digit codes that are created when a gallon of fuel is produced or imported for domestic use, contain information about the fuel producer, and act as proof that the fuel produced satisfies the congressional mandate. There are four classifications of RINs, each with its own binding component of the mandate. However, the classifications are nested, causing complex interactions between the classes (Figure 1). Because of this nesting of the components, there are essentially four separate mandates that blenders must meet. The “conventional” RIN is associated with the broadest mandate for overall biofuel use. Fuels that meet this mandate may be any type of biofuel, including corn starch (or conventional) ethanol. The next level of RIN is the “advanced” category. Biofuels that qualify as advanced may not come from corn starch based ethanol. Implicitly, the difference between the amount of biofuel required as advanced and the overall mandate may be supplied by conventional ethanol, listed as Item C in Figure 1. Within the advanced biofuel category, there are two sub-mandates that create narrower classifications of RINs: biomass-based diesel (“biodiesel”) and cellulosic and agricultural waste based biofuel (“cellulosic biofuel”). Cellulosic ethanol comes from non-starch sources such as switchgrass (*Panicum virgatum L.*), corn stover (the stalks remaining after corn is harvested for grain), and other sources such as wood chips. The part of the advanced mandate in excess of these two sub-mandates can be met by “other advanced” biofuels, such as sugar cane ethanol purchased from Brazil.

The possibility arises that, based on technology or prices, fuel of a particular type may be produced in excess of the mandate in a given year. Blenders obligated to meet the mandate would have extra RINs, giving them three options in such an instance: (1) the RINs may be “demoted” to satisfy a broader mandate in the current year; (2) the RINs may be stored for the current year and later used to satisfy up to 20% of the following year’s mandate; or (3) the RINs could be stored for the current year and then allowed to expire unused. For example, if enough was produced in a given year, cellulosic ethanol could be used to satisfy its own mandate with sufficient excess that it also displaced much of the other advanced biofuels in meeting the advanced mandate. Theoretically, a surge of cellulosic ethanol production could displace all other ethanol types that meet the overall mandate. Similarly, extra advanced RINs can be used instead of conventional RINs to meet the overall mandate.

These one-way relationships have implications on the prices of RINs. The mandate is assigned to a blender based on the firm’s market share, and each blender is responsible for fulfilling all parts of the mandate. RINs can be traded between blenders, enabling compliance for blenders who do not use enough of all types of biofuel; this creates a market for mandates. The RIN prices will demonstrate whether or not mandates are binding, and how binding they are. If a mandate becomes more difficult to meet, the RIN price rises and, with it, the costs of compliance. However, the EPA may waive mandates. The legislation gives specific rules that EPA must follow if the cellulosic biofuel mandate is waived instead of rising from zero in 2009 – which was approximately the amount of commercial production in that year – to 16 b.g. in 2022 (over

10% of current US motor fuel use by volume), and consequently depends on rapid technological innovation in feedstock delivery and processing. Because of this, the questions we address are how cellulosic ethanol technology and mandate interact, and what are the broader consequences for agriculture and in terms of compliance costs?

The lack of information mentioned prior makes answering this question difficult. As such, testing different scenarios of assumed values for technological change can provide a range of possible outcomes. This would grant insight into how different factors affect RIN prices and broader agricultural markets, allowing for better informed energy policy design.

Literature Review

One of the factors which will certainly affect the price of a RIN is the yields of the respective feedstocks. Because corn has been produced in large amounts historically, the data is available on how much stover per acre can be obtained, based on the corn grain yield. Brechbill and Tyner (2008) cite Lang's (2002) equation which converts from corn yield in bushels per acre to tons of stover per acre. However, this study uses a 1-to-1 ratio of corn harvested to stover produced. Pordesimo et al. (2004) note that a 0.8-to-1 ratio may be more realistic; that is, 0.8 tons of stover harvested per one ton of corn harvested. For the purposes of their paper, Brechbill and Tyner assumed 4.25 ton/ac (tons per acre) of stover harvest. Other works by Quick (2003); Glassner et al. (1998); Atchison and Hettenhaus (2003); and Sokhansanji and Turnhollow (2002) have assumed values between 3.6 and 5 tons per acre of stover. Also, producers may not harvest all available stover from the field, preferring to leave it as a soil-enriching agent. The exact value of stover per acre harvested is uncertain and will vary based on exogenous conditions such as weather, soil type, and location.

Switchgrass yields assumed in prior literature have likewise covered a broad range of values. Tiffany et al. (2006) assume a yield of 4 ton/ac, Walsh et al. (1996) assume a yield of 4-5 ton/ac, and Perrin et al. (2003) found yields to be between 2.5 and 3 ton/ac. Popp and Hogan (2007) assume switchgrass yields to be 3 ton/ac in the first year of harvest and 5 ton/ac in following years. Kszos et al. (2002) found switchgrass yields in the Corn Belt to be 5.98 ton/ac. Duffy and Nanhou (2001) and Brummer et al. (2001) create several yield scenarios ranging from 1.5 to 6 ton/ac. Kszos et al. (2002), Duffy and Nanhou (2001), and Brummer et al. (2001) each assume or find a 10 year production life of a stand of switchgrass. It should be noted that these papers focus on Corn Belt and Midwestern states. Southeastern states have shown higher yields in switchgrass production. For instance, Fike et al. (2006) found an average yield of 6.3 ton/ac across several Southeastern sites including Raleigh, NC, Jackson, TN, and Blacksburg, VA, with more than 8.9 ton/ac reported in Knoxville, TN.[2] Oak Ridge National Labs' BIOCOST model uses regional values for switchgrass yield listed in the Table 1 (Walsh and Becker 1996). Finally, Cassida et al. (2005), while more focused on differentiation between genotypes, do provide a short trend of switchgrass yields across stands in several different areas, as seen in Table 2. It is easy to see that switchgrass yields vary greatly across regions, and even across states within a given region. How technology will affect yields in future years is uncertain.

[2] Fike et al. reported their results in Mg/ha, and a conversion factor of .446 (Mg/ha)->(ton/ac) was used. Taken from http://www.scijournals.org/misc/conversion.shtml. Similar metric conversions are used throughout the paper.

Another factor which will affect the price of a RIN is that amount of fuel that is extracted per ton of feedstock. For cellulosic ethanol, Pimentel and Patzek (2005) cite Samson (1991) in assuming 0.048 gallons of ethanol per pound of switchgrass. Vogel (1996) cites Turhollow, Johnson, and Cushman (1988) in assuming 70 gallons of ethanol per ton of biomass. Babcock et al. (2007) likewise assume 70 gallons of ethanol per ton of biomass in their discussion of the cost of conversion. For corn-based (conventional) ethanol, a review of conversion rates is provided by Shapouri, Duffield, and Graboski (1995), who use 2.53 gallons of ethanol per bushel of corn (gal/bu). The studies mentioned and the reported conversion rates in gal/bu are: Pimentel (1991), 2.50; Keeney and DeLuca (1992), 2.56; Marland and Turhollow (1991), 2.50; and Morris and Ahmed (1992), 2.55. Plants built more recently produce even more ethanol from a bushel of corn. While these studies provide rates of ethanol extraction, the amount in which technology will affect future extraction rates is uncertain. The EPA provides a projection of ethanol from various feedstocks (Tao and Aden 2008). We use these numbers to provide scenarios for technological change, as explained below.

Earlier but similar versions of the model used in this paper (explained in the Methods section) were used for other biofuel policy and market analyses; the model used here is comparable to the models used in other studies. Meyer et al. (2009) use it to assess how alterations in tariffs, credits, and mandates affect ethanol markets and, through ethanol markets, crop and livestock markets. Thompson, Meyer, Kalaitzandonakes, and Kaufman (2009) compare specifically the ethanol tariff and the size of the mandate that corn ethanol can fill in terms of their implications for corn prices. Westhoff et al. (2008) used this model to estimate the contribution of the most recent Farm Bill to biofuel policies. Thompson, Meyer, and Westhoff (2009) use model output to estimate how changes in corn yields and petroleum prices affect corn prices with and without the biofuel use mandates in place. Whistance and Thompson (2010) and Whistance, Thompson, and Meyer (2010) reverse this logic to ask how biofuel policy effects on crop markets, as estimated from this model, go on to affect natural gas quantities and prices.

De Gorter and Just (2009a, 2009b) also use partial equilibrium economic modeling techniques to represent the biofuel use mandate and other biofuel policies. There are some technical differences, such as applying the mandate as a share of total use, side-stepping the details of explicitly modeling the RIN market (and omitting the potential for RIN stocks), and incorporating only one overall mandate rather than the full set of four mandates. Elobeid et al. (2006) use an earlier version of this model, with some adjustments, to suggest long-run effects of U.S. biofuel production on commodity prices. Elobeid and Tokgoz (2008) use the same model for agricultural commodities, but apply a different model for biofuel markets and policies. Apart from partial equilibrium approaches, global general equilibrium model work seeks to simulate the effects of biofuel production on markets for all goods in all countries or regions, but sometimes foregoes specificity with respect to policy implementation or commodities (Birur, Hurt, and Tyner, 2009; Keeney and Hertel, 2009; Van Meijl, Rheenen, Tabeau, and Eickhout, 2006).

In the following analysis, we explore the implications of two paths for a subset of variables that indicate the improvements in cellulosic biofuel technology over the next 10 years (Figure 2).[3]

---

[3] The high technology yield path was determined by taking the 2007 and 2022 extraction yields supplied in a spreadsheet by the EPA and used in their Federal Reference Methods analysis in preliminary rule making and

Methods

Farmers, input suppliers, biofuel investors, and policy makers need to know how technological advances in cellulosic feedstock production, transportation, and refining into ethanol interact with the mandated volumes of use. To make this assessment, we use a set of equations that puts the technology and policy in the context of economic decision-making. For example, the area allocated to cellulosic feedstocks depends on the returns to these activities relative to competing land uses. Investment in cellulosic biofuel production capacity depends on profitability, or more specifically whether or not the margin between the output and input prices at least meets the cost of capital. Cellulosic ethanol prices depend on the going price of ethanol plus any premia associated with tax credits and any additional value caused by the mandate.

We use an economic model that represents supplies and demands of inter-related agricultural commodities and biofuel markets aggregated to the regional or national level. Traditional agricultural commodities in the model include corn, wheat, soybeans, barley, sorghum, oats, hay, beef, pork, chicken, turkey, eggs, and milk and milk products. Cellulosic feedstock, ethanol, and biodiesel markets are represented as well, as discussed below. For the current experiment, we focus on U.S. markets; the rest of the world is represented by U.S. trade equations for each agricultural commodity or biofuel. The model is an annual one that looks ahead 10 years in part to take into account the dynamics of biological processes, such as in establishing perennial grasses that can only later be harvested and sold to a biofuel refinery, and the delays of building refinery capacity.

The model also represents markets for two likely cellulosic feedstocks, namely stover co-produced with corn – albeit not typically harvested – and switchgrass. In the case of stover, we simulate the amount of stover harvested by taking into account natural limits and fertilizer prices as well as the stover price. Ethanol refining capacity and capacity utilization depend on the margin between output cellulosic ethanol value and input costs, including stover, per ton. We represent the decisions to burn stover for energy or to use it for animal feed which we judge to be unlikely but possible alternative uses. The stover price clears the stover market, balancing quantities supplied by harvesting from corn acres with the quantity demanded for conversion into ethanol or for other uses. Key uncertainties include the cost of transporting stover from farm to ethanol plant (which varies with petroleum prices), the cost of converting the cellulosic input into ethanol, and the yield of ethanol per ton of stover. The switchgrass representation used here is similar to the stover market model, but simpler.[4] Instead of a price-clearing mechanism, we use the cellulosic ethanol price less margins and costs to determine the switchgrass price (if positive). The same uncertainties about stover are also unknowns for switchgrass, but switchgrass yield per acre is another critical factor. An aggregate for all other cellulosic ethanol production is also included. This quantity responds positively to the cellulosic ethanol price, but we do not distinguish among other possible sources of cellulosic biofuels at this time.

---

interpolating between them to determine linear growth. The low technology scenario then halves the growth over the same period.

[4] The substitution between switchgrass and traditional crop area is critically important, but at this point is based on relatively simple assumptions. Also, we do not consider the possibility that other acreage drawn into switchgrass, such as from pasture, might have market effects as well.

The model reflects three key elements of U.S. biofuel policy: trade measures, tax credits, and mandates. We assume that announced or current policy will continue over the next ten years. The trade measures assumed to be in place over the next ten years are 2.5% a duty on ethanol imports and a charge of $0.54 per gallon on all ethanol imports that do not fall under the Caribbean Basin Initiative. Ethanol imports from Brazil pay the $0.54 charge. Tax credits in the model are (1) the long-standing federal tax credit given to fuel blenders for each gallon of biofuel they use; and (2) tax credit exclusively for cellulosic biofuels established by the most recent Farm Bill. The first tax credit is assumed to continue to be $0.45 per gallon for ethanol and $1.00 per gallon of diesel, although its continuation is not certain at the time of writing. The tax credit to cellulosic biofuel producers introduced by the Farm Bill equals $1.01 per gallon less any other tax credit, or $0.56 per gallon of ethanol given our assumption about the first tax credit. All tax credits and the tariff are scheduled to expire during our 10-year projection period, including the tax credit that targets cellulosic biofuel producers. The results we present below based on a continuation of all these programs would be altered if we assumed instead that they will be allowed to expire.

We represent the mandates by modeling the markets for each type of RIN. The production of a type of RIN equals the quantity of biofuels used domestically that meet the legislated criteria. For example, cellulosic RIN production equals the volume of cellulosic biofuels used. The key element of the demand for RINs is to show compliance. Fuel blenders must submit enough RINs of each type to show that their obligations have been met. (Technically, they can meet their obligations by buying and selling enough biofuels to generate enough RINs themselves, or they buy RINs from other blenders who blend more biofuels than required and have extra RINs.) So the mandated volume represents the key demand for RINs each year. In addition, we note the implementing regulations allow for as much as 20% of the mandate in any year to be satisfied using RINs generated in the previous year. We conclude that blenders will want to have extra RINs at the end of each year if the price is not too high so that they have some protection in the event that circumstances in the following year make compliance more costly. We represent this desire as a demand for RIN stocks that is much akin to the stock demand for corn or any other storable commodity. RIN prices vary to clear RIN markets.[5] Refineries sell biofuels that have RINs attached to them. We calculate the price of this joint output as the sum of the price of the biofuel plus the corresponding RIN price.[6] Thus, the price of ethanol made from corn before the RIN is the sum of the rack equivalent retail ethanol price and the tax credit. The ethanol plant price per gallon of conventional ethanol sold is this ethanol price plus the price of a conventional RIN. Ethanol made from a cellulosic feedstock would sell for the sum of the same ethanol price (rack equivalent retail price plus tax credit) plus the price of a cellulosic RIN.

[5] Technically, there are further steps than this. First, these are complementary slackness conditions that we represent as a Fischer-Burmeister nonlinear complementarity problem (NCP). The RIN price can be zero if the mandate is not binding and 20% of next year's mandate is available at the going market prices of biofuels and feedstocks. Second, the mandates are hierarchical. For example, a cellulosic biofuel also meets the advanced mandate and an advanced biofuel also help to satisfy the overall mandate. The reverse is not true as a so-called "conventional" biofuel only counts towards the overall mandate, but not towards advanced or cellulosic biofuels. This hierarchy implies that the price of an advanced RIN cannot be less than the price of a conventional RIN. If the cellulosic mandate is not waived – a possibility discussed in the text – then the cellulosic RIN price must be higher than advanced and conventional RIN prices.
[6] We omit RIN transaction costs. If the use exceeds the mandate by a very large amount, a RIN price could fall to zero in our model, but in reality some minimal price would be necessary to cover trading costs.

The law establishing biofuel mandates allows the EPA to waive them. In the event that the EPA waives the cellulosic mandate, the law commands the EPA to offer a sort of credit. This credit is proffered to blenders for a preset price that is the higher of $0.25 or $3.00 less the average price of gasoline, adjusted for inflation in either case. Blenders can buy credits for any amount of the waived cellulosic mandate that they cannot meet using cellulosic RINs. We expect the credits to set an effective cap on the RIN price in the event of a waiver. In the model, if we assume that the cellulosic mandate is waived then we assume that this credit sets the cellulosic RIN price. In its regulations to implement this element of the legislation, the EPA makes clear that these credits cannot be used to meet other mandates, so they put a limit only on the cellulosic RIN price.[7]

One advantage of the model we apply in the present experiment is that we simulate stochastically. We do not look ahead over the next 10 years with one particular assumption about such uncertain factors as weather shocks to crop yields, petroleum prices, and global commodity demands. Instead, we take 500 randomly determined possibilities for these and other factors. Yields can be above average or to turn out quite badly, petroleum prices spike or fall, and demands are higher or lower than normal. This simulation method allows us to see how policies affect markets in a variety of different contexts. Each of the use mandates for the four types of biofuels may or may not be binding in any given year. If feedstock prices are high because of poor yields or strong demand, then the mandate is more likely to be binding. If petroleum prices are low so consumers are less willing to switch to biofuels, then mandates are more likely to be binding. The opposite is also true: good crop yields, weak commodity demand, and high petroleum prices all decrease the probability of binding mandates. The results that follow summarize the outcomes of 500 different possible market conditions over the next ten years.

Results

The model is simulated stochastically with three different possibilities:

1. Low technology growth, cellulosic mandate waived;
2. High technology growth, cellulosic mandate waived;
3. Low technology growth, cellulosic mandate not waived; and
4. High technology growth, cellulosic mandate not waived.

High technology growth assumes the EPA extraction estimates as mentioned in the literature review are correct. Low technology growth assumes that the initial EPA extraction estimates are correct, but that year-over-year growth is 50% lower than reported, as seen in Figure 2. A summary of the results is listed in Table 3. The summary shows the different scenarios in three time periods: the 2013/14 marketing year, the 2019/20 marketing year, and an average of the data over ten years from the 2010/11 marketing year to the 2019/20 marketing year.

The amount of cellulosic ethanol produced follows expectations: the amount of ethanol produced is highest when the mandate is enforced, with little regard to the technology, followed by a high technology level with the mandate waived, and finally the low technology scenario that results in the least ethanol produced. It is not surprising that the mandate will be met if it is not waived, and the question in this case is really how expensive it is to meet the mandate – a point we return to later. The results with the mandate waived suggests that the market agents will respond to the

---

[7] Thus the cellulosic RIN price could be lower than the advanced RIN price in the event the cellulosic mandate is waived.

biofuel support and generally rising petroleum prices; the incentive to produce more cellulosic biofuels can affect markets. Production will increase more quickly if technological improvements come quickly. Implicitly, we assume that the EPA will reset the cellulosic mandate to a level that is consistent with what people in the market can provide given the underlying technology.

Total ethanol production follows a similar pattern. Conventional (corn based) ethanol production still accounts for a majority of production in all four scenarios, but looking at the average tells an interesting story: the amounts remain relatively stable across the scenarios, with only a slight decrease when the cellulosic mandate is not enforced. This suggests that the combined effects of existing production capacity for conventional ethanol and the overall mandate have a greater impact on future conventional ethanol production than the cellulosic mandate, given our assumptions. With low cellulosic production, conventional ethanol use is at least supported by the overall mandate, but rises above that level if a strong petroleum price causes consumers to replace more gasoline with ethanol. The increases in average total ethanol production caused by the cellulosic mandate or better cellulosic ethanol production technology quickly makes the overall mandate binding, supporting conventional ethanol use.

Rounding out ethanol supply, ethanol imports change little in these scenarios as compared to the impacts on domestic production. We see imported sugar-cane ethanol as the primary source of other biofuels that help to meet the advanced mandate.[8] In most simulations, blenders continue to import sugar-cane ethanol even if new ethanol supplies are available because they the associated RINs are the cheapest way to comply with the advanced mandate. Similarly, conventional ethanol is unlikely to fall very far because of its contribution to the overall mandate.

The additional supply of cellulosic ethanol in cases with high technology or an enforced cellulosic mandate do not cause much displacement with other biofuels because of the other mandates. Instead, the additional volumes push down ethanol prices. However, at least over a 10-year period, the demand for ethanol is considered to be very elastic. Despite some short-run costs of pushing more ethanol use – the “blend wall” as infrastructure must be developed and consumers must buy flex-fuel vehicles – the price of ethanol will not fall much relative to the gasoline price.[9] The simulated retail prices suggest that the technology and the waiver have similar impacts, but the decision whether or not to waive the mandate might affect ethanol markets somewhat more.

RIN prices tend to rise if the ethanol retail price is pushed lower by greater supplies. The RIN prices also follow the expected hierarchy, with prices of biodiesel and unwaived cellulosic ethanol staying above the advanced biofuel prices, which in turn are above the conventional biofuel prices. However, when looking at the cellulosic RIN prices, one sees a situation which does not follow expectations. This reflects the extreme sensitivity of the 10-year path of

[8] As noted before, cellulosic biofuels and biodiesel also count towards the advanced mandate. For example, it is sometimes that case in our simulation results that biodiesel use exceeds the mandated volume in a particular year, with the extra displacing some imported sugar-cane ethanol.

[9] In our representation, we allow some feedback from biofuels to petroleum fuel prices. However, these effects are judged to be small based on preliminary analysis and we do not complicate the discussion here with this information. The general conclusion remains that the ethanol demand is very elastic over the 10-year period.

cellulosic biofuel capacity to its past, at least in this estimation. Imposing the mandate early on gives a signal to build additional production capacity that is carried forward. In each subsequent year, initial capacity is higher and the mandate for that year is rendered more feasible. In contrast, the credit offered with a waiver is not as high and does not give the same initial impetus to build cellulosic feedstock capacity. The curious end result is that the credit associated with the waiver can in some years be higher than the RIN price without a waiver.[10] On the other hand, the average results, even excluding the difficult first year of the cellulosic mandate (marketing year 2009/10) show that the RIN price is higher if this mandate is not waived. In any case, it must be stressed that this comparison is between a case that assumes a waiver in all years and an alternative that assumes no waiver in any year. We expect that the RIN price would spike in any year after the first that a waiver is discontinued and cellulosic biofuel use must rise to the volume mandated in the original legislation.

Compliance costs also hint at an important complicating factor. For the case of a binding and unwaived cellulosic mandate, the results are clear: if technology improves more quickly, then it costs less to meet the use mandates. For the case of a waived mandate, however, these simulation results show that the compliance cost tends to be greater if the cellulosic biofuel technology accelerates more quickly. This result follows from our assumption that the new volume of cellulosic biofuel production will be greater with better production technology and a nearly identical cellulosic ethanol price.[11] With the same cost per unit, as defined by the credit, and a bigger volume, the compliance costs are higher.[12]

The prices of corn, wheat, and soybeans stay relatively stable across scenarios, indicating small impacts from the cellulosic mandate and cellulosic biofuel production technologies over the next ten years and in the presence of broader mandates. These prices did not change more than $0.05, or 1%, across scenarios for the years summarized below. While these changes are not especially large in magnitude, their relative sizes suggest the underlying mechanisms of the land use decision. There is some decrease in corn grain used for ethanol if cellulosic technology improves quickly or if the cellulosic mandate is not waived. This tends to reduce the corn price. However, greater switchgrass area will draw some area from traditional crops, which tends to increase corn prices.[13] Switchgrass area also displaces some soybean and wheat area, and the cross-effects of each crop with corn are significant. For soybeans, there are complications due to the biodiesel

---

[10] This outcome might be generated in part by our assumption that the cellulosic mandate is or is not waived for all the years of the projection period, regardless of whether or not technological progress makes the mandate more achievable over time. In practice, the EPA will probably exercise its powers with greater discretion.

[11] Technically, our assumption follows this logic. If the EPA waives the legislated cellulosic mandate, then the EPA must set a new level of required use. We assume that this new volume is the amount that would be produced at the cellulosic ethanol price (which equals the retail ethanol price plus credit). The EPA has considered production potential in its efforts to implement the law to date. However, we omit the possibility of error in the EPA estimates or that they use some criteria other than the quantity supplied at this point.

[12] Compliance costs fall on fuel blenders initially, but we expect the blenders to pass these new costs of business to consumers who buy motor fuels that blenders sell. As these costs are built in to blenders' margins, the prices of all motor fuels to consumers will rise. Our compliance costs are based on our RIN prices and, as we omit transaction costs from RINs, we also exclude them from our compliance cost calculations.

[13] We assume that 40% of switchgrass area comes from traditional crops, of which a small share is assumed to be corn area.

demand for vegetable oil and changes in the distillers grain markets.[14] The net effect on soybean prices is a very slight increase in both the average and the 2019/20 marketing year if the cellulosic mandate is not waived. A similar small increase can be seen in the price of wheat, suggesting that new fuel feedstocks will take land away from wheat or cause more competition in other uses.

Conclusions

The Energy Independence and Security Act of 2007 mandates the increased use of cellulosic biofuels over the course of the next decade. We have simulated using an economic model what happens if the mandates are enforced or waived under certain assumptions about cellulosic biofuel production technology. To the best of our knowledge, this is the first use of a simulation model with all four mandates represented as endogenous complementary slackness problems and with all four RIN markets balancing for market-clearing prices. To exploit this model, we simulate 500 times over a 10-year period with varying conditions, such as petroleum prices and crop yield shocks, and average over them. Our experiments show what happens if cellulosic biofuel production technology increases more or less quickly, and if the cellulosic mandate is or is not waived.

One key finding relates to the market impacts of the cellulosic biofuel technology and the cellulosic mandate waiver. As long as only the EPA reduces exclusively the minimum volume of cellulosic biofuel used, and not volumes of other biofuels, the majority of the effects are absorbed by RIN markets and not passed on to corn or other traditional crops markets. The greater or smaller cellulosic biofuel use that results from varying assumptions about these factors affect retail biofuel prices. However, the potential that a falling retail price for biofuels translates into lower prices to biofuel producers is reduced by the presence of the array of mandates. Even if final consumers might normally switch to the new supplies of biofuel as the cellulosic mandate grows or if cellulosic technology leads to greater volumes, the blenders must continue to buy and sell at least certain amounts of biofuels, and even must produce a partly preset combination of types of biofuels. As such, there is little scope for substitution between cellulosic, imported advanced, and conventional ethanol. Instead, RIN prices are likely to fluctuate.

A second key finding with broader implications is how cellulosic biofuel technology and mandate affect compliance costs (excluding transaction costs). If the mandate is imposed, then better technology lowers compliance costs. Even so, simulations results suggest an average 2019/20 RIN price from 500 simulations of more or less than one dollar if meeting the mandate of about 10 b.g. of cellulosic biofuel by the 2019/20 marketing year. The product of the two alone implies something on the order of $10 billion. This is added to costs of meeting other mandates – and at higher RIN prices as discussed above – and a total compliance cost of $19 billion with the lower technology path and $16 billion with the high technology path.

[14] Biodiesel demand can be affected indirectly. To give two examples, (1) the lower retail ethanol price leads to lower advanced RIN price and in some years that determines the biodiesel RIN price; and (2) ethanol availability and compliance costs change gasoline and diesel prices, leading to some changes in biodiesel use. Distillers grains are co-produced with conventional ethanol made from corn starch. This good is typically used instead of corn and some soybean meal in animal feeds, leading to some indirect on soybean markets through the initial impact on soybean meal.

If the mandate is waived, then a technology improvement can have the counter-intuitive effect of increasing compliance costs, depending on how the mandate is implemented. There are two steps to this result. First, with the mandate waived, legislation requires that a credit is offered, and we assume this credit largely determines the cellulosic RIN price. Second, with the waiver, we assume that the EPA chooses to reduce the cellulosic biofuel mandate to a new level that reflects what is technically feasible. Thus, if better technology means more cellulosic biofuel can be made, then the EPA is assumed to require that a correspondingly greater amount is used. The consequence of these two assumptions is that there would be more cellulosic biofuel RINs at a fixed price, so better technology means higher compliance costs in the presence of a waiver.

This research suggests several areas for further study. One is the process of cellulosic biofuel production expansion from approximately zero to billions of gallons, which is at this point a matter for speculation. However, it seems likely that capacity available in any year will depend on past returns, so initial prices in very thin markets matter for the path of the 10-year period. While stochastic simulation generalizes results from any particular path, it remains a key point of sensitivity. Second is the question of how much land allocated to cellulosic feedstocks could come from land used currently for traditional crop production. If the assertion that these new dedicated feedstocks would come from land that is not used for any commercial purposes today, then there would be less reason to expect any upward pressure on corn and other traditional crop prices. Conversely, if feedstocks are grown exclusively high-productivity land, then upward pressure on crop prices will be more pronounced.

References

Abbott, P., C. Hurt, W. Tyner. 2009. "What's Driving Food Prices? March 2009 Update." Farm Foundation Issue Report.

Atchison, J.E. and J.R. Hettenhaus. 2003. "Innovative Methods for Corn Stover Collecting, Handling, Storing and Transporting." National Renewable Energy Laboratory. NREL/SR-510-33893. March.

Babcock, Bruce A., Philip W. Gassman, Manoj Jha, and Catherine L. Kling. 2007. "Adoption Subsidies and Environmental Impacts of Alternative Energy Crops." Briefing Paper 07-BP 50, Center for Agricultural and Rural Development, Iowa State University. March.

Birur, D., Thomas Hertel, and Wallace Tyner. "Impact of Biofuel Production on World Agricultural Markets: a Computable General Equilibrium Analysis." GTAP Working Paper No. 53. 2008.

Brechbill, Sarah C. and Wallace E. Tyner. 2008. "The Economics of Biomass Collection, Transportation, & Supply to Indiana Cellulosic & Electric Utility Facilities." Purdue University Dept. of Ag Econ, Working Paper #08-03, Apr 25.

Cassida, K. A., J. P. Muir, M. A. Hussey, J. C. Read, B. C. Venuto, and W. R. Ocumpaugh. 2005. "Biomass Yield and Stand Characteristics of Switchgrass in South Central U.S. Environments." Crop Science: 45 (2): 673.

De Gorter, Harry, and David Just. 2009a. "The Economics of a Blend Mandate for Biofuels." *American Journal of Agricultural Economics* 91 (3): 738-750.

___. 2009b. "The Welfare Economics of a Biofuel Tax Credit and the Interaction Effects with Price Contingent Farm Subsidies." *American Journal of Agricultural Economics* 91 (2): 477-488.

Elobeid, Amani, and Simla Tokgoz. 2008. "Removing distortions in the U.S. Ethanol Market: What Does it Imply for the United States and Brazil?" *American Journal of Agricultural Economics* 90 (4): 918-932.

Elobeid, Amani, Simla Tokgoz, Dermot Hayes, Bruce Babcock, and Chad Hart. 2006. "The Long-Run Impact of Corn-Based Ethanol on the Grain, Oilseed, and Livestock Sectors: A Preliminary Assessment." Center for Agricultural and Rural Development (CARD) Briefing Paper 06-BP 49.

Fike, John H., David J. Parrish, Dale D. Wolf, John A. Balasko, James T. Green Jr., Monroe Rasnake, and John H. Reynolds. 2006. "Switchgrass Production for the Upper Southeastern USA: Influence of Cultivar and Cutting Frequency on Biomass Yields." Biomass and Bioenergy 30: 207–213.

Glassner, D.A., J.R. Hettenhaus, and T.M. Schechinger. 1998."Corn Stover Collection Project." *BioEnergy '98: Expanding BioEnergy Partnerships*: 1100-1110.

Keeney, D.R., and T.H. DeLuca. 1992. "Biomass as an Energy Source for the Midwestern U.S." *American Journal of Alternative Agriculture* 7:137- 143.

Keeney, Roman, and Thomas W. Hertel. 2009. "The Indirect Land Use Impacts of U.S. Biofuel Policies: The Importance of Acreage, Yield, and Bilateral Trade Responses." *American Journal of Agricultural Economics* 91 (4): 985-909.

Marland, G., and A.F. Turhollow. 1991. "CO2 Emissions From the Production and Combustion of Fuel Ethanol From Corn." Oak Ridge National Laboratory, Oak Ridge, Tennessee. Atmospheric and Climate Research Division. Office of Health and Environmental Research. U.S. Department of Energy. February.

Meyer, Seth, Pat Westhoff, and Wyatt Thompson. 2009."Impacts of Selected US Ethanol Policy Options" FAPRI-MU Report #04-09.

Morris, D. and Irshad Ahmed. 1992. "How Much Energy Does it take to Make a Gallon of Ethanol?" Institute for Self Reliance, Washington, DC. December.

Pimentel, David. 1991. "Ethanol Fuels: Energy Security, Economics, and the Environment." *Journal of Agricultural and Environmental Ethics* 4:1-13.

Pimentel, D. and Tad W. Patzek. 2005. "Ethanol Production Using Corn, Switchgrass, and Wood; Biodiesel Production Using Soybean and Sunflower." *Natural Resources Research* 14(1). March.

Popp, M. and R. Hogan, Jr. 2007."Assessment of Two Alternative Switchgrass Harvest Transport Methods." *Farm Foundation Conference Paper.* April.

Public Law (PL) 110–140. 2007. Energy Independence and Security Act of 2007. frwebgate.access.gpo.gov/ cgi-bin/getdoc.cgi? dbname=110_cong_public_laws& docid=f:publ140.110.pdf. March 10, 2008.

Quick, G.R. 2003. "Single-Pass Corn and Stover Harvesters: Development and Performance." *Proceedings of the International Conference on Crop Harvesting and Processing.* ASAE Publication Number 701P1103e. 9 February.

Samson, R. 1991. "Switchgrass: a living solar battery for the prairies." Ecological Agriculture Projects, Mcgill Univ. (Macdonald Campus, Ste-Anne-de-Bellevue, QC, H9X3V9 Canada. Copyright@ 1991 REAP Canada.

Shapouri, Hosein, James A. Duffield and Michael S. Graboski. 1995. “Estimating the Net Energy Balance of Corn Ethanol: an Economic Research Service Report.” USDA, Economic Research Service, Office of Energy and New Uses. Agricultural Economic Report #721. July.

Sokhansanj, S. and A.F. Turhollow. 2002. “Baseline Cost for Corn Stover Collection.” *Applied Engineering in Agriculture* 18, no. 5: 525-530.

Tao, Ling, and Andy Aden. 2008. “Technoeconomic Modeling to Support the EPA Notice of Proposed Rulemaking (NOPR).” National Renewable Energy Laboratory, U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy. November.

Thompson, W., S. Meyer, and P. Westhoff. 2009. "How Does Petroleum Price and Corn Yield Volatility Affect Ethanol Markets with and without an Ethanol Use Mandate?" *Energy Policy* 37 (2): 745-749.

Thompson, W., S. Meyer, N. Kalaitzandonakes, and J. Kaufman. 2009. “Ethanol Policy Changes to Ease Pressures in Corn Markets: Could They Work?” *Choices* 24 (1): 40-45.

Turhollow, A.F., J.W. Johnson, and J.H. Cushman. 1988. “Linking Energy Crop Production to Conversion: the Case of Herbaceous Lignocellulosic Crops to Ethanol.” *RERIC International Energy Journal* 10:41-49.

Van Meijl Hans, T. van Rheenen a, A. Tabeau a, B. Eickhout. 2006. “The impact of different policy environments on agricultural land use in Europe.” *Agriculture, Ecosystems and Environment* 114: 21–38.

Vogel, Kenneth P. 1996. “Energy Production From Forages (or American Agriculture—Back to the Future).” *Journal of Soil and Water Conservation.* March. 51(2):137-139.

Walsh, Marie E., and D.A. Becker. 1996.“BIOCOST: A Software Program to Estimate the Cost of Producing Bioenergy Crops.” Proceedings of Bioenergy ‘96, Nashville, Tennessee, September 15-19. pp. 480 to 486.

Westhoff, Pat, Wyatt Thompson, and Seth Meyer. 2008. "Biofuels: Impact of Selected Farm Bill Provisions and other Biofuel Policy Options" FAPRI-MU Report #06-08.

Whistance, Jarrett, and Wyatt Thompson. 2010. "How does increased corn-ethanol production affect US natural gas prices?" *Energy Policy*.

Whistance, Jarrett, Wyatt Thompson, and Seth Meyer. 2010. "Ethanol policy effects on US natural gas prices and quantities." *American Economic Review*.

Table 1: Switchgrass Yields and Yield Ranges used in BIOCOST

	Unit	NE	APP	CB	LS	SE	SP	NP
				Region				
Yield	(dt/ac/yr)	4.87	5.84	5.98	4.8	5.49	4.3	3.47
Yield Range	(dt/ac/yr)	3.50-5.50	4.36-6.62	4.95-6.73	3.50-6.00	3.40-6.45	2.55-5.98	2.00-5.49

NE = CT, NH, NJ, NY, MA, ME, PA, RI, VT
APP = DE, KY, MD, NC, TN, VA, WV
CB = IA, IL, IN, MO, OH
LS = MI, MN, WI
SE = AL, AR, FL, GA, LA, MS, SC
SP = CO, KS, NE, OK, TX
NP = MT, ND, SD, WY

Table 2: Switchgrass Yields in ton/ac from Cassida et al. (2005)

	AR	LA	TX		
Year	Hope	Clinton	College Station	Stephenville	Dallas
1998	6.29	2.14	7.18	4.04	6.49
1999	6.27	3.25	8.77	4.88	7.19
2000	6.92	3.65	3.75	4.61	6.28
2001	-	4.6	5.22	4.17	-

Figure 1: Nature of Nested Mandates

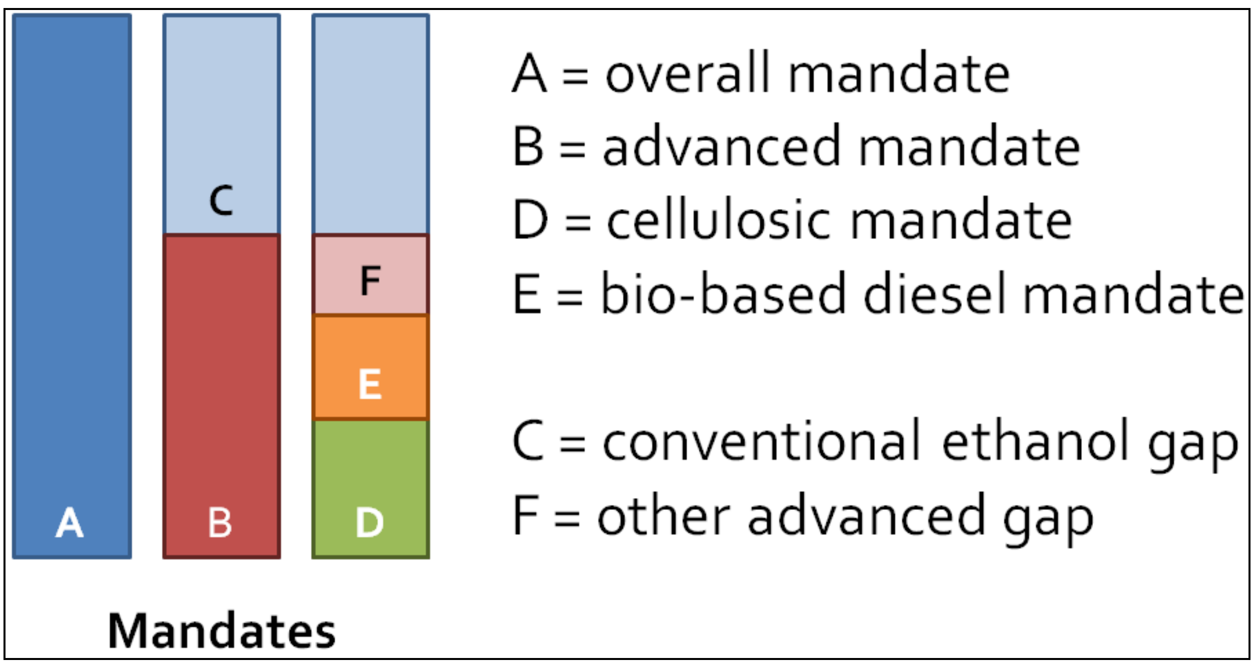

Figure 2: Corn stover and switchgrass cellulosic ethanol extraction rate paths, gallons per ton

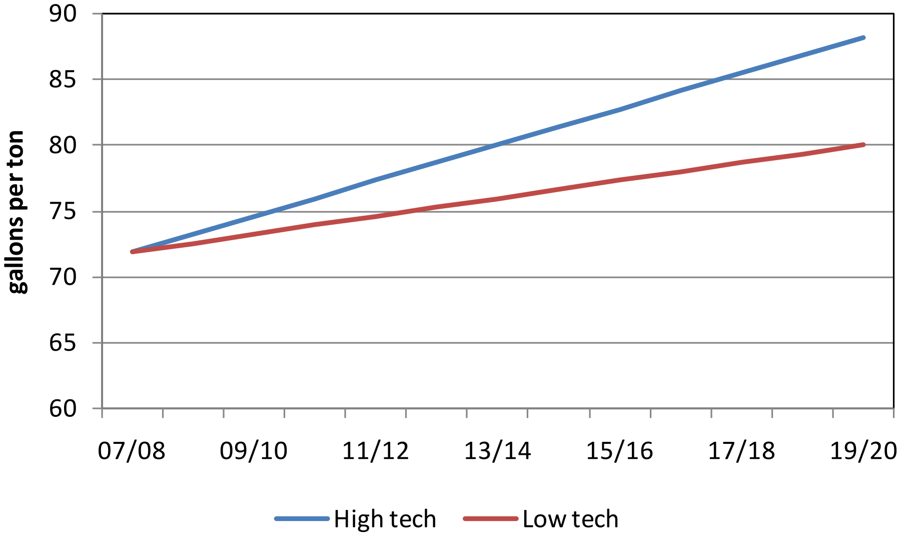

Table 3: Summary of Model Results

	2013/14 marketing year				2019/20 marketing year				Average, 2010/11-2019/20			
	Low tech Waiver	High tech Waiver	Low tech No waiver	High tech No waiver	Low tech Waiver	High tech Waiver	Low tech No waiver	High tech No waiver	Low tech Waiver	High tech Waiver	Low tech No waiver	High tech No waiver
Ethanol market												
Production (bil. gal.)	14.8	14.8	15.8	15.9	20.2	22.8	26.7	26.8	16.2	16.9	19.0	19.0
Conventional	14.6	14.5	14.3	14.2	17.2	16.9	16.5	16.5	15.4	15.3	15.0	15.0
Cellulosic	0.2	0.3	1.6	1.6	3.0	5.9	10.2	10.3	0.8	1.7	4.0	4.0
Imports (bil. gal.)	0.5	0.5	0.6	0.6	2.7	2.6	2.8	2.9	1.2	1.2	1.2	1.3
Prices ($/gal.)												
Conventional	1.91	1.90	1.87	1.87	1.96	1.93	1.91	1.90	1.93	1.92	1.90	1.90
Cellulosic	3.28	3.26	3.34	3.17	3.44	3.38	3.57	3.25	3.32	3.29	3.54	3.31
Other advanced	1.96	1.95	1.93	1.93	2.50	2.48	2.51	2.51	2.17	2.16	2.14	2.15
Retail	2.03	2.02	1.94	1.94	2.12	2.08	2.07	2.05	2.06	2.04	2.00	1.99
Renewable Identification Numbers (RINs)												
Prices ($/ RIN-gal.)												
Conventional	0.07	0.08	0.14	0.14	0.09	0.12	0.16	0.16	0.08	0.10	0.15	0.15
Advanced	0.13	0.13	0.20	0.20	0.62	0.68	0.76	0.77	0.32	0.34	0.39	0.39
Cellulosic	0.88	0.88	1.05	0.89	1.01	1.02	1.27	0.95	0.91	0.91	1.23	1.00
Biodiesel	0.47	0.47	0.47	0.47	0.66	0.70	0.78	0.79	0.52	0.53	0.56	0.56
Compliance costs (bil.$)	1.9	2.1	4.3	4.0	7.5	11.2	18.9	15.8	3.5	4.6	9.4	8.3

Note: “waiver” or “no waiver” refers only to the cellulosic mandate. Volumes required for the overall, advanced, and biodiesel mandate are assumed to continue to imply the same minimum volumes of use of other biofuels.