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The Role of Biofuel Policy and Biotechnology in the Development of the Ethanol Industry in the United States

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The US Renewable Fuel Standard sets a lower bound on the amount of biofuels used, with consequences for behavior of agricultural commodity markets that currently supply the vast majority of feedstocks for biofuel production. In this article, maize biotechnology is considered taking into account the impacts of US biofuel mandates. The impact of a hypothetical technology that reduces the severity of negative maize yield shocks is estimated using a structural economic model simulated stochastically. The importance of mandated levels of use of biofuels depends on whether they are binding. If biofuel use exceeds mandated levels, then mandates have little impact. If mandates are binding, then the markets' ability to respond to price movements can be reduced. In either case, aggregate maize demand is inelastic in these projections, so yield technology improvements can reduce total revenue to maize production.

Key words: maize yields, biotechnology, biofuel mandates, RFS, ethanol, stochastic simulation.

Introduction

Debate in the United States over biofuel policy intensifies as rising biofuel use mandates require more advanced cellulosic biofuels that cost more than conventional, corn-starch ethanol, leading to higher mandate compliance costs. For example, during the Senate debate about the Farm Bill in the summer of 2012, three amendments (SA 2267, SA 2283, and SA 2338) were proposed that would end the Renewable Fuel Standard (RFS2), which establishes these mandates. These efforts reflect a broader movement that is concerned with the impact of mandates on food prices, feed prices, and consumer and taxpayer costs. Questions about the RFS2 have intensified as drought settled on key corn-growing regions in the United States during Summer 2012. The impact of the mandates on these variables is not straightforward, however, and this article uses economic analysis to examine the effect of mandates on the evolution of the agriculture and biofuel sector. The impact of a different technology for maize that limits negative maize yield shocks is simulated to illustrate this complexity. This exercise is stylized, but relevant to current events and future decisions. If in the future drought-resistant maize seed biotechnologies are developed and adopted in the United States, then the impacts on maize markets and producer returns depend in part on how biofuel mandates affect overall demand for maize.

Quantitative economic analysis using models is a useful tool to avoid simplifying complicated interactions, or even ignoring them. For example, during the food-versus-fuel debate as it played out in popular press, it was suggested that US biofuel policy bore sole responsibility for the increasing volumes of maize and vegetable oil feedstocks diverted to biofuel production in the period leading up to and including the 2005-2008 spike in agricultural commodity prices. This argument did not match well with more scientific assessments that highlighted the role of rising petroleum prices and the phasing out of methyl tertiary butyl ether as a fuel additive (Westhoff, Thompson, Kruse, & Meyer, 2007), nor the widespread view that petroleum prices could drive maize price (Tyner & Taheripour, 2008). More generally, the attribution of the price spikes to biofuels as the single cause—let alone biofuel policies in isolation—has been invalidated as overly simplistic; additional attribution has been provided to a number of other factors (Abbott, Hurt, & Tyner, 2008, 2009; Dewbre, Giner, Thompson, & von Lampe, 2008; European Commission, Directorate-General for Agriculture and Rural Development [EC], 2008; Food and Agriculture Organization of the United Nations [FAO], 2008; International Food Policy Research Institute (IFPRI), 2007; Meyers & Meyer, 2008; Organisation for Economic Co-operation and Development [OECD-FAO], 2008, 2010; US Department of Agriculture [USDA], Economic Research Service [ERS], 2008; World Bank, 2008; Westhoff, 2010). Transient factors, such as regional yield shortfalls and export controls, along with surging energy prices, changes in policy-induced grain stocks, and population and income growth, are cited as other contributing factors. Policy debate is about the future, not the past. Whereas much of the scientific assessment listed above has focused on characterizing appropriately the list of causal factors behind the recent spikes in commodity prices, the more relevant question is the possibility that biofuel policies mitigate or exacerbate future price spikes. Moreover, the extent to which past performance is indicative of future events is unclear. In the case of US biofuel policy, for example, discussions about the roles of blenders' tax credits and the ethanol-specific tariff may be irrelevant now that these policies have expired. It has been observed that the US biofuel use mandates were generally non-binding during the price spike of the past because the amount of biofuel used exceeded the mandate. The Energy Independence and Security Act of 2007 (EISA) sets out rising mandated volumes which, along with the expiration of blenders' credits, are likely to see mandates becoming increasingly binding. Under these conditions, mandates have direct effects on biofuel use and they become costly, whereas that has not often been true in the past.

Scientists have shown that crop yield response to price changes are one of the key factors important in determining sectoral response to biofuel production shocks (Keeney & Hertel, 2009). Yet applied models often treat the underlying technologies as exogenous, leaving yield response to be adjustments around these trends or assumed overall technology paths. This seems true of medium-term outlook partial equilibrium models operated at the ERS, the AGLINK-COSIMO model maintained by collaboration between OECD and the FAO and used by Agriculture and Agri-Food Canada (AAFC) and the EC, and the Food and Agricultural Policy Research Institute at the University of Missouri (FAPRI-MU) models of US and other markets. Global Trade Analysis Project's (GTAP) "A-matrix" controls the technologically feasible combinations of inputs to generate outputs, but is typically exogenous with respect to model simulation results. This treatment of yield as deviations around a long-run trend reflects the role crop yield technology development has played in the past. Hybrid seeds, improved crop management practices, precision agriculture for targeting inputs, genetic engineering, and other improvements help to explain the trend of rising post-war crop yields that Westhoff (2010) observes. The key focus in this analysis, however, is on yield developments that improve abiotic stress tolerance, such as drought resistance in maize.

The role of adaptation to circumstances for long-term analysis remains an open research question (Antle & Capalbo, 2010). This is a question not only of trends, but also of variability. Returning to the hypothetical comparison of two projections relating to climate change, if one has greater volatile weather, yields, and prices over a long period of time than the other projection, then it is appropriate to expect investments in new technologies that reduce yield variation. Under a traditional breeding program, the selection of genotypes for drought tolerance (or abiotic stressors) is often not part of the screening phase, as heritability and genetic variances in grain yield decrease under stress, reducing the variation among the genotypes; this makes selection more difficult and reduces the expecting yield gains (Banziger, Edmeades, Beck, & Bellon, 2000). Gains in tolerance of abiotic stressors come in a context of overall improving yields. These improvements in average crop yields have also come with changes in yield distributions over time, as observed by Zhu, Goodwin, and Ghosh (2011), in which increases in average yields are accompanied by increases in crop yield distributions. However, the yield loss to abiotic stress appears to be declining through the use of transgenic crops (Yu & Babcock, 2010), leading to the USDA Risk Management Agency (RMA) to offer reduced crop insurance premium rates for producers using select transgenic hybrids.

Economists have studied yield distributions and their market effects, sometimes focusing on the relevance to crop insurance policies. This has often focused on the question of identifying the best distribution to represent yield variations around trends (Claassen & Just, 2011; Harri, Coble, Ker, & Goodwin, 2011; Ker & Coble, 2003; Norwood, Roberts, & Lusk, 2004; Ramirez, Misra, & Field, 2003). Recent research uses economic simulation models to investigate how changes in maize yields in the United States induced by climate change could affect markets, including the interaction with biofuel policies (Diffenbaugh, Hertel, Scherer, & Verma, 2012; Thompson, Meyer, & Campbell, 2011).

In this article, we investigate the potential that price-induced innovations in seed technologies improve maize's resistance to abiotic stresses such as drought and thus reduce the downward swings in yields. We explore the market impacts of deploying drought-resistant maize in the United States in terms of its impacts on prices and quantities. Moreover, we do so in the context of current US biofuel policies, thus focusing on the interaction between a new technology that reduces yield volatility and a realistic policy environment.

Method

Representation of US Markets and Policies

The FAPRI-MU stochastic model is used for these experiments. The main US agricultural and biofuel markets are represented in an annual dynamic partial equilibrium model. This economic model has been extensively used in analysis of US agricultural and biofuel policies (Binfield, Whistance, & Thompson, 2012; Kruse, Westhoff, Meyer, & Thompson, 2007; Meyer & Thompson, 2012; Thompson, Meyer, & Westhoff, 2010; Thompson, Whistance, & Meyer, 2011; Westhoff & Gerlt, 2012). Components of this model are described elsewhere (Gerlt & Westhoff, 2011; Meyer, Binfield, & Westhoff, 2009; Meyer & Thompson, 2010; Meyers, Westhoff, Fabiosa, & Hayes, 2010; Thompson et al., 2010; Westhoff, Brown, & Hart, 2006). Relevant aspects are summarized here, beginning with biofuel markets.

US markets for ethanol and biodiesel are represented separately, each with its own supplies, demands, and market-clearing price. The model also includes demand behavior for local use requirements, low-level blends (E10 and E15) and E85 for flex fuel vehicles, and therefore incorporates the issue of the ethanol 'blend wall' (in that ethanol must be discounted relative to gasoline by more than the energy difference alone to induce E85 market expansion). Renewable Identification Numbers (RINs) are tradable compliance certificates created to verify that blenders are using at least as much biofuel as required under the mandates of the EISA of 2007 (Thompson, Meyer, & Westhoff, 2009) and are fully represented within the system. This allows the system to simulate when mandates are binding (determining the quantity blended) or non-binding (when prices are such that the volumes of biofuels used exceed the mandates).

Monte Carlo model experiments are used in these exercises. For each scenario, as defined below, the model is simulated 500 times (see Meyer, Binfield, & Westhoff, op cit, for more details of the stochastic process). Each of the 500 simulations starts with a random draw on key determining factors. Shocks to crop yields and key demands (including trade and stock holding) and petroleum and energy-related costs are varied according to historical distributions. Correlation among blocks of these variables, such as yield shocks, is maintained. Because each set of exogenous data generates its own particular outcome for biofuel and agricultural commodity markets, each is characterized by its own starting point for analysis. In the case of the biofuel mandates, which require minimum levels of use, the ranges of simulated market conditions correspond to a range of mandate conditions, with some more binding than others. Given the dynamic nature of the model structure and multi-period supply and demand response for some variables, the stochastic shocks have lingering effects.

The Baseline

The basis of comparison for this investigation is a baseline produced in early 2012 (Binfield et al., 2012; FAPRI-MU, 2012) that assumes current policy is maintained. Both cellulosic and other advanced mandates are scheduled to grow dramatically. The ability to produce these types of fuel in the quantities needed in the United States does not currently exist and is unlikely to be developed in the time frame required by mandates. In the face of these challenges, the cellulosic requirement has been waived by the EPA, and it is assumed to be waived down to the level of cellulosic ethanol predicted by the model in the baseline. The short-fall in cellulosic biofuel relative to the RFS2 is assumed not to be shifted, in its entirety, to other types of biofuels, so more advanced biofuels are not required to make up the gap between target and actual cellulosic biofuel. The part of the mandates that can be met by using conventional ethanol stabilizes at a level not far in excess of existing capacity, and we do not explore any waivers of this mandate even though there have been recent proposals to do so as the drought intensified in the summer of 2012. The overall mandate set out by legislation (EISA total RFS2) and the lower level of the baseline—taking into account the assumption that the cellulosic biofuel mandate continues to be waived (Applied RFS2) and that this shortfall is not shifted to other parts of the mandate—are shown in Figure 1. The part that can be met using corn-starch ethanol, called the "conventional gap," is also shown.

The assumptions regarding RFS2 implementation are crucial to determining the impacts of the mandate removal scenario undertaken. Stochastic simulations decrease the dependence on any particular set of key external factors because many possible values are used. The oil price is particularly important. The mean value for oil prices is very close to IHS Global Insight projections of January 2012. The mean refiners' acquisition oil price rises to slightly above \$100 per barrel in the near term before falling to around \$90 per barrel at the end of the projection period. There is significant variation under the 500 scenarios in this variable with the gap

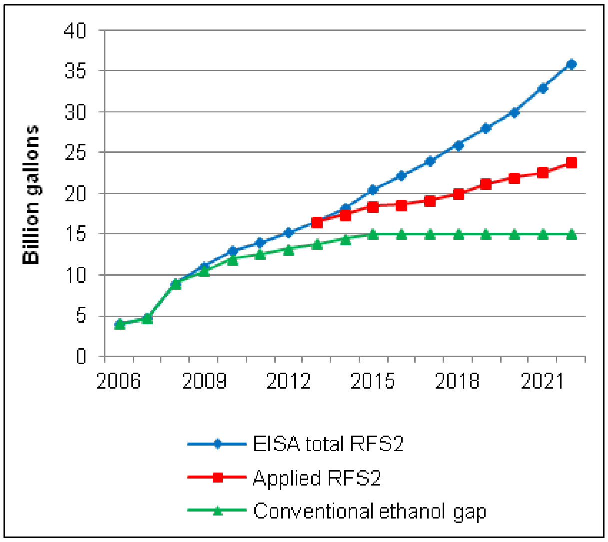

Figure 1. Renewable Fuel Standard mandates biofuel use.
Source: EISA 2007 and authors' calculations

between the 10th percentile and 90th percentile ranging between $90 and $100 per barrel depending on the year. Mean maize prices for the 10-year period are just under $5 per bushel, with the 90th and 10th percentiles at around $6 and $3.50 per bushel, respectively.

Scenarios

The model is simulated four times, with the following scenarios:

i Baseline with mandates and no change in yield distributions.
ii Mandates discontinued and no change in yield distributions (Scenario 1). Mandates are set to zero from the 2012/13 crop year on.
iii Mandates and maize yield improvement (Scenario 2). Here, maize yields are improved through reduced downside variation.
iv Mandates discontinued and maize yield improvement (Scenario 3). (Scenarios 1 and 2 are combined.)

These are stylized exercises to illustrate the importance of the mandates in determining the impact of changing technology. We do not guess whether mandate elimination is likely nor advocate any policy course of action. Even if a reader judges that the scenarios are plausible in their own right, in practice the short-run impacts of such a significant change in policy would depend on details as to when this was announced and the details of the policy termination. The decision to remove the mandates is merely an analytical method to show how their presence affects market outcomes.

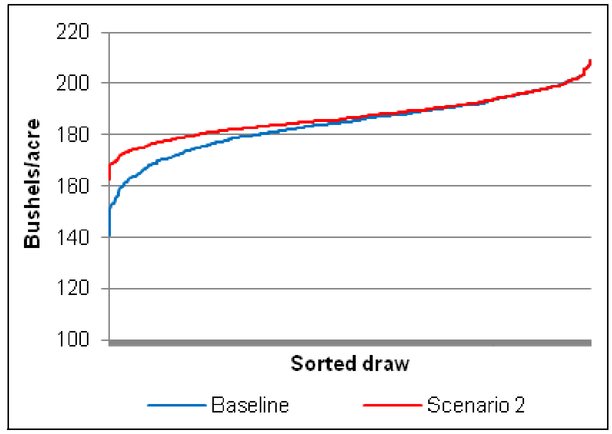

Figure 2. National maize yields in 2021 under the baseline and under improved maize yield scenario (Scenario 2).

Yield distribution is readily studied using stochastic model simulations. To implement the yield improvement technology, for the 500 stochastic draws where there is a negative maize yield shock relative to the trend, this negative is halved. There is no change to the instances of a positive shock. This results in a change in both the distribution of yields in the 500 draws, and an increase in the mean maize yields by roughly 6.4 bushels/acre (0.41 tonnes per hectare). The assumptions that have been made regarding crop yield improvements are not based on any specific product or technology, rather it is to illustrate the potential impacts of this kind of change. For the scenario, any negative adjustments generated by the random draws, representing yields below trend, are halved, and these are weighted to generate the national maize yield deviation that enters the yield equation along with price.

The impact of these changes is shown in Figure 2, which presents the yields for each of the 500 draws under the baseline and Scenario 2 for 2021. The simulation results have been sorted over the yields from smallest to largest. With above-trend yields, which may occur under excellent growing conditions, the hypothetical seed technology that mitigates down-side yield risk is assumed to have no direct effect—yields overall are very good—so the scenario yields (underlying deviations from trend) are the same as the baseline yields, apart from some modest price effects and model dynamics from previous periods.

The baseline and scenario yields diverge at the left side of the figure. These are cases associated with below-average yields in many or all of the key growing regions of the United States. In these cases, the hypothetical seed technology that reduces down-side yield risk has an effect. Again, we assume that these negative deviations are halved. As implemented in this exercise, the new yield technology causes a change in the distribution that reduces the negative yield risk without affecting yields if they are at or above trend.

The scenarios are differentiated based on whether the yield distribution is altered, but also by whether biofuel use mandates are imposed. Mandates affect biofuel use and consequently have indirect impacts on maize markets through the demand for maize as a feedstock to make conventional ethanol. To highlight the role of mandates in setting the stage overall, the first section below compares the case of baseline maize yield distributions with and without mandates in place. The hypothetical biotechnology simulation results are reported subsequently.

Scenario 1. Mandate Effects in the Biofuels and Maize Markets

Table 1 presents a summary of the results of the scenario simulations. Simulation results given in this table are averages of the 500 simulations for each of the scenarios. The removal of mandates eliminates one of biofuel's primary policy underpinnings, and there is a decline in production and consumption of all types of biofuel. Total ethanol use is 27% lower, on average, falling from 19.38 billion gallons (b.g.) to 14.09 b.g. without the mandate in place.

The mandate has four components, each of which can have a different degree of impact on markets. At one extreme, a component of the mandate has no direct impact if it is not binding because use in any case exceeds the target. At the other extreme, if the mandate is set higher than the amount of biofuel people would otherwise choose to use, then it is binding and has direct impacts. For the four mandate components over 500 simulations, the declines among fuel types if the mandate is eliminated are not uniform. In the absence of mandates, cellulosic biofuel production is drastically reduced, from an average of 2.19 b.g. to an average of 0.36 b.g. if the mandates are eliminated. Maize-starch-based ethanol also declines, from 15.76 b.g. on average to 14.18 b.g. However, conventional ethanol is more competitive relative to gasoline given that the stochastic mean oil price is $92 per barrel over the period, so the reduction of 10% in conventional ethanol production, on average, is far less severe than the 84% reduction in average cellulosic biofuel production.

In the baseline, mandated consumption of ethanol rises above the blend wall. When the mandate is removed, in most of the simulations ethanol use falls close to the blend wall level. The low blend market can be filled by relatively cheaper conventional ethanol and so the market for other ethanol is limited. In these experiments, ethanol use above this level typically requires both more ethanol—meaning more conventional ethanol capacity or higher-priced advanced and cellulosic biofuels—and steeper discounts in ethanol price to induce E85 expansion. Clearly, this result is conditional of the size of the low-blend market, which is itself dependent on the level of gasoline consumption and also the possible development of the E15 market and consumers' attitude toward that fuel.

If mandates are discontinued, then RINs are superfluous. In the baseline with the mandates, on the other hand, the average RIN values shown here represent measures of the degree to which the mandate is binding. The average conventional RIN value of $0.60 per gallon suggests that it is binding in many or most of the stochastic simulations, but perhaps not stringently binding—a view supported by the fact that conventional ethanol use falls the least when going to the discontinued mandate case. The advanced RIN value averages much higher, at $1.10 per gallon, indicating that this mandate is more binding than the overall mandate. Compliance costs, which average more than $20 billion a year in the baseline, are eliminated if the mandate is discontinued.

Ethanol price differences between the baseline and the discontinued mandate case reflect the value of the biofuel and any accompanying RIN. The retail ethanol price is the price of this type of fuel, without a RIN, as determined by the balance of all supplies of ethanol and all uses. Without a mandate, the fuel blenders are not required to push as much ethanol into the market, so the retail price rises. The wholesale or rack price of biofuels is distinguished by the type of RIN that accompanies domestic use of this biofuel. Conventional, advanced, and cellulosic ethanol are physically identical goods, but they count differently towards the RFS2; therefore, each of these fuels would have its own value depending on how useful they are in helping to achieve mandate compliance, plus the value of the physical ethanol itself. As a consequence, the value of the RIN is embedded in the wholesale prices of these biofuels in the baseline. In the discontinued mandate case, there is no distinction by ethanol type so there is no reason for them to sell at different wholesale prices. In this scenario, all wholesale ethanol prices converge to $1.93 per gallon, on average,

Table 1. Biofuel market effects.

September-August year 2017-2021 average	Baseline values without yield improvement		Improved maize yields through reduced downside variation, and change from base			
			Mandates		No mandates	
	Mandates	No mandates	Level	Change	Level	Change
			(Dollars/barrel)			
Petroleum, refiners acquisition	91.91	91.91	91.91	0.0%	91.91	0.0%
Yield			(Bushels/acre)			
Maize	177.96	177.58	180.53	1.4%	180.17	1.5%
Ethanol supply and use			(Million gallons)			
Production	18,249	14,799	18,293	0.2%	14,945	1.0%
From maize	15,763	14,177	15,822	0.4%	14,323	1.0%
Other conventional	295	265	293	-0.9%	266	0.0%
Cellulosic (biofuels)	2,190	357	2,178	-0.5%	357	0.0%
Imports (ethyl alcohol)	2,047	42	2,042	-0.2%	35	-16.3%
Domestic disappearance	19,380	14,092	19,389	0.0%	14,216	0.9%
Exports (ethyl alcohol)	879	744	909	3.4%	759	2.0%
Ending stocks	1,020	855	1,024	0.4%	864	1.0%
Biodiesel supply and use			(Million gallons)			
Production	1,336	454	1,336	0.0%	456	0.4%
Domestic disappearance	1,285	353	1,285	0.0%	355	0.5%
Ethanol prices			(Dollars per gallon)			
Conventional rack, Omaha	2.05	1.93	2.02	-1.5%	1.91	-0.9%
Cellulosic rack	3.65	1.93	3.65	-0.1%	1.91	-0.9%
Other advanced rack	2.56	1.93	2.55	-0.2%	1.91	-0.9%
Effective retail	2.21	2.57	2.21	-0.1%	2.55	-0.7%
Biodiesel rack price	5.04	2.65	5.03	-0.2%	2.65	0.0%
RIN values						
Conventional ethanol	0.60	0.00	0.57	-5.3%	0.00	n.a.
Advanced ethanol	1.10	0.00	1.10	-0.5%	0.00	n.a.
Cellulosic ethanol	2.20	0.00	2.19	-0.3%	0.00	n.a.
Biodiesel						
Aggregate measures			(Billion dollars)			
Net farm income	95.03	90.06	93.89	-1.2%	88.79	-1.4%
Net CCC outlays	8.96	8.98	8.92	-0.4%	8.94	-0.5%
RFS consumer mandate cost	20.69	0.00	20.15	-2.6%	0.00	n.a.
Total US food expenditures	1,594.40	1,592.00	1,593.40	-0.1%	1,591.10	-0.1%

which is 6-47% less than the average wholesale prices in the baseline. Thus, discontinuing the RFS2 is seen to cause both higher retail prices and lower wholesale prices because less ethanol must be bought and sold in most simulations relative to the baseline case with the mandates.

Ethanol trade results are complicated because imports typically count towards one mandate and exports reduce supplies available domestically for a different mandate. Ethanol imports in the baseline projections are sugarcane ethanol that helps to satisfy the advanced mandate. The advanced mandate in the baseline projections tends to be much more binding than the mandate component that conventional ethanol helps to fill, so the price of advanced ethanol that meets the advanced mandate is higher than the conventional ethanol price. Without the mandates, there is no reason for any distinction between ethanol prices. With RFS2 discontinued, there is no longer an incentive to import ethanol at a higher price than domestically produced

Table 2. Crop market effects.

September-August year 2017-2021 average	Baseline values without yield improvement		Improved maize yields through reduced downside variation, and change from base			
			Mandates		No mandates	
	Mandates	No mandates	Level	Change	Level	Change
Area planted			(Million acres)			
Maize	90.90	89.62	90.52	-0.4%	89.33	-0.3%
Soybeans	74.12	73.47	74.23	0.1%	73.52	0.1%
Wheat	55.15	55.60	55.02	-0.2%	55.48	-0.2%
Major crops	313.44	310.37	312.96	-0.2%	309.97	-0.1%
CRP	30.32	31.07	30.57	0.8%	31.23	0.5%
Major crops and CRP	343.77	341.44	343.53	-0.1%	341.20	-0.1%
Yield			(Bushels/acre)			
Maize	177.96	177.58	180.53	1.4%	180.17	1.5%
Soybeans	47.38	47.21	47.36	0.0%	47.19	0.0%
Wheat	47.75	47.69	47.73	-0.1%	47.67	0.0%
Maize market			(Million bushels)			
Production	14,839	14,599	14,991	1.0%	14,766	1.1%
Feed and residual use	5,166	5,402	5,235	1.3%	5,461	1.1%
Fuel alcohol use	5,722	5,146	5,743	0.4%	5,199	1.0%
Exports	2,410	2,501	2,467	2.4%	2,551	2.0%
			(Million metric tons)			
Distillers grains production	40,441	36,847	40,563	0.3%	37,184	0.9%
Other crop production			(Million bushels)			
Soybeans	3,464	3,421	3,467	0.1%	3,422	0.0%
Wheat	2,258	2,274	2,252	-0.3%	2,268	-0.3%
Crop prices			(Dollars/bushel)			
Maize	4.68	4.43	4.55	-2.7%	4.32	-2.5%
Soybeans	11.48	10.70	11.39	-0.8%	10.62	-0.7%
Wheat	6.06	5.85	6.00	-1.0%	5.79	-0.9%

conventional ethanol, so ethanol imports fall by 98%, on average.

Baseline ethanol exports are partly an indirect consequence of the mandates. As the United States imports sugar cane ethanol to meet the generally binding advanced mandate in the baseline, foreign ethanol prices are driven higher. The higher foreign prices encourage the United States to export more conventional ethanol in the baseline. In the scenario with discontinued mandates, the United States no longer imports high-priced ethanol to meet the advanced mandate, so ethanol prices in other countries fall. This means there is less incentive to export conventional biofuel, so average US ethanol exports are 15% lower in this scenario relative to the baseline. These results for ethanol trade depend in part on the assumption that the Brazilian ethanol market remains tight.

The fall in blender demand for ethanol puts downward pressure on feedstock prices as well, with maize use for producing biofuels just over 10% lower in the mandate elimination case than in the baseline, on average (Table 2). This reduction causes the maize price to average 5% lower in the discontinued mandate case relative to the baseline, allowing other uses to take up some of the slack in the market and forcing maize production to be lower. Maize exports rise above historical levels as price declines, to average 2.50 billion bushels in the discontinued mandate case as compared to 2.41 billion bushels in the baseline. Feed and residual maize quantities also tend to be higher in the discontinued mandate case as a lower maize price induces livestock sector expansion, but also because of modest declines in availability of distillers grains co-produced with maize starch ethanol.

The biodiesel mandate is binding in the baseline simulations. The average high baseline RIN price suggests that it is costly to meet this RFS2 component according to the assumptions used here. Moving from the baseline to the case with discontinued mandates results in almost three-quarters less biodiesel use in the United States. As a consequence of less soybean oil used to make biodiesel, as well as cross-impacts among crop markets, soybean prices are lower in the case of discontinued mandates. With lower maize and soybean demand, acres are reallocated among crops with some gains by wheat as maize and soybean prices are most affected by the shift from the baseline with mandates to the discontinued mandate case.

Lower crop prices and more livestock products lead to lower food consumer expenditure if the mandates are discontinued relative to the baseline with mandates. The $2.4 billion reduction each year, on average, constitutes about 0.1% of total food expenditures. The impact on taxpayer expenditures on traditional agricultural commodity programs is also slightly different between the two cases. Net farm income is 5% lower if mandates are discontinued relative to the baseline with mandates, on average, although this aggregate impact does not necessarily reflect the case of an individual crop or livestock farmer.

Effects of Adding Drought-resistant Yield Technology

The responsiveness of maize demand is a critical factor in determining key impacts of a technology shock that affects yields, including whether maize net income per hectare rises and draws more land into maize production, or falls and pushes land out of maize production.

Scenario 2. Average Impacts with Mandates in Place

The biofuel use mandates, because they are binding in the vast majority of stochastic simulations, reduce the ability of one key use of maize to respond. There is no mandate for conventional ethanol use, technically speaking—let alone production—and there is some flexibility in the mandates caused by the ability to roll-over RINs. Nevertheless, binding mandates decrease responsiveness of the demand for maize used to make ethanol to price signals. This reduces in turn the ability of the market to absorb the additional maize produced if a new seed technology delivers higher yield, forcing the price to fall all the more to balance markets. Biofuel use mandates exacerbate market inelasticity, leading to larger negative price impacts for a given quantity increase. The yield technology causes the maize price to average 2.7% lower than in the baseline if mandates are present for a 1.2% average increase in yields. The practical outcome for a farmer looking at per-acre net income from maize is that if the country-wide yield increase has an accompanying price reduction that is greater in proportional terms, then net income per acre from this crop falls. Maize area is off slightly, averaging 0.4% lower in the scenario relative to the baseline.

With mandates, the price decrease causes only a 0.4% average increase in fuel alcohol from maize, leaving other uses to absorb more of the production increase. The limited additional conventional ethanol production and small overall impacts on ethanol volumes partly reflects the binding mandates. For example, as the advanced mandate is met almost entirely by imported sugar cane ethanol and conventional ethanol cannot help to meet this mandate, there is no possibility that conventional ethanol will displace advanced ethanol imports with mandates in place. Ethanol imports hardly change, falling by -0.2% on average, even though conventional ethanol is cheaper with the new maize yield technology. Instead of expanded use to make ethanol, most of the additional maize ethanol production is exported or absorbed in the feed sector. The principle effect regarding biofuels is on the conventional RIN price, which averages 5.3% lower with the yield improvement. Cheaper maize reduces conventional ethanol production costs, so the overall mandate becomes less binding in the simulations with better maize yield technology relative to the baseline, leading to 2.6% lower average mandate compliance costs. More of the benefits of the technology improvement flow to consumers of agricultural commodities and motor-fuel users when mandates are binding, although the prices of both start at higher levels.

Average Impacts Without Mandates

Mandates complicate market impacts of the yield technology because some expected responses are curtailed by binding mandates. The key comparison is the difference between the average value of all simulations in Scenario 3 (mandate discontinued, yield technology improvement reducing negative part of yield distribution) relative to the average value of all simulations in Scenario 1 (mandate discontinued, baseline yield distribution), as shown in the right-most column of the tables.

Maize yield averages 1.5% higher with this maize seed technology assumption in place. The impact of

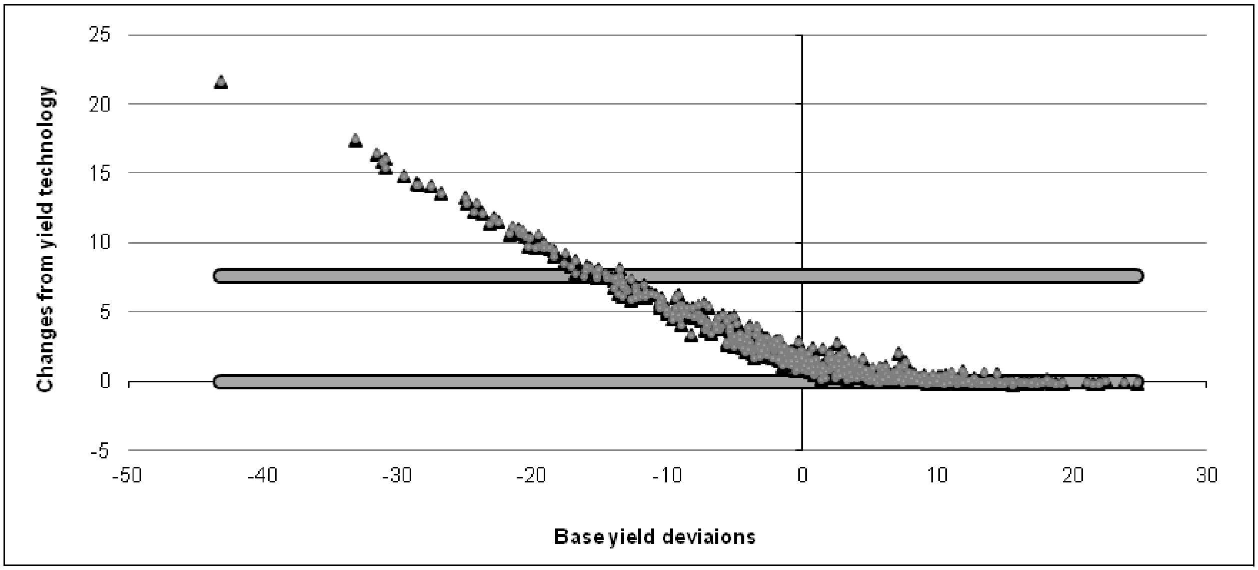

Figure 3. Change in maize yields (bu/ac) from technology application under alternative biofuel policies (2021).
The x-axis is the yield deviation in the baseline. The y-axis is the change induced by the introduction of the hypothetical yield technology that reduces downside yield risk. This comparison has two sets of points—one for Scenario 2 that shows technology impacts with mandates in place (▲), and another for Scenario 3 that shows technolgy impacts without mandates (●). The lines denote 10th and 90th percentiles of these changes.

greater yields on maize farm returns depends critically on how the additional supplies affect the price. The maize price effect is a 2.5% average reduction relative to the case of no mandates without the new yield technology. The outcome of a 1.5% shift in supply inducing a 2.5% reduction in price indicates that aggregate maize demand is inelastic, albeit less inelastic than in the presence of mandates. Recall that the previous case, with mandates in place, showed that the new maize technology caused a larger decrease in maize price and a small increase in ethanol use of maize. In the present case, without mandates to constrain response, the average price reduction caused by the new technology is smaller and ethanol use of maize increases more. In the absence of mandates, then, ethanol use of maize is no longer constrained by the policy and is likely to move more in response to changes in the maize price. Maize area is reduced slightly because of lower maize net returns. As maize price and net returns fall, demand substitution and land substitution lead to lower crop prices more generally.

Ethanol market impacts of the new technology appear modest. With the lower maize price, conventional ethanol is more profitable so more is produced and sold, both domestically and abroad. Total ethanol use in the United States rises by about 1% on average, and exports by 2%, with imports falling by 16%. The domestic ethanol prices all fall by half a penny per liter, with this change constituting a relative change of the wholesale price than of the retail price.

With the yield distribution change but no mandates in place, the impact on food expenditure is a reduction of about 0.1% on average, and the impact on government expenditures on traditional agricultural programs also falls slightly.

Distributional Impacts

The results discussed so far represent averages over all 500 stochastic simulations for each scenario. The impact of a new maize seed technology that reduces down-side yield risk without affecting average or above-average yields is not expected to be constant under all market conditions. Rather, we expect an asymmetric response, with the largest impacts occurring if the randomly determined shock to maize yield is most severely negative and no direct impact if the random yield shock is positive. In this section, we show some of the distributional impacts of this hypothetical technology.

The distribution of maize yields demonstrates asymmetry in the scenario design (Figure 3). If there was no change, then the observations would all lie on the y-axis value of 0, and this is approximately what happens for above-trend yield shocks (Figure 3, right side of graph). This is not the case for negative yield shocks because, by assumption, negative yield shocks are reduced pro-

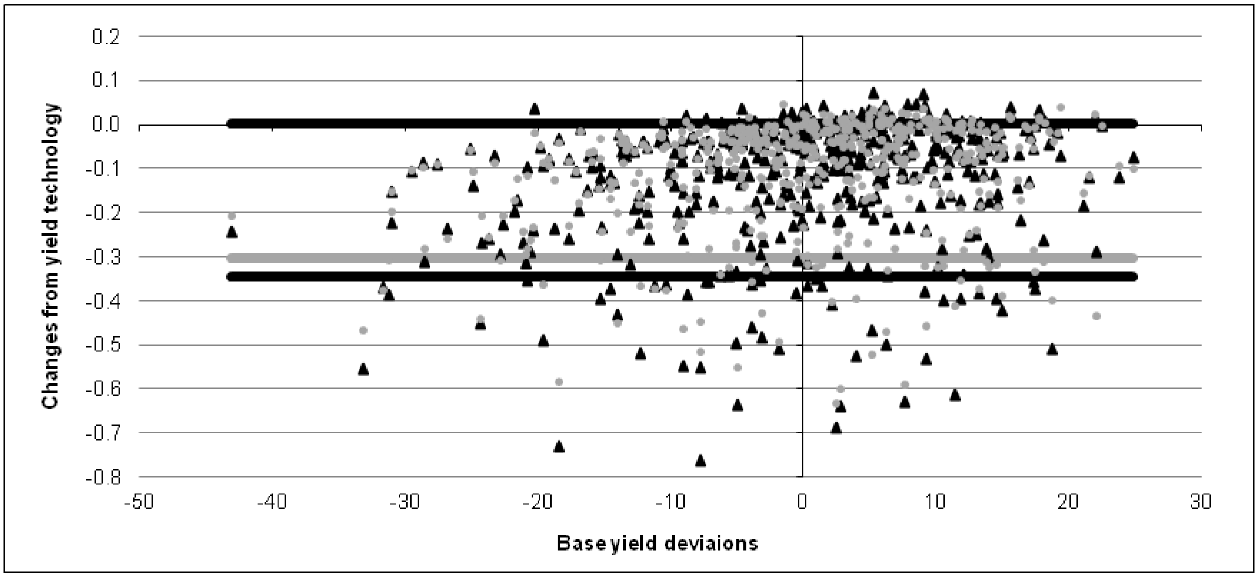

Figure 4. Effects on maize market net returns ($/acre) from introduction of maize yield technology.

portionately by the hypothetical technology so the points all show a positive change in moving from baseline yield to the yield of the hypothetical technology, either with or without the mandates in place (Figure 3, left side of graph).

As final crop yields are endogenous with respect to price, the assumed technology effect is not the sole factor determining maize yields. Thus, when plotting the baseline deviations against the final yield deviations from introducing the yield technology, we do not get an exact relationship as current and past prices effect the final crop yield. Even the positive deviations where no adjustments to the stochastic deviations are made show movement, as past and current price effects and market conditions impact the final yield draw.

These results show the range of yield impacts in moving from base case to technology scenario, with or without mandates, adding information to the average values shown earlier. The preceding tables also demonstrate the negative effects on maize prices from the introduction of the yield technology, but those effects are not evenly distributed and depend on the policy context. The 10th and 90th percentile lines, with (black horizontal lines) or without (grey horizontal lines) the mandate, show that most of the changes in maize yield fall in the range between an increase of about 7 or 8 bushels per acre and no change at all. As indicated by the points themselves, too, the hypothetical technology shock is asymmetric by assumption, and increases yields or leaves them unchanged.

Maize return impacts depend on yield and price. In cases that the yield technology increases the yield relative to the baseline, the price tends to be lower. This relationship is shown in the averages represented in tables discussed earlier, and is also apparent in the distribution of maize returns per acre in the final year of the projection period (Figure 4). Although complicated by the fact that net returns the final year, shown here, depend on changes in previous years, the general result is that maize net returns tend to be almost unchanged or lower. In the presence of mandates (▲), the yield improvement causes reductions in maize net returns. The maize return changes caused by introducing the technology are smaller if the market is less inelastic, because the price effect is smaller, so the simulations in the discontinued mandate case demonstrate less negative maize return effects (●). This is also apparent in the higher 10th percentile associated with the simulations with mandates discontinued (grey horizontal lines) as compared to the 10th percentile of changes caused by the new technology if mandates are in place (black horizontal lines).

Conclusions

Technology that improves crop yields can increase or decrease net returns to crop production depending on how much crop prices fall, which itself depends on aggregate demand elasticity. In the case of the US maize crop, where markets have been subject to massive structural changes with the recent rapid expansion of biofuels, this is uncertain. Historical market estimates that exclude ethanol omit a use category that represents approximately half of domestic use today. Studies of only a few years ago might have calculated a break-even maize price that would measure the price at which ethanol refineries would be willing to buy any amount of maize and still make money for a given petroleum price—an assumption of a perfectly elastic demand for maize. More recently, studies have adopted the component of the mandate that conventional ethanol can meet as an unvarying quantity, thus reducing market elasticity dramatically even though there is no conventional ethanol mandate, mandates can be exceeded, and conventional ethanol can be exported. Here, we apply a more nuanced understanding of how ethanol markets and biofuel policies affect maize demand and, consequently, maize market response to technological improvements in yields over a medium-term projection period.

In our baseline with many hundreds of simulations, overall biofuel use is often bound by the mandate, and ethanol use pushes against the blend wall. In this context, comparing the average increase in production associated with the assumed yield improvement to the average maize price decrease suggests an aggregate market elasticity of -0.38. Even if mandates are discontinued, the market elasticity increases only to -0.45 in these estimates. The key driver of this change is the demand for maize to make ethanol, which is -0.14 with mandates in place and -0.41 without mandates in place, but it is still subject to blend-wall constraints on further expansion. Response would be greater if given more time to adjust, to allow for expansion into E85 markets and adjustments in ethanol production capacity, as well in other processing sectors and animal numbers.

The petroleum price is one of the most critical factors in determining whether mandates are binding. Given the assumptions of this exercise, mandates tend to be binding, with a petroleum price in the range of $90-100 per barrel. Mandates can create new interactions and sever others. For example, with mandates in place, the domestic conventional ethanol rack price is less correlated with ethanol imports in the simulation results than if mandates are discontinued (-0.20 versus +0.53). The link between the ethanol and feedstock markets in general is sensitive, with the correlation between ethanol retail price and maize net returns weaker if mandates are present than if they are discontinued (+0.12 versus +0.46). Because analysis of how a new technology affects markets depends on market response and because petroleum prices play a part in setting the context in terms of whether mandates are binding, the petroleum price represents one important aspect of the context for studies of agricultural technology.

Cautious extrapolation of these results leads to some suggestions for analysts who answer to decision makers. Clearly, results presented above stress the need to define the context in terms of the policies (to note if there are mandates that may be binding) and markets (such as limitations on or costs to biofuel use expansion). More specific to biofuel analysis, results warn against assertions that improvements in biofuel feedstock technology will necessarily improve producer returns. For example, if second-generation biofuels are made from new crops and sold to fulfill the requirements of a binding mandate, then is it the case that demand for this crop is perfectly inelastic with respect to even fairly substantial shifts in supply? If so, then would the increase in biomass crop productivity drive down the price by so much that net returns to this activity would fall, discouraging planting or further investment in technology improvement? Policymakers might reasonably expect researchers who analyze new feedstocks for next-generation biofuels to be able to define results for a variety of contexts and to identify how policy options interact with markets in order to determine the directional impact on net income impacts of feedstock production technology improvements.

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