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Nicole Condon[1], Heather Klemick[2], and Ann Wolverton[2]

Abstract

The literature on the impacts of biofuels on food prices is characterized by contradictory findings and a wide range of estimates. To bring more clarity to this issue, we review studies on U.S. corn ethanol production released between 2008 and 2013. Normalizing corn price impacts by the change in corn ethanol volume, we find that each billion gallon expansion in ethanol production yields a 2-3 percent increase in corn prices on average across studies. We also conduct a meta-analysis to identify the factors that drive the remaining variation in crop price impacts across studies. We find that the baseline and policy ethanol volumes, projection year, inclusion of ethanol co-products, biofuel production from other feedstocks, and modeling framework explain much of the differences in price effects across studies and scenarios. Our study also distinguishes between analyses that estimate long-run equilibrium impacts of biofuels and short-run studies that consider the effects of unexpected policy or weather shocks, which can lead to temporary price spikes. Preliminary findings from the gray literature suggest that short-run impacts on corn prices per billion gallons of corn ethanol production in response to unexpected shocks are higher. Last, we examine a small number of studies that consider the implications of biofuel policies for food security worldwide. The literature suggests that biofuels expansion will raise the number of people at risk of hunger or in poverty in developing countries.

Key words: ethanol, biofuels, Renewable Fuel Standard, food prices, food security, meta-analysis

Subject area: Agriculture: Land Use, Energy, Environmental Policy, Transportation

JEL classification: C54, Q16, Q18, Q42

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During the last decade, there has been more than a five-fold increase in global liquid biofuel production. The U.S., Brazil, and the European Union lead the world in biofuel production, bolstering their biofuel industries with mandates, subsidies, and favorable trade policies. The International Energy Agency (2011) has projected that the share of biofuels in global transportation fuel will increase from the current two percent to 27 percent by 2050.

The growth in biofuel production has been mirrored by a rise in food crop prices. After nearly 30 years of low or decreasing prices, world commodity prices began rising in the mid-2000s, with the FAO food price index reaching a historical high in the summer of 2008 that was surpassed in late 2010 (FAO 2013). The confluence of these two trends has triggered a debate surrounding the tradeoff between food and fuel resources. U.S. biofuel policies have received particular scrutiny because of the U.S.'s role as a leading exporter of agricultural commodities.[3] However, correlation alone is not sufficient to establish a causal link between biofuel production and food crop prices without controlling for other factors.

This policy issue has spurred an extensive literature by academics, government agencies, and other organizations examining the economic, social, and environmental impacts of biofuels. Effects of biofuels on agricultural commodity prices have received considerable attention. This literature is characterized by contradictory findings and a wide range of estimated impacts. Recent reviews of the literature highlight this range: Zhang et al. (2013) find projections ranging from 5 to 53 percent for increases in the price of corn by 2015 as a result of biofuel policy, while literature summarized by the National Research Council (2011) on the proportion of the 2007-2009 corn price spike attributable to biofuels includes estimates from 17 to 70 percent. Such

[3] In the 2011-2012 marketing year, U.S. production accounted for approximately 33 percent of world corn exports, 18 percent of wheat exports, and 40 percent of soybean exports (USDA 2013a).

divergent results make it difficult to assess the relative merits of policies that reduce, expand, or otherwise alter biofuel production trends.

To bring more clarity to the issue of biofuel impacts on food crop prices, we review the recent literature on U.S. corn ethanol policy. Restricting the scope of our study to a single feedstock—corn—and to studies released between 2008 and 2013, we control for differences across studies in modeling technique, feedstocks, time period, scenario, and other assumptions. Zhang et al. and the National Research Council note that the differences across studies make it nearly impossible to compare results or estimate impacts with any accuracy. However, we employ several strategies in an attempt to place studies on a similar footing to facilitate such comparisons. First, to control for the large differences in ethanol volumes considered across different scenarios, we normalize corn price impacts by ethanol quantity to calculate two metrics: the percent change in corn prices per one billion gallon increase in corn ethanol production (a semi-elasticity measure), and the percent change in corn prices per one percent increase in corn ethanol production (an elasticity measure). Looking across studies and scenarios, we find that each billion-gallon expansion in corn ethanol production (or alternately, each 10 percent expansion in production) yields a 2 to 3 percent increase in long-run corn prices on average.

While these normalized price metrics make for more straightforward comparisons across studies, considerable differences still remain. Therefore, we also conduct a meta-analysis to parse the contribution of key assumptions and structural choices to long-run estimates. The meta-analysis allows us to identify which factors drive the large differences in commodity price impacts across studies. We estimate the meta-analysis using a random effects model to address the fact that estimates from the same study are not independent. We find that the modeling framework (partial versus general equilibrium), projection year, inclusion of ethanol co-products, other biofuel feedstocks, and baseline and policy ethanol volumes explain much of the variation in price effects across studies and scenarios.

Our study distinguishes between analyses that estimate long-run equilibrium impacts of biofuels and short-run studies that consider impacts before markets have time to fully adjust to policy changes. Most of the literature to date has only examined long-run impacts, typically several years into the future, but a few recent and still unpublished studies have considered the effects of unexpected policy or weather shocks over a limited time horizon, which can lead to temporary price spikes. Unsurprisingly, we find much higher impacts on corn prices per billion gallons of corn ethanol production in studies using a short-run framework. Such short-term disruptions to commodity prices could have important implications for food security among low-income people without consumption-smoothing options even if the long-run impacts of biofuels are modest.

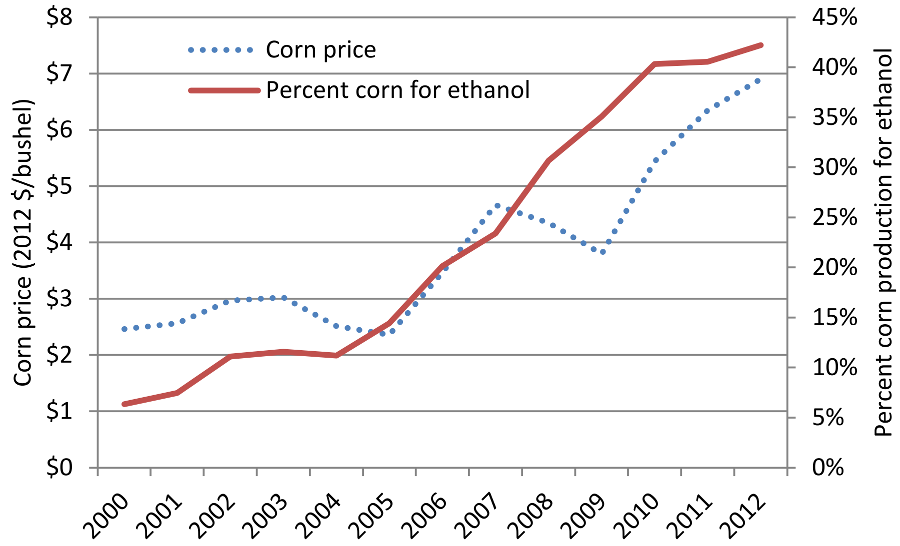
We also examine a small number of studies that explicitly consider the impacts of biofuel policies on food security worldwide. Raw commodities make up a small proportion of the cost of finished food products in high-income countries, muting the effects of commodity price rises, but they may be felt more acutely in low-income countries where raw commodities make up a large share of household budgets. While the literature is characterized by heterogeneous findings, it suggests that biofuels expansion is likely to raise the numbers of people at risk of hunger and/or in poverty in developing countries on balance.

The article is structured as follows. The background section discusses trends in U.S. biofuel policy and corn prices. Section 3 reviews long-run studies of the impact of U.S. corn ethanol production on corn prices. We identify 19 studies released since 2008 that provide sufficient information to include in our review. Because many studies examine several scenarios, we include a total of 83 estimates in the meta-analysis. Section 4 turns to short-run studies. We normalize the corn price results to allow for comparisons with the long-run studies, but we do not perform a meta-analysis in this section because only six short-run studies are available. Section 5 discusses the link between biofuels-driven commodity price increases and food security. A final section concludes by summarizing the findings and identifying areas for further research.

2. Background: Historic U.S. Policy and Price Trends

Ethanol is the primary biofuel produced in the United States, with corn-based ethanol comprising more than 90 percent of domestic ethanol production (U.S. DOE 2011). From 2000 to 2012, U.S. ethanol production increased by more than 700 percent, from 1.6 billion gallons to 13.3 billion gallons. As shown in Figure 1, the percentage of U.S. corn harvest diverted to ethanol production has steadily increased from less than 10 percent to over 40 percent. Over the same period, the real corn price received by farmers has more doubled. Other crop prices have also increased, as cropland has been reallocated in response to rising prices.

Figure 1: Annual Corn Prices and Percent Corn Production Used for Ethanol

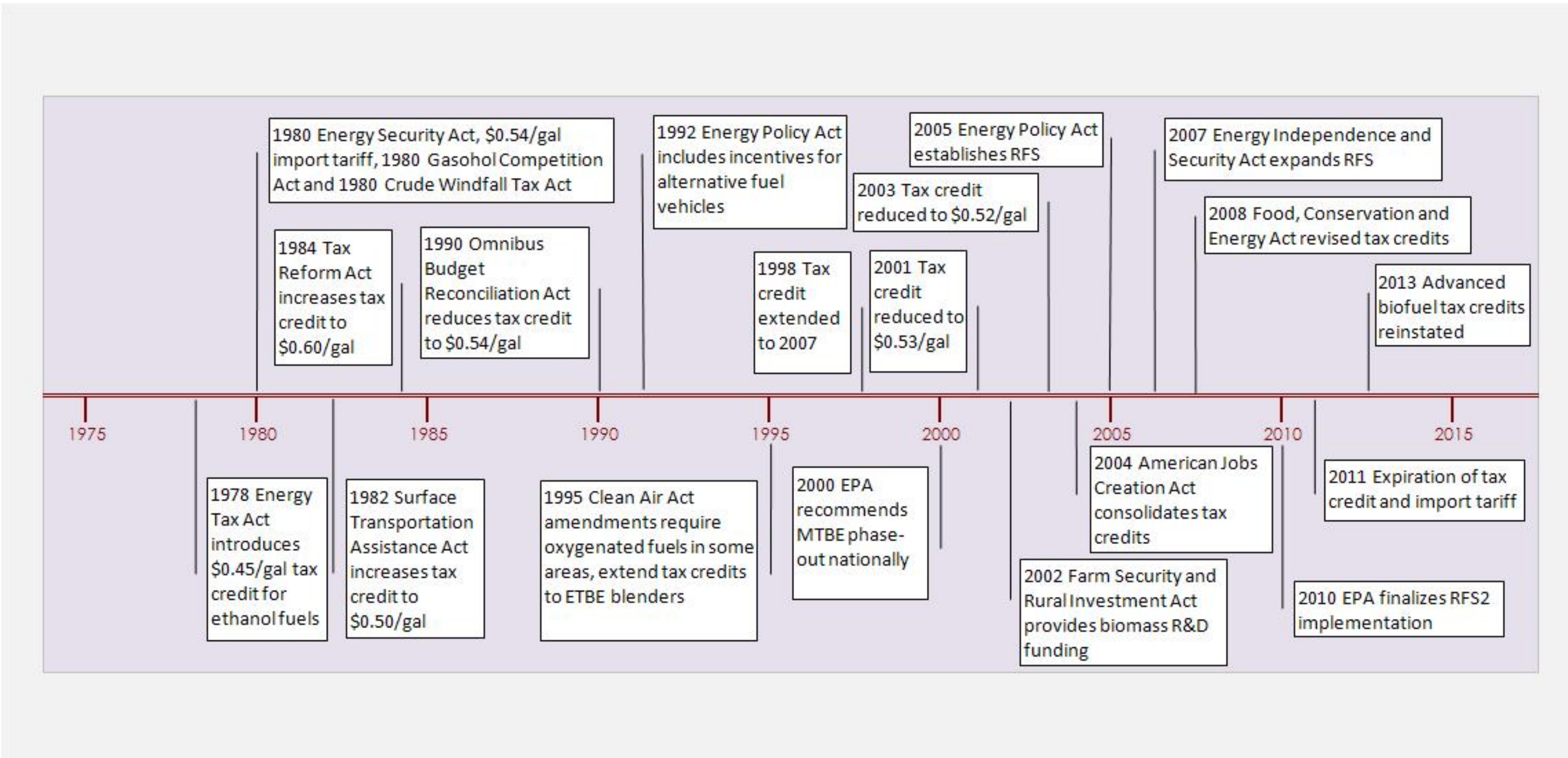


Source: USDA Economic Research Service Feed Grains Database (USDA 2013b)

The rapid increase in food crop prices from 2006 to 2008 coincided with a dramatic expansion of the U.S. Renewable Fuel Standard (RFS), highlighting the blending mandate as a potential driver of price trends. However, the RFS was only the latest in a series of policies promoting renewable fuels in the United States stretching back three decades. The U.S. ethanol policy timeline (Figure 2) illustrates the policy changes that have occurred over the last 35 years. Marking the beginning of U.S. biofuel policy support, the 1978 Energy Tax Act included a $0.45 tax credit for fuels at least 10 percent ethanol by volume. The Energy and Security Act of 1980 provided incentives for ethanol producers in the form of insured loans, price guarantees and purchase agreements. In the same year, Congress levied a $0.54/gal import tariff and passed the 1980 Gasohol Competition Act, which banned retaliation against ethanol retailers. The 1980 Crude Windfall Tax Act extended the ethanol-gasoline blend tax credit. The size of subsidies steadily increased due to additional legislation in the 1980s. The 1992 Energy Policy Act defined blends with 85 percent ethanol as alternative transportation fuels and set requirements and tax credits for the adoption of alternative fuel vehicles. The ethanol industry was further strengthened during the 1990s and 2000s due to oxygenate mandates for gasoline and state-level bans of methyl tert-butyl ether (MTBE). The Farm Security and Rural Investment Act (or Farm Bill) of 2002 provided additional support to the industry by creating support programs and allocating funding for research and development of biomass energy projects. The American Jobs Creation Act of 2004 consolidated existing tax credits under the volumetric ethanol excise tax credit.

The 2005 Energy Policy Act established the RFS, mandating the blending of 7.5 billion gallons of renewable fuel with gasoline annually by 2012. The Energy Independence and Security Act (EISA) of 2007 expanded these requirements, setting a target of 36 billion gallons of biofuels to be produced or imported by the United States annually by 2022, and establishing greenhouse gas (GHG) reduction criteria. This updated Renewable Fuel Standard (referred to as RFS2) divided renewable fuels into four different categories based on feedstock and GHG reductions and set specific targets for cellulosic and other advanced biofuels. For instance, corn ethanol can be used to satisfy up to 15 billion gallons of the biofuels mandate starting in 2015. The Food, Conservation and Energy Act (2008 Farm Bill) extended the import tariff, reduced the corn-based ethanol tax credit, and increased the tax credit for cellulosic ethanol blends. In 2010, the EPA finalized regulations to implement the RFS2 program. The ethanol production tax credit and the import tariff expired at the end of 2011 (though cellulosic biofuel and biodiesel tax credits were temporarily extended in 2013), establishing production mandates as the principal government support system for a growing U.S. biofuel industry.

Figure 2: History of U.S. Ethanol Policy



Unless crop production is perfectly elastic, diversion of some portion of the corn harvest for use as biofuel feedstock is bound to put upward pressure on food crop prices, other market fundamentals held equal. However, a correlation between biofuel production and food crop prices is not sufficient to infer a causal relationship or to parse the exact contribution of biofuels to food crop price increases. As agricultural commodity prices spiked in 2008, researchers increasingly turned their attention toward this question.[4]

A slew of studies from the academic and gray literatures in 2008 and 2009 contributed to the debate about rising food crop prices (Timilsina and Shrestha 2010). Studies from this period ranged from qualitative discussions to back-of-the-envelope calculations to formal quantitative exercises using partial or general equilibrium economic models. While the potential role of biofuels garnered considerable attention, the literature identified several other contributors to the food price spike on both the demand and supply sides. They included rising food demand due to higher population and income levels in developing countries, drought in major exporting countries, trade restrictions, devaluation of the U.S. dollar, and speculation in commodity markets (Abbott, Hurt & Tyner 2009, Collins 2008, Mitchell 2008, Trostle 2008).

The price of energy also received significant attention for contributing to higher food crop prices, though it is difficult to isolate its effect from that of biofuel production. Oil prices reached $133 per barrel at the peak of the commodity price rise in July 2008, an increase of 94 percent from 2007. Oil prices increase the price of food crops directly by pushing up the cost of inputs like petroleum-based fertilizer and indirectly by making biofuels more competitive with

[4] Another controversy surrounding biofuels is their greenhouse gas (GHG) impact, accounting for indirect market-driven factors like land use change. An extensive literature has developed around this question since 2008, starting with Searchinger et al. (2008). We do not address the issue of biofuel GHG emissions in this paper, except to note that a lower land supply elasticity would tend to minimize GHG emissions due to the clearing of native vegetation but also lead to steeper crop price increases in response to biofuel expansion. Several studies whose main focus is estimating the lifecycle GHGs associated with biofuel production also produce estimates of crop price impacts that we included in our review of long-run studies.

gasoline, spurring diversion of crop feedstocks from food to fuel (Baffes & Haniotis 2010). Tenenbaum (2008) highlights the connection between food crop prices and oil prices, suggesting that high oil prices may intensify competition between these commodities. In response to a request by Texas to partially waive the RFS2 requirements, EPA (2008) found that the mandate was likely not binding because high oil prices increased demand for ethanol even absent the mandate. This result demonstrates that biofuel production need not always be policy-driven; market forces can also stimulate demand.

Despite some agreement about the collection of factors responsible for increasing agricultural commodity prices in 2008, the literature has yielded wildly disparate estimates for the magnitude of the effect caused by biofuels. The National Research Council's (2011) report on the Renewable Fuel Standard presents estimates for the contribution of biofuels to the increase in corn prices during 2007-2009 from nine studies, with results ranging from 17 percent to 70 percent.[5] Although these analyses purportedly address a single policy question, a closer look reveals that they do not yield an apples-to-apples comparison. Besides using distinct analytic approaches, the studies examine different policy instruments, different world regions' biofuel targets, and even different timeframes within the 2007-2009 period. These factors, as well as assumptions about demand and supply elasticities and whether indirect effects are included, can have a large effect on the results (Baier et al. 2009). Another review of nine biofuel expansion studies (Zhang et al. 2013) examines the reasons why the range in estimated food crop price impacts is so large. The authors identify several potentially important differences, including modeling structure, international trade, co-products, land supply elasticity, and energy market

[5] The NRC report includes two additional studies (Banse et al. 2008 and Fischer et al. 2009) in its review that are not comparable because they present estimates of the aggregate increase in crop prices due to biofuels relative to a lower- or no-biofuels reference scenario rather than estimates of the proportion of the total increase in crop prices due to biofuels.

assumptions. However, they stop short of any quantitative analysis to parse the relative importance of these factors in driving the results.

The National Research Council (2011) also makes the important point that food crop price increases do not translate into commensurate changes in retail food prices. They find that a 20 to 40 percent rise in corn prices would only cause a one to two percent increase in the retail price of grocery food items in the US. Babcock (2010) asserts that the price of corn is one of the most important factors in determining the cost of livestock and related products, because it serves as a reference price for other key carbohydrate sources, such as barley and wheat. However, Baier et al. (2009) note that the prices for processed goods are driven more by labor, packaging, marketing and transport costs than by the raw commodity prices. Food crop price changes are likely to have bigger impacts on consumers in developing countries because they typically rely more heavily on raw agricultural products and spend a greater portion of their incomes on staple foods (Roberts and Schlenker 2013; Zhang et al., 2013; Runge and Senauer, 2007).

In the next section of our paper, we take a systematic look at the factors that account for the wide range in biofuel impacts on food crop prices. While the studies mentioned above take a retrospective look at the period surrounding food crop price spikes in 2008, we focus instead on prospective, long-run analyses of the effect of biofuel policies on agricultural commodity prices.

3. Long-Run Effects of U.S. Ethanol Expansion on Corn Prices

Recent years have seen a proliferation of studies projecting long-run effects of biofuel expansion on agricultural commodity markets. Such studies can help anticipate average impacts in the future, accounting for likely market responses and technological progress, but they can also mask the potential for short-term fluctuations that could adversely affect food security. This section reviews recent estimates of the long-term impact of biofuel expansion on agricultural commodity prices. We examine a few different measures of the estimated price impact, including both absolute and normalized price changes. We also conduct a meta-analysis to consider several factors that may drive the differences in results across studies.

We limit our review to studies that estimate the impact of U.S. corn ethanol production on corn prices (or a close proxy for corn prices such as grain prices) by comparing a business-as-usual baseline with one or more policy scenarios. While long-run analyses have considered biofuels in different world regions, the effects of increased U.S. corn ethanol production have garnered particular attention. Most of the studies identified examine the EISA Renewable Fuels Standard (RFS2) as a main driver of ethanol expansion, but some also consider growth fueled by other domestic or international policies or market forces.[6]

We identify relevant studies by searching academic databases including EconLit and Google Scholar, as well as checking the references of already-identified studies. We limit our review to original quantitative analyses such as econometric analyses or computable equilibrium model simulations that estimate changes in grain prices and ethanol production levels.[7] We also focus on studies that hold constant across the baseline and policy scenarios other potential exogenous drivers of crop price changes over time, such as income and population growth.[8] As noted above, we focus here on long-run studies that implicitly or explicitly allow markets time to adjust to new policy and market signals. Empirical estimates of short-run impacts are discussed

[6] While we include studies that examine biofuel policies in other world regions *in addition* to the U.S., we exclude studies primarily focusing on other world regions (e.g., Banse et al. 2008, who focus on the EU, and Timilsina et al. 2012, who assess potential global production, of which US production makes up less than one percent).
[7] We obtained information about price effects directly from the study authors when it was not reported in the paper (Anderson and Coble 2010, Chakravorty et al. 2012, and Tyner et al. 2010).
[8] One exception to this criterion is Fernandez-Cornejo et al. (2008), who construct a baseline that is not a true business-as-usual projection because it holds yields constant at 2005/06 levels, while accounting for yield growth only in the policy scenario. Thus, the policy scenarios encompass changes in both yields and biofuel targets.

in section 4. Because of the desire to reflect the most recent research, we include journal articles, reports from government agencies or international organizations, and working papers completed between 2008 and 2013 in our review. This time period is highly relevant for understanding the impacts of current policy, as the ramp up of renewable fuel requirements included in EISA began in 2008. When multiple studies from a research group use the same model and similar baseline and policy scenarios, we select only one for inclusion; in this case, we prioritize recent journal articles, analyses focusing on RFS2 as a driver of biofuel expansion, and the most recent working paper if a journal article does not exist.

We identify 19 studies meeting these criteria. They include 13 journal articles, three working papers, and three government or international organization reports. Table 1 lists the studies and reports the range of estimated corn price changes. Several studies examine multiple scenarios, yielding a total of 83 estimates. Seventy-three of these represent corn ethanol expansion scenarios, while ten of them examine a decrease in corn ethanol production. For scenarios that examine a decrease in corn ethanol, we report the absolute value of the change in prices resulting from the drop in ethanol production.

Table 1. Long-Run Studies Estimating Impact of U.S. Corn Ethanol on Corn Prices

Study	Model	Number of scenarios	Policy instrument	Corn price change*
Journal articles				
Anderson & Coble	Probabilistic supply and demand model	1	RFS2	7%
Chen & Khanna	BEPAM	6	RFS2, tax credits, import tariffs	24%-52%
Cui et al.	Multi-market model	5	RFS2; other optimal and suboptimal biofuel policies	17%-44%†
Fernandez-Cornejo et al.	FARM II	2	RFS2 & Brazilian ethanol policy	23%
Hayes et al.	FAPRI-CARD	2	RFS2, tax credits, import tariffs	19%-22%
Hertel et al.	GTAP-BIO	2	RFS2	16%-18%
Hochman et al.	Supply and demand model of fuel and agricultural markets	2	100% decrease in ethanol production	7%-12%†
Huang et al.	CAPSiM-GTAP	2	RFS2, EU, and Brazilian biofuel policy; market-driven expansion	15%-50%
Meyer & Thompson	FAPRI-MU	3	RFS2 with partial cellulosic waiver	-0.2%-13%
Mosnier et al.	GLOBIOM	8	Deviations from RFS2	0%-13%†
Roberts & Schlenker	Supply and demand model	2	RFS2	20%-30%
Rosegrant et al.	IMPACT	2	RFS2, EU, and Brazilian biofuel policy; doubling existing targets	26%-72%
Tyner et al.	Partial equilibrium model	14	RFS2, fixed and variable subsidies	7%-71%
Working papers				
Bento et al.	Dynamic multi-market model	4	RFS2, tax credits	12%-25%
Chakravorty et al.	Dynamic multi-market model	2	RFS2 and EU biofuel policy	0.5-19%
Roberts & Tran	Competitive storage model	9	RFS2	14%-44%
Government/international organization reports				
OECD-FAO	AGLINK-COSIMO	1	RFS2 and EU biofuel policy; removal of policy support	6%-7%†
Gehlhar et al.	USAGE	6	RFS2	3%-5%
U.S. EPA	FAPRI-CARD, FASOM	2	RFS2	3%-8%

* Five studies examine the price change of a commodity other than corn: Chakravorty et al. (2012b) examine cereals, OECD-FAO (2008) and Hertel et al. (2010) use coarse grains (comprised primarily of corn), and Roberts and Schlenker (2013) and Roberts and Tran (2012) use a calorie-weighted average of corn, soy, rice, and wheat.
† The cross denotes studies that include scenarios examining a decrease rather than an increase in corn ethanol. We report the absolute value of the price change for these scenarios.

An initial glance reveals a striking range of estimates. At the high end, Rosegrant et al. (2008) project that doubling RFS2 and other world biofuel policy targets would raise corn prices by 72 percent relative to business-as-usual, while at the low end, Meyer and Thompson (2012) estimate that a small expansion in first-generation biofuels that occurs indirectly in response to a large decrease in cellulosic ethanol production could lead to a slight *drop* in corn prices of less than one percent in one of their scenarios. Even when we focus on the 31 scenarios that examine RFS2 alone, holding constant other policy and market drivers, the range of price effects spans an order of magnitude—from three percent (U.S. EPA 2010 and Gehlhar et al. 2010) to 71 percent (Tyner et al. 2010). This variation is similar to the range reported in other reviews such as Zhang et al. (2013) and National Research Council (2011).

What could account for such divergent estimates of food crop price impacts from the same policy? Each study and scenario varies along many dimensions, from assumptions about international biofuel policies to the year for which projections are made. Zhang et al.'s (2013) literature review highlights model structure, land supply assumptions, international trade, co-products, scenario design, agriculture-fuel market linkages, crude oil price assumptions, and the elasticity of substitution between biofuels and petroleum as key assumptions but does not isolate the contribution of each to the price impact of biofuels on agricultural commodities. We more formally investigate the role that some of these (and other) factors play in our meta-analysis.

Table 2 provides summary information for several factors that we were able to quantify across most or all of the studies.[9] The first of these is modeling approach. Most studies use computable equilibrium models, whether partial equilibrium (PE) or general equilibrium (GE) models. PE models analyze the impact of a policy change on one or more markets and do not take into account all sectors in a given economy. PE models are sometimes criticized for their

[9] Appendix Table A provides the full dataset for the long-run studies.

inability to control for interactions between all related markets or fully account for aggregate economic effects, but they are particularly useful for investigating discrete relationships that might otherwise be missed in models designed to consider macroeconomic implications. In contrast, GE models simulate all interconnected markets in the economy. One drawback of GE applications in biofuel analysis is that they are highly aggregate representations of the economy, such that important details of the agriculture and energy sectors are sometimes omitted, but GE models have represented the bioenergy sector with varying degrees of detail (Kretschmer and Peterson 2010). GE models also tend to use larger implicit supply elasticities than PE models (Kretschmer and Peterson 2010).

Table 2. Key Variations across Long-Run Ethanol Studies

	Mean*	Std dev	Min	Max	Obs
Baseline corn ethanol (bgal)**	7.7	4.7	0	20.6	83
Change in corn ethanol from baseline to policy (bgal)	7.0	7.9	-7.5	35.2	83
GE model (1 = yes, 0 = no)	21%	0.4	0	1	83
Year†	2015	6.4	2005	2030	83
Ethanol co-products included (1 = yes, 0 = no)	78%	0.4	0	1	83
Change in other biofuels from baseline to policy (bgal)‡	9.1	10.1	-9	26.9	43
Corn (vs. aggregate commodity) (1 = yes, 0 = no)	74%	0.4	0	1	83
No oil market (1 = yes, 0 = no)	26%	0.4	0	1	83
Baseline crude oil price ($/barrel)§	85.5	27.7	38	160	55
Published article (1 = yes, 0 = no)	68%	0.5	0	1	83

*Each study is given equal weight when calculating the mean and standard deviation to avoid giving more weight to studies with a greater number of scenarios.

** Rosegrant et al. present tons of biofuel feedstock. We converted these quantities to biofuel volumes using information provided by the authors (Msangi personal communication, September 2013)

† OECD-FAO reports results for 2013-2017, and Meyer & Thompson report results for 2016-2020; we use the average year from each study in our quantitative analysis.

‡ Other biofuels include all domestic and international biofuels besides corn ethanol, such as soy biodiesel, sugarcane ethanol, and cellulosic biofuels. Summary statistics for non-corn-ethanol biofuel volumes are only given for those studies that model them.

§ Oil price summary statistics are only reported for studies that incorporate oil markets into the model. Baseline oil prices were not reported in several of these studies and had to be obtained elsewhere or estimated. Zhang et al. (2013) provide estimates for the oil prices used in Fernandez-Cornejo and Hertel et al. We used historic data from EIA (2013) to obtain the oil prices in Hochman et al. Gasoline price assumptions for Chen and Khanna were found in Chen (2010) and converted to oil prices using the assumption that each $1 per barrel increase in oil translates to a 2.4 cent per gallon increase in gasoline (EIA 2012).

Of the studies in this review, four use GE models and fourteen use PE models. Among the GE studies, Hertel et al. (2010) use the GTAP-BIO global trade model, which includes land cover data corresponding to 18 agro-ecological zones, to estimate the effects of RFS2 on global land use and GHG emissions while considering market-driven responses in food demand and crop yields. Huang et al. (2012) use a similar GTAP-based CGE model updated to incorporate the biofuels sector to estimate the price effects of global biofuel expansion due to mandates and market conditions.[10] Fernandez-Cornejo et al. (2008) apply FARM II, a USDA-developed CGE model linked with land cover and climatic data for different agro-ecological zones, to assess the impacts of RFS2 and Brazilian sugarcane ethanol production under different crop yield growth assumptions. A USDA Economic Research Service report by Gehlhar et al. (2010) examines the effects of RFS2 under different assumptions about oil prices and biofuel tax credits using USAGE, a CGE model.

Turning to the PE studies, most rely on detailed models of agricultural markets that capture interactions across commodities. Rosegrant et al. (2008) examine the effects of both continuing and doubling global biofuel policy targets using IMPACT, a global PE model of the agricultural sector. Tyner et al. (2010) use a PE model to estimate the effects of RFS2 and other biofuel subsidies under varying oil price assumptions. OECD-FAO (2008) assesses the impacts of world biofuel expansion (including the pre-EISA RFS) using the Aglink-Cosimo modeling system. The Food and Agriculture Policy Research Institute model maintained by the Iowa State University Center for Agricultural and Rural Development (FAPRI-CARD), a PE model with detailed representations of domestic and international agriculture and ethanol markets, is used by Hayes et al. (2009) to examine the effect of RFS2 and biofuel tax credits under different oil

[10] The authors also use CAPSiM, a PE model of the Chinese agricultural sector, to examine the implications for income and agricultural production in China. The CAPSiM portion of the analysis is excluded from our review of long-run studies due to its non-US focus but is discussed in the section on food security.

prices. U.S. EPA (2010) also uses the FAPRI-CARD model in its Regulatory Impact Assessment for RFS2, as well as using the Forest and Agricultural Sector Optimization Model (FASOM), a dynamic model of U.S. agriculture and forestry, as an alternative approach. (Beach and McCarl 2010 provide a description of the FASOM approach.) Meyer and Thompson (2013) apply FAPRI-MU, a different version of the FAPRI model maintained at the University of Missouri that focuses on domestic markets, to conduct a stochastic analysis of the effects of increasing corn ethanol and imported advanced biofuels to make up for a partial waiver of the cellulosic biofuels mandate. Mosnier et al. (2013) examine scaling RFS2 up or down using the Global Biosphere Management Model (GLOBIOM), an international model of land-based sectors including agriculture, forestry, and bioenergy.

A few papers use multi-market models that integrate agriculture and fuel markets but do not explicitly represent other sectors of the economy. Chakravorty et al. (2012b) use a dynamic PE model with endogenous land allocation to examine the effect of RFS2, EU, and middle-income countries' biofuel targets on world food prices and GHG emissions. Chen and Khanna (2013) use the Biofuel and Environmental Policy Analysis Model (BEPAM), a dynamic non-linear programming model of agricultural and fuel markets, to study RFS2, biofuel tax credits and import tariffs under varying assumptions about imported sugarcane ethanol supply. Bento et al. (2012) also use a dynamic multi-market model of land, food, and fuel markets to examine net GHG impacts of RFS2 with and without volumetric tax credits. Cui et al. (2011) construct a highly stylized model of U.S. corn and petroleum markets to assess a variety of biofuel policies, including RFS2 and alternative fuel tax and biofuel subsidy combinations. Hochman et al. (2010) examine the relationship between energy and agricultural markets, accounting for potential responses by OPEC to increased biofuel production.

The three remaining studies do not use detailed computable equilibrium models of the agriculture sector and instead conduct relatively simplified PE analyses of crop supply and demand that do not model interactions among agricultural commodities. However, they all involve original analysis beyond a simple application of supply and demand elasticities estimated elsewhere that warrants inclusion in our review. Roberts and Schlenker (2013) conduct an econometric analysis using weather shocks to estimate crop supply and demand elasticities and then apply them to calculate agricultural commodity price effects of biofuel expansion. Roberts & Tran (2012) use a competitive storage model to estimate the effects of RFS2 on world food prices as a function of how much time markets have to adjust to the policy.[11] Anderson & Coble (2010) estimate the price impacts of RFS2 using a rational expectations framework that accounts for the stochastic nature of supply and demand shocks.

The different objectives of the studies just described suggest that their baseline and policy scenario corn ethanol production levels vary considerably. Even though several studies model the RFS2, which calls for 15 billion gallons of renewable fuels (most likely corn ethanol) starting in 2015, there are large differences in baseline corn ethanol volumes, leading to different estimates of the expansion in production needed to achieve the mandate. For instance, U.S. EPA (2010) projects 12 billion gallons of corn ethanol under business-as-usual conditions. In contrast, Tyner et al.'s (2010) $40 per barrel oil scenario yields no ethanol without the mandate. These studies estimate baseline corn ethanol production endogenously as a function of oil prices, crop yields, and other parameters. Other studies fix the baseline exogenously, typically based on production in a recent year (e.g., Gehlhar et al. 2010, Roberts and Tran 2012). Some of these studies include scenarios that go beyond the RFS2 mandate to examine the impacts of more

[11] In this section, we focus on the long-term equilibrium price results estimated by Roberts and Tran (2012). In the next section, we discuss the paper's estimated short-term price effects when the policy shock is unanticipated.

aggressive expansion (e.g., Rosegrant et al. 2008), while others examine the effects of reducing or entirely eliminating biofuel production (e.g., Hochman et al. 2010). Tyner et al. (2010) also includes scenarios in which the ethanol mandate is non-binding; due to high oil prices, baseline ethanol production surpasses the mandate even absent the policy. These scenarios illustrate the diversity of conditions examined across the studies, but they are excluded from our analysis because they provide no information about the change in crop prices in response to a change in ethanol production.

Another relevant assumption is the treatment of ethanol co-products. Distillers' dried grains (DDGs) are a joint output of the corn ethanol production process that can be used as animal feed, mitigating some of the effect of higher grain prices on the livestock industry. Corn oil is another potential output that could itself be used to produce biodiesel. Most recent analyses account for at least the DDG co-product, but three of the earlier studies do not (Rosegrant et al. 2008, Fernandez-Cornejo 2008, Anderson and Coble 2010). Roberts and Schlenker (2013) and Roberts and Tran (2012) consider scenarios with and without recycling one-third of the calories of corn ethanol as livestock feed.

The projection year differs across studies, with several studies estimating results out to the year 2020 or beyond, and others holding conditions at status quo levels except for the biofuel policy shock. The projection year serves as an indicator for assumptions about food demand, input costs, and crop yields, which are typically not reported directly and thus could not be included in our dataset.[12] Crop yields in particular are key assumptions that could affect the price impacts from biofuel production. Most studies assume steady improvement in crop yields over time, thus lessening competitive pressure for land in the future. Some studies use USDA

[12] The fact that some studies aggregate multiple crops could make yield and input cost assumptions difficult to compare as well.

projections to estimate future crop yield gains (e.g., U.S. EPA 2010), while others implicitly hold yields constant at current levels (e.g., Roberts and Schlenker 2013, Tyner et al. 2010). Some analyses also allow endogenous crop yield changes in response to the policy (e.g., Hertel et al. 2010). While projection year is not a perfect proxy for crop yields and other technological improvements, it can at least partially control for these critical assumptions. In the next section on short-run price impacts, we discuss the impact of drought conditions that sharply curtail yields.

The representation of oil markets also varies across studies. Five of the studies in our review do not incorporate oil prices at all; food crop prices and biofuel production are modeled as a function of agricultural market parameters and sometimes other exogenous drivers like income, but not energy markets (Anderson and Cobble, Mosnier et al., Roberts and Schlenker, Roberts and Tran, and Rosegrant et al.). The remaining studies model the effect of oil prices on agricultural markets, and some of them also account for the feedback effect of biofuels on the price of fuel. They reflect the fact that oil prices are a key determinant of ethanol production absent a binding mandate. In Huang et al.'s (2012) study, a doubling of oil prices from $60 per barrel in the baseline to $120 per barrel in the market-driven expansion scenario leads to an eightfold increase in corn ethanol, making the government mandate non-binding. Tyner et al. (2010) find that oil price assumptions have a large effect on baseline ethanol production, and hence the impact of RFS2 and other biofuel policies on ethanol expansion.[13] High oil prices spur higher ethanol production in the baseline, so imposing a mandate will lead to a smaller increase in ethanol production, and ultimately smaller commodity prices changes relative to the baseline

[13] Thompson et al. (2009) show similar results in an analysis using the FAPRI-MU model. However, this study was excluded from the meta-analysis in favor of a more recent publication using FAPRI-MU by the same research group (Meyer and Thompson 2012).

than a situation with lower oil prices. At the same time, because petroleum is an input in crop production, higher oil prices can lead to higher corn prices.

The elasticity of substitution between biofuels and oil is still another potentially important factor. If studies assume that technical barriers to increased substitutability of biofuels for petroleum such as the ethanol "blend wall" are overcome, then projections for ethanol expansion would likely be higher.[14] However, the elasticity of substitution is not in our dataset because very few studies report this information.

Another important difference across studies is the inclusion of biofuels other than corn ethanol. Eleven of the 19 studies in our review include scenarios examining a change in US corn ethanol production only. The remaining studies also consider changes in other domestic or international biofuels between the baseline and policy scenarios. Several include increases in soy biodiesel, cellulosic ethanol, or imported advanced biofuels (typically sugarcane ethanol) resulting from the RFS2. Five of these studies model biofuel expansion resulting from policies in the EU, Brazil, and other world regions. It is difficult to disentangle the effect of corn ethanol production on corn prices in studies that model increases in other types of biofuels. Demand for other biofuel feedstocks could raise corn prices indirectly, even in the case of non-food feedstocks, which could still heighten competitive pressures for cropland. For example, one scenario in Meyer and Thompson (2012) finds a decrease in corn prices in response to a substantial fall in cellulosic ethanol production. Price effects in such studies should not be attributed solely to U.S. corn ethanol. In addition, inclusion of advanced technologies like cellulosic ethanol in the modeling framework could serve as a proxy for technological change.

[14] The term "blend wall" refers to the maximum amount of ethanol that can be blended into the fuel supply due to technical and regulatory constraints. Federal regulations do not currently allow use of ethanol blends exceeding ten percent in conventional vehicles manufactured before 2001.

As already mentioned, most studies estimate changes in corn prices, but a few examine prices of a more aggregate measure incorporating other agricultural commodities. Hertel et al. and OECD-FAO examine coarse grains, which are primary corn but also include other grains used as livestock feed such as sorghum. Roberts and Schlenker (2013) and Roberts and Tran (2012) examine a calorie-weighted commodity basket comprised of corn, soy, rice, and wheat. Chakravorty et al. (2012b) provide information on an aggregate commodity that includes all grains, starches, sugar and sweeteners and oil crops (personal communication). While these different metrics make it more difficult to compare results across studies, we include these studies in our review because corn comprises a substantial amount of the aggregate commodity in all cases. In addition, corn, other grains, and soy serve as substitutes and compete for land and other inputs, making their prices highly correlated (Roberts and Schlenker 2013). It is also worth noting that all of the studies included here estimate effects on raw agricultural commodities; thus, none of them speak directly to the issue of biofuels' impact on retail food prices.

Of the studies that focus on corn prices, more than half report actual prices from the baseline and policy scenarios, but several studies only give percent changes in price in the policy scenario relative to the baseline. Most studies examine US corn prices, though three studies (Chakravorty et al., OECD-FAO, and Rosegrant et al.) focus instead on world corn prices. Pass through of corn price shocks from the US to other countries could be muted due to trade barriers, which would make corn price impacts from US biofuel policy lower than impacts on corn markets domestically.

The elasticity of demand for food is an assumption that could have important implications for price impacts but is only reported in a few studies and is therefore excluded from our dataset. A few studies that highlight the elasticity of demand find that the impact of biofuels on crop prices rises if demand for food is less elastic (Hertel et al. 2010, Roberts and Tran 2012). Roberts and Schlenker (2013) derive new estimates for the elasticity of demand for food calories from corn, soy, rice, and wheat ranging from -0.05 to -0.08, though the demand for corn alone is likely to be more elastic since the weighted food metric includes corn's major substitutes.

Normalized Corn Price Impacts

In our view, the differences in the magnitude of the change in corn ethanol production between the baseline and policy scenario create the most fundamental obstacle to comparing results across studies. For instance, the divergence in price impacts from RFS2 estimated by U.S. EPA (2010) and under the Tyner et al. (2010) $40 per barrel oil price scenarios is unsurprising considering that they anticipate vastly different increases in the level of ethanol production (2.7 billion gallons and 15 billion gallons, respectively). In effect, the price impacts reported in Table 1 conflate changes in ethanol production levels and changes in corn prices per unit of ethanol expansion.

One way to make the results more comparable across studies is to examine the change in corn price while controlling for the change in corn ethanol production. We do this by converting the results from each study into two common metrics: the percent change in corn price per billion-gallon increase in corn ethanol (a semi-elasticity measure), and the percent change in corn price per percentage point increase in corn ethanol (an elasticity measure). In other words, we normalize the change in prices by the change in corn ethanol quantity, where the latter is measured in either volumetric or percentage terms.

Table 3 presents the normalized corn price results compared with the non-normalized price changes across all scenarios in each study. As in Table 1, we report the absolute value of the change in corn price for scenarios that examine a decrease in corn ethanol because these results are typically negative. However, when the price effects are normalized by the change in ethanol volume, the negative signs cancel out yielding effects that are usually positive, so we do not report absolute values for the normalized price effects. Note that Meyer and Thompson and Mosnier et al. include scenarios with counterintuitive results, in that an increase (decrease) in corn ethanol volume accompanies a decrease (increase) in corn price; these scenarios have negative normalized price effects.

Table 3 shows that once we isolate the price effect of biofuels expansion while holding the level of expansion constant, the range of estimates within each study shrinks greatly even when the absolute price differences are sizable. For example, the seven to 71 percent absolute price impact range estimated by Tyner et al. shrinks to a three to five percent increase per billion gallons of ethanol production. Similarly, Rosegrant et al.'s range of 26 to 72 percent narrows to an estimate of 2.2 to 2.6 percent per billion gallons. Across most of the studies, the range of price effects spans only one or two percentage points. A similar result holds for the percent price change per percentage increase in corn ethanol production; the effects fall within a relatively narrow band. This narrowing of estimates confirms that a large portion of the variation in reported price effects from ethanol production stems from the differences in corn ethanol volumes examined within studies.

Chakravorty et al. (2012a) find that an additional 16 to 42 million people in India may be forced into poverty after accounting for changes in consumption in response to changes in prices across markets, including higher agricultural prices and rising agricultural wages and incomes. The higher estimate is predicated on full pass-through of world prices into the domestic market, while the lower estimate assumes some government intervention to prevent full pass-through. Rosegrant et. al (2008) find that increased ethanol expansion results in significantly reduced calorie availability and heightened levels of regional malnourishment in 2020, with particularly large effects occurring in sub-Saharan Africa (four and eight percent, respectively, under moderate and drastic biofuels expansion), a region already suffering from food scarcity.

Bryant et al. (2010) predict moderate effects on the number of people at risk of hunger. This moderate effect may be due to the relatively small increase in ethanol production that is modeled (five billion gallons). However, the authors do not directly report the change in corn or food prices from their model, so a comparison to the price effects of other studies is not possible. The variation in their results stems from the proportion of ethanol produced from corn starch versus corn stover; greater reliance on corn stover reduces impacts on hunger.[29] While the predicted effect of ethanol expansion on hunger is relatively small, it is concentrated in a few regions; more than 40 percent of those at risk of hunger are located in China and the Far East.

Fisher et al. (2009) find that 40 million to 140 million more people will be at risk of hunger in 2020 than in the baseline. This translates to between 1.4 million and 2.5 million people per billion gallons of ethanol. While about two-thirds of the cereals needed to produce more ethanol stem from expanded crop production in their model—largely in developed countries—the remaining third derives from reduced consumption for food and feed—largely in developing

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[29] Cellulosic ethanol is available under two scenarios: (1) at today's full cost; and (2) at 55 percent of the full cost. In the first case, 1.25 billon of the five billion gallons of total ethanol produced is met by cellulosic from corn stover. In the second case, four billion gallons of the requirement are met this way.

	RFS2 with partial cellulosic waiver	3.4%	15.5	16.7	corn	2016-2020
	RFS2 with partial cellulosic waiver	12.9%	15.5	19.6	corn	2016-2020
OECD-FAO	RFS2 & EU DRE	6.0%	12.0	15.0	CG	2013-2017
	removal of biofuel policy support	-7.0%	12.0	9.5	CG	2013-2017
Roberts & Schlenker	RFS2, C	20.0%	0.0	11.0	CRWS	2009
	RFS2, no coproducts	30.0%	0.0	11.0	CRWS	2009
Roberts & Tran	RFS2, AE	39.9%	3.9	15.0	CRWS	2015
	RFS2, AE, demand less elastic	44.0%	3.9	15.0	CRWS	2015
	RFS2, AE, demand more elastic	36.4%	3.9	15.0	CRWS	2015
	RFS2, C, demand more elastic	14.4%	3.9	15.0	CRWS	2015
	RFS2, C	15.3%	3.9	15.0	CRWS	2015
	RFS2, C, demand less elastic	16.9%	3.9	15.0	CRWS	2015
	RFS2, demand less elastic	25.8%	3.9	15.0	CRWS	2015
	RFS2, demand more elastic	22.3%	3.9	15.0	CRWS	2015
	RFS2, no coproducts	23.6%	3.9	15.0	CRWS	2015
Rosegrant et al.	Biofuel expansion	26.0%	3.9	16.0	corn	2020
	Drastic biofuel expansion	72.0%	3.9	32.0	corn	2020
Tyner et al.	RFS2	7.4%	13.0	15.0	corn	2006
	RFS2	70.9%	0.0	15.0	corn	2006
	RFS2	65.6%	1.2	15.0	corn	2006
	RFS2	27.2%	8.4	15.0	corn	2006
	fixed subsidy	24.1%	13.0	19.1	corn	2006
	fixed subsidy	20.3%	16.3	21.5	corn	2006
	fixed subsidy	17.4%	18.7	23.3	corn	2006
	fixed subsidy	15.3%	20.6	24.6	corn	2006
	fixed subsidy	7.0%	0.0	1.9	corn	2006
	fixed subsidy	42.1%	1.2	10.7	corn	2006

	fixed subsidy	30.4%	8.4	15.7	corn	2006
	variable subsidy	57.0%	0.0	12.6	corn	2006
	variable subsidy	49.2%	1.2	12.1	corn	2006
	variable subsidy	11.6%	8.4	11.4	corn	2006
U.S. EPA	RFS2	3.4%	12.3	15.0	corn	2022
	RFS2	8.4%	12.3	15.0	corn	2022

SC: Increased sugarcane ethanol supply

CG: coarse grains; CSRW: calorie-weighted average of corn, soy, rice, and wheat

C: with co-products; AE: alternate demand and supply elasticities

N/A: Oil price is not applicable in studies that do not include oil markets in the model.

Table A. Data from Long-Run Ethanol Studies (continued)

Study	Modeling framework	Ethanol coproduct included	Oil price ($/barrel)	Study type	Change in other biofuels (bgal)
Anderson & Coble	PE	N	N/A	journal article	0
Bento et al.	PE	Y	69	working paper	0
	PE	Y	69	working paper	0
	PE	Y	78	working paper	0
	PE	Y	78	working paper	0
Chakravorty et al.	PE	Y	121	working paper	23.1
	PE	Y	105	working paper	0.7
Chen and Khanna	PE	Y	124	journal article	22.7
	PE	Y	124	journal article	19
	PE	Y	124	journal article	19
	PE	Y	124	journal article	20.2
	PE	Y	124	journal article	21.9
	PE	Y	124	journal article	24.2
Cui et al.	PE	Y	63	journal article	0
	PE	Y	63	journal article	0
	PE	Y	63	journal article	0
	PE	Y	63	journal article	0
	PE	Y	63	journal article	0
	PE	Y	63	journal article	0
Fernandez-Cornejo et al.	GE	N	38	journal article	5.3
	GE	N	38	journal article	5.3
Gelhar et al.	GE	Y	80	government	16
	GE	Y	101	government	16
	GE	Y	101	government	16
	GE	Y	80	government	16

	GE	Y	101	government	16
	GE	Y	80	government	16
Hayes et al.	PE	Y	105	journal article	0.2
	PE	Y	75	journal article	18.3
	GE	Y	60	journal article	0
	GE	Y	60	journal article	0
Hochman et al.	PE	Y	62	journal article	0
	PE	Y	77	journal article	0
Huang et al.	GE	Y	60	journal article	21.6
	GE	Y	60	journal article	26.9
Mosnier et al.	PE	Y	N/A	journal article	0.3
	PE	Y	N/A	journal article	0.6
	PE	Y	N/A	journal article	-0.6
	PE	Y	N/A	journal article	-0.3
	PE	Y	N/A	journal article	4.5
	PE	Y	N/A	journal article	9
	PE	Y	N/A	journal article	-9
	PE	Y	N/A	journal article	-4.5
	PE	Y	N/A	journal article	6.3
	PE	Y	N/A	journal article	4.5
	PE	Y	N/A	journal article	9
	PE	Y	N/A	journal article	-9
	PE	Y	N/A	journal article	-4.5
	PE	Y	N/A	journal article	6.3
Meyer & Thompson	PE	Y	112	journal article	-5.6
	PE	Y	112	journal article	-0.3
	PE	Y	112	journal article	-4.6
OECD-FAO	PE	Y	104	international organization	6.1
	PE	Y	104	international organization	-5.4

Roberts & Schlenker	PE	Y	N/A	journal article	0
	PE	N	N/A	journal article	0
Roberts & Tran	PE	N	N/A	working paper	0
	PE	N	N/A	working paper	0
	PE	N	N/A	working paper	0
	PE	Y	N/A	working paper	0
	PE	Y	N/A	working paper	0
	PE	Y	N/A	working paper	0
	PE	N	N/A	working paper	0
	PE	N	N/A	working paper	0
	PE	N	N/A	working paper	0
Rosegrant et al.	PE	N	N/A	journal article	3.8
	PE	N	N/A	journal article	8.1
Tyner et al.	PE	Y	100	journal article	0
	PE	Y	40	journal article	0
	PE	Y	60	journal article	0
	PE	Y	80	journal article	0
	PE	Y	100	journal article	0
	PE	Y	120	journal article	0
	PE	Y	140	journal article	0
	PE	Y	160	journal article	0
	PE	Y	40	journal article	0
	PE	Y	60	journal article	0
	PE	Y	80	journal article	0
	PE	Y	40	journal article	0
	PE	Y	60	journal article	0
	PE	Y	80	journal article	0
U.S. EPA	PE	Y	116	government	2.9
	PE	Y	116	government	14.8

Table B. Long-run Corn Price Responsiveness to Biofuels Expansion Excluding Ethanol Quantities

	Price change
Baseline corn ethanol (bgal)	Excluded
Corn ethanol change (bgal)	Excluded
GE model	-0.0670
	(0.0880)
Projection year	0.0070
	(0.0045)
Co-products included	-0.109*
	(0.0660)
Change in other biofuels (bgal)	0.0076***
	(0.0029)
Corn (vs. aggregate commodity)	-0.0892
	(0.0719)
Oil price ($)	-0.0020*
	(0.0012)
No oil market	-0.146
	(0.134)
Journal article	0.0958
	(0.0768)
Constant	-13.73
	(9.068)
Observations	83
R-squared: overall	0.30
within	0.15
between	0.38
Number of panel groups	19

Table C. Data from Short-Run Stochastic Partial Equilibrium Studies

Study	Scenario	Baseline corn ethanol (bgal)	Policy corn ethanol (bgal)	Commodity	Projection year	Mean baseline corn yield	Consider oil market?	Ethanol coproduct included
McPhail & Babcock (2008)	Mandate	9.5	10.9	corn	2008-2009	151	Y	Y
	Mandate; drought	3.2	10.1	corn	2008-2009	113	Y	Y
	Mandate; bumper crop	11.4	11.4	corn	2008-2009	169	Y	Y
	Mandate; no blender credit	6.2	10.4	corn	2008-2009	151	Y	Y
Babcock (2012a)	No mandate; drought	14.3	12.3	corn	2012-2013	138	Y	
	RM; drought	14.3	12.9	corn	2012-2013	138	Y	
Babcock (2012b)	No mandate; strong drought	13.3	11.5	corn	2012-2013	123.4	Y	
	RM; strong drought	13.3	12	corn	2012-2013	123.4	Y	
Tyner et al. (2012)	RM by 2 BG; strong drought	14.2	12.1	corn	2012-2013	120	Y	
	RM by 2.4 BG; strong drought	14.2	10.7	corn	2012-2013	120	Y	
	RM by 6.05 BG; strong drought	14.2	8	corn	2012-2013	120	Y	
	RM by 2 BG; median drought	14.2	14.2	corn	2012-2013	126	Y	
	RM by 2.4 BG; median drought	14.2	10.7	corn	2012-2013	126	Y	
	RM by 6 BG; median drought	14.2	8	corn	2012-2013	126	Y	
	RM by 2 BG; weak drought	14.2	14.2	corn	2012-2013	132	Y	
	RM by 2.4 BG; weak drought	14.2	10.7	corn	2012-2013	132	Y	
	RM by 6 BG; weak drought	14.2	8	corn	2012-2013	132	Y	
Roberts & Tran (2012)	Unexp mandate	3.9	15	CSRW	2015	126	N	N
	Unexp; less elastic dd	3.9	15	CSRW	2015	126	N	N
	Unexp; more elastic dd	3.9	15	CSRW	2015	126	N	N
	Unexp mandate; C	3.9	15	CSRW	2015	126	N	Y
	Unexp; C; less elastic dd	3.9	15	CSRW	2015	126	N	Y
	Unexp; C; more elastic dd	3.9	15	CSRW	2015	126	N	Y
	Unexp mandate; AE	3.9	15	CSRW	2015	126	N	N
	Unexp; AE; less elastic dd	3.9	15	CSRW	2015	126	N	N

Study	Scenario	Baseline corn ethanol (bgal)	Policy corn ethanol (bgal)	Commodity	Projection year	Mean baseline corn yield	Consider oil market?	Ethanol coproduct included
	Unexp; AE; more elastic dd	3.9	15	CSRW	2015	126	N	N
Roberts and Tran (2013)	RM by 10%; exp; 2012 yield	15	13.5	corn	2013	123.4	N	N
	RM by 10%; unexp; 2012 yield	15	13.5	corn	2013	123.4	N	N
	RM by 20%; exp; 2012 yield	15	12	corn	2013	123.4	N	N
	RM by 20%; unexp; 2012 yield	15	12	corn	2013	123.4	N	N
	RM by 30%; exp; 2012 yield	15	10.5	corn	2013	123.4	N	N
	RM by 30%; unexp; 2012 yield	15	10.5	corn	2013	123.4	N	N
	RM by 40%; exp; 2012 yield	15	9	corn	2013	123.4	N	N
	RM by 40%; unexp; 2012 yield	15	9	corn	2013	123.4	N	N
	RM by 50%; exp; 2012 yield	15	7.5	corn	2013	123.4	N	N
	RM by 50%; unexp; 2012 yield	15	7.5	corn	2013	123.4	N	N
	RM by 10%; exp; 2011 yield	15	13.5	corn	2013	147.2	N	N
	RM by 10%; unexp; 2011 yield	15	13.5	corn	2013	147.2	N	N
	RM by 20%; exp; 2011 yield	15	12	corn	2013	147.2	N	N
	RM by 20%; unexp; 2011 yield	15	12	corn	2013	147.2	N	N
	RM by 30%; exp; 2011 yield	15	10.5	corn	2013	147.2	N	N
	RM by 30%; unexp; 2011 yield	15	10.5	corn	2013	147.2	N	N
	RM by 40%; exp; 2011 yield	15	9	corn	2013	147.2	N	N
	RM by 40%; unexp; 2011 yield	15	9	corn	2013	147.2	N	N
	RM by 50%; exp; 2011 yield	15	7.5	corn	2013	147.2	N	N
	RM by 50%; unexp; 2011 yield	15	7.5	corn	2013	147.2	N	N
	RM by 10%; exp; 2010 yield	15	13.5	corn	2013	152.8	N	N
	RM by 10%; unexp; 2010 yield	15	13.5	corn	2013	152.8	N	N
	RM by 20%; exp; 2010 yield	15	12	corn	2013	152.8	N	N
	RM by 20%; unexp; 2010 yield	15	12	corn	2013	152.8	N	N
	RM by 30%; exp; 2010 yield	15	10.5	corn	2013	152.8	N	N
	RM by 30%; unexp; 2010 yield	15	10.5	corn	2013	152.8	N	N

Study	Scenario	Baseline corn ethanol (bgal)	Policy corn ethanol (bgal)	Commodity	Projection year	Mean baseline corn yield	Consider oil market?	Ethanol coproduct included
	RM by 40%; exp; 2010 yield	15	9	corn	2013	152.8	N	N
	RM by 40%; unexp; 2010 yield	15	9	corn	2013	152.8	N	N
	RM by 50%; exp; 2010 yield	15	7.5	corn	2013	152.8	N	N
	RM by 50%; unexp; 2010 yield	15	7.5	corn	2013	152.8	N	N

RM: Relax RFS2 mandate; CSRW: calorie-weighted average of corn, soy, rice, and wheat; C: with co-products; AE: alternate demand and supply elasticities; Exp: expected; Unexp: unexpected