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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.

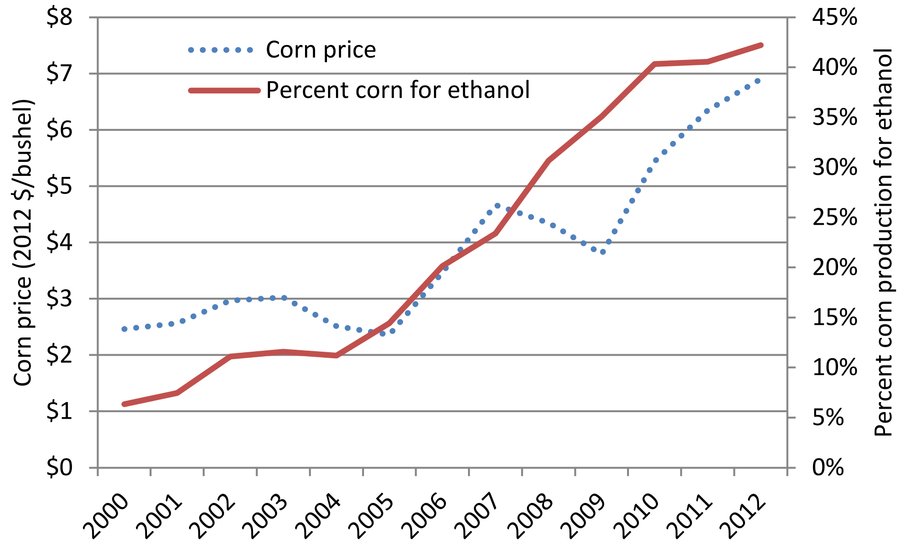
We also examine a small number of studies that explicitly consider the impacts of biofuel policies on food security worldwide. Raw commodities make up a small proportion of the cost of finished food products in high-income countries, muting the effects of commodity price rises, but they may be felt more 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

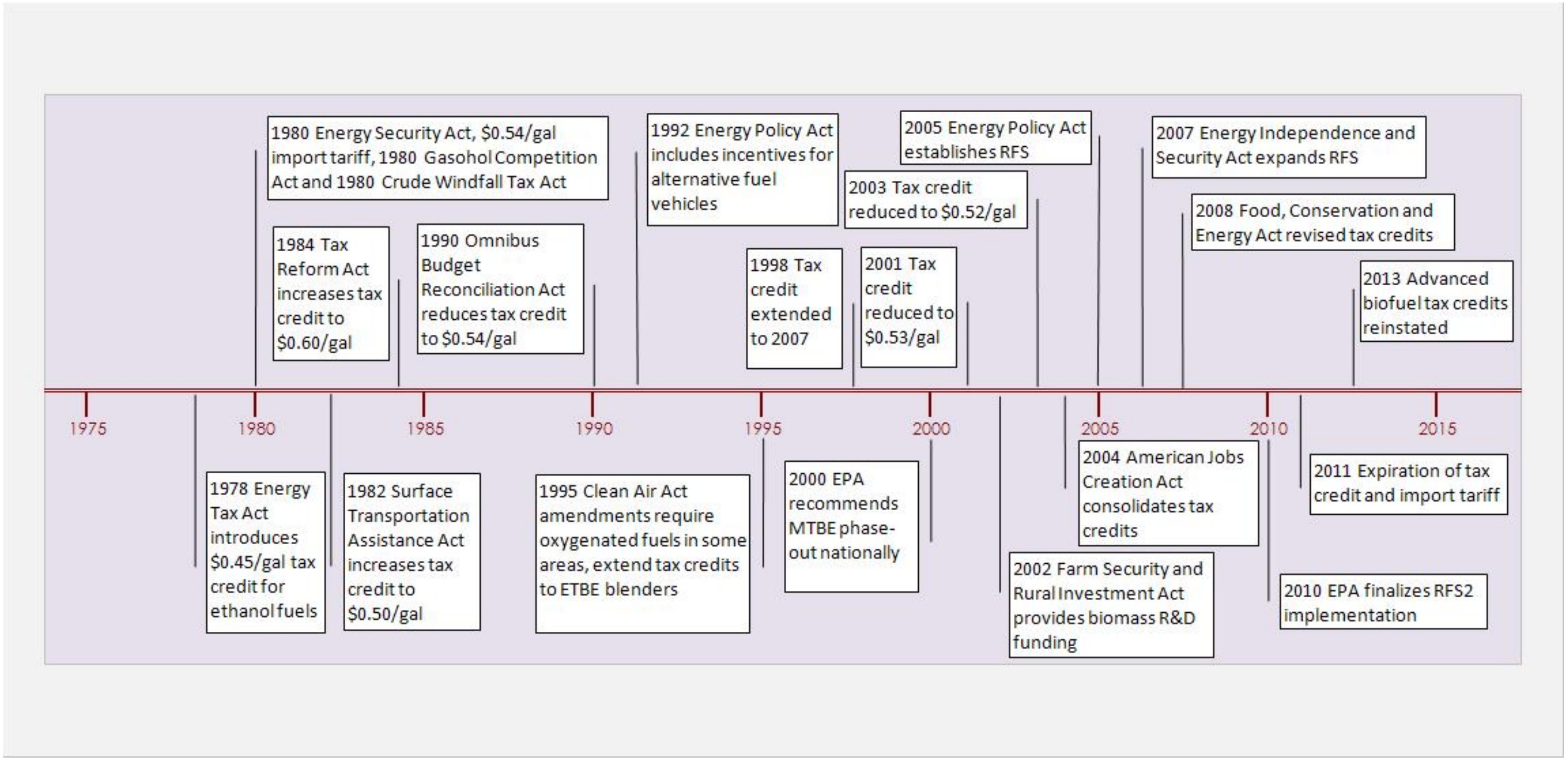


Source: USDA Economic Research Service Feed Grains Database (USDA 2013b)

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

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[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.

Table 3. Long-Run Impact of Corn Ethanol on Absolute and Normalized Corn Prices

Study	Price change	Price change per billion gallon increase in ethanol	Price change per 1% increase in ethanol
Anderson & Coble	7.0%	7.0%	0.60%
Bento et al.	12% - 25%	7.7% - 8.4%	0.90% - 1.01%
Chakravorty et al.	0.5% - 19%	2.9% - 4.6%	0.21% - 0.47%
Chen & Khanna	24% - 52%	3.1% - 5.7%	0.12% - 0.22%
Cui et al.	17% - 44%†	2.1% - 3.8%	0.13% - 0.23%
Fernandez-Cornejo et al.	23%	2.3%	0.11%
Gehlhar et al.	3% - 5%	0.4% - 0.7%	0.04% - 0.05%
Hayes et al.	19% - 22%	2.2% - 2.9%	0.26% - 0.36%
Hertel et al.	16% - 18%	1.2% - 1.3%	0.20%
Hochman et al.	7% - 12%†	1.9%	0.07% - 0.12%
Huang et al.	15% - 50%	1.4% - 1.5%	0.07%
Meyer & Thompson	-0.2% - 13%	-2.5% - 3.1%	-0.39% - 0.49%
Mosnier et al.	0% - 13%†	-0.3% - 2.0%	-0.04% - 0.26%
OECD-FAO	6% - 7%†	2.0% - 2.9%	0.24% - 0.35%
Roberts & Schlenker	20% - 30%	1.8% - 2.7%	*
Roberts & Tran	14% - 44%	1.3% - 4.0%	0.05% - 0.15%
Rosegrant et al.	26% - 72%	2.2% - 2.6%	0. 08% - 0.10%
Tyner et al.	7% - 71%	3.4% - 4.8%	0.05% - 0.79%
U.S. EPA	3% - 8%	1.3% - 3.1%	0.15% - 0.38%
Study-weighted average	19.1%	2.9%	0.24%

† 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.
*Roberts & Schlenker use a baseline of no corn ethanol production, so we cannot calculate a price change per percentage increase in ethanol.

The range of estimates *across* studies is still substantial, however, even when considering normalized price changes. On the low end, Mosnier et al. (2013) report a counterintuitive finding that lowering the RFS2 mandate to 75 percent of its target level would result in a slight *increase* in corn prices in the year 2030 (i.e., a negative normalized price impact), while expanding the RFS2 to 125 or 150 percent of established levels would have no effect on corn prices. Bento et al. (2012) estimate the highest normalized price impact—an increase in corn prices of around 8 percent per billion gallon increase in corn ethanol production (or alternately, a one percent increase in corn prices per percent increase in corn ethanol) in 2012 and 2015. Taking the study-weighted average across all scenarios, each billion gallon increase in corn ethanol raises corn prices by 2.9 percent. Similarly, a 10 percent expansion in corn ethanol production increases corn prices by an average of 2.4 percent.

Meta-Analysis of Ethanol's Impact on Corn Prices

Given the wide range of normalized price effects, it is clear that ethanol production levels do not fully explain the differences among estimates. We conduct a meta-analysis to investigate the remaining sources of variation in estimated corn price impacts. We consider the three different outcome variables reported in Table 3: the price change, the price change per billion gallons of corn ethanol, and the price change per percentage point increase in corn ethanol. We include as potential explanatory variables the baseline corn ethanol volumes and the change in corn ethanol between baseline and policy scenario; inclusion of ethanol co-products; projection year; changes in the volume of non-corn-ethanol biofuels from baseline to policy scenario; whether corn is the modeled commodity (versus a more aggregate crop commodity); whether oil prices are included in the model and the oil price for those that include it; and whether the study appears in a peer-reviewed journal.[15][16]

We estimate random effects models to address the fact that estimates produced by the same study are not independent (Nelson and Kennedy 2009). We also weight the regressions to

[15] As already noted, our dataset includes studies that examine both decreases and increases in corn ethanol. To account for the fact that normalizing changes the sign of the corn price effect in the ethanol decrease scenarios, we multiply the change in the volumes of corn ethanol and of all other biofuels by negative one and include the resulting product as right-hand side variables in the normalized price regressions for these scenarios.

[16].As a sensitivity analysis, we also ran regressions including dummy variables denoting whether studies reported world (vs. domestic) prices and whether international policy changes were modeled in the scenario in addition to US policy. Because neither of these variables was statistically significant in any of the three equations, we excluded them from the final regressions reported in the paper.

give each study equal weight rather than weighting studies with more scenarios more heavily.[17] It is not possible to estimate the equations using study fixed effects because several attributes (e.g., model structure) only vary at the study level.

Table 4 reports the meta-regression results for all three measures of corn price change. The factors we are able to quantify across all studies explain a sizable portion of the variation across estimated price effects, as indicated by R-squared statistics of around 0.40 for both normalized equations and 0.84 for the non-normalized corn price regression.

Turning to the explanatory variables, the change in corn ethanol production between the baseline and policy scenario is the most important factor driving the non-normalized change in corn prices; each billion gallon increase in corn ethanol production increases corn prices by about two percent, holding constant all other factors included in the regression. The negative coefficient on baseline ethanol suggests that price impacts are smaller the higher the starting level of biofuel production. Baseline corn ethanol and the change in corn ethanol volume are also included in the normalized price impact equations to investigate whether there are non-linearities in this effect (similar to including squared terms in the absolute price change equation). The results show that the change in corn ethanol is no longer a significant predictor of price changes once they have been normalized. Baseline corn ethanol volume has a strongly positive effect on the corn price change per percentage point increase in ethanol. This result is a bit of a numerical artifact that occurs because scenarios with low levels of baseline ethanol naturally lead to changes in production that are very large in percentage terms (causing a large denominator) even when they are moderate in volumetric terms.

[17] A common practice in meta-analysis is to weight by the inverse of the variance of the effect size to give more weight to more precise estimates (Nelson and Kennedy 2009). However, the estimates in our study are derived from equilibrium simulation models rather than econometric models (with the exception of Roberts and Schlenker), so estimates of variance or proxies such as sample size are not available.

Table 4. Long-run Corn Price Responsiveness to Biofuels Expansion: Meta-Regression Results

	Price change	Price change per billion gallon increase	Price change per percentage increase
Baseline corn ethanol (bgal)	-0.0106**	0.0012	0.0005***
	(0.0042)	(0.0009)	(0.0001)
Corn ethanol change (bgal)	0.0213***	-6.73e-05	-5.31e-06
	(0.0015)	(0.0002)	(3.40e-05)
GE model	-0.195***	-0.0193*	-0.0008
	(0.0427)	(0.0103)	(0.0013)
Projection year	0.002	-0.00165***	-0.0002***
	(0.0023)	(0.0004)	(5.53e-05)
Co-products included	-0.118***	-0.0126**	-0.0009
	(0.0330)	(0.0054)	(0.001)
Change in other biofuels (bgal)	-0.0018	0.0009***	0.0001***
	(0.0017)	(0.0003)	(4.17e-05)
Corn (vs. aggregate commodity)	0.0509	0.0104	0.0007
	(0.0394)	(0.0095)	(0.0012)
Oil price ($)	0.0003	-0.0002	-1.86e-05
	(0.0008)	(0.0001)	(2.23e-05)
No oil market	-0.109	-0.0096	-5.84e-05
	(0.0751)	(0.0163)	(0.0021)
Journal article	-0.0150	-0.0147	-0.0014
	(0.0359)	(0.0096)	(0.0012)
Constant	-3.783	3.378***	0.473***
	(4.688)	(0.827)	(0.111)
Observations	83	83	78
R-squared: overall	0.84	0.39	0.41
within	0.76	0.20	0.33
between	0.89	0.42	0.44
Number of panel groups	19	19	18

Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

The modeling framework is important in the non-normalized corn price and corn price per billion gallon equations. Studies using computable general equilibrium models find price effects that are lower by almost 20 percentage points in absolute terms and two percentage points in normalized terms than those using partial equilibrium models. This result makes sense intuitively considering that GE models typically use larger implicit supply elasticities than PE models (Kretschmer and Peterson 2010), and they also allow for adjustments in resource allocation across all markets in the economy, which can lessen impacts in the directly affected sector. The modeling framework has a negative but not statistically significant effect on price change per percentage increase in corn ethanol.

The projection year is negatively associated with the normalized corn price results, indicating that price effects are expected to be more moderate farther into the future. This result is not surprising, particularly if the projection year reflects crop yields (which are typically assumed to improve over time) and other types of technological progress that we were not able to include directly. The price change per billion gallons of corn ethanol is projected to decline by 1.7 percentage points over a ten-year period. Of course, if anticipated crop yields do not materialize due to climate change or other factors, then estimates of biofuel price effects in 2020 and beyond could turn out to be overly optimistic.

Accounting for ethanol co-products is another important technological factor in determining normalized corn price impacts. Studies that account for the use of a portion of corn ethanol feedstock as livestock feed find smaller price increases in response to higher corn ethanol production, as expected. The corn price rise per billion gallon increase in corn ethanol is more than one percentage point lower when co-products are included. Accounting for co-products results in non-normalized prices that are lower by 12 percentage points.

Production of other biofuels also affects normalized corn prices. Increases in domestic and international non-corn-ethanol biofuels drive up corn prices indirectly, potentially through raising the price of land and other inputs. This result confirms that it is inappropriate to attribute corn price changes solely to the change in corn ethanol production in scenarios that include other biofuels.

Specifying corn as the examined commodity rather than a more aggregate product such as cereals also increases estimated price effects, though the effect is not statistically significant in any of the equations. It is unsurprising that the effects of a corn ethanol mandate would be felt most strongly in corn markets themselves and be somewhat dissipated in other agricultural commodity markets, though it may not be too unusual that this effect is not significant considering that markets for other commodities included in these metrics tend to move in tandem with corn.

Studies that do not incorporate oil prices find smaller non-normalized price effects than those that do, but this effect is not significant in any of the equations. Focusing on studies that include oil market effects, oil prices are also not a significant determinant of corn price response in any of the three equations. This result does not imply that oil prices are not important in determining the effect of biofuels on corn price; rather, it suggests that oil prices have no effect on corn prices *after controlling for the change in ethanol production*. To further emphasize this point, we conduct a sensitivity analysis to consider the effect of oil prices when ethanol quantity is not held constant across scenarios. The results show that oil prices do indeed affect corn price increases (though the effect is only significant at the 10 percent level). Each $10 per barrel increase in oil prices reduces the impact of corn ethanol expansion policies on corn prices by two percentage points; because corn ethanol production is already high when oil prices are high, biofuel policy has less of an impact on corn ethanol volumes. Conversely, lower oil prices lead to larger price effects by increasing the gap between baseline and policy scenario ethanol production. (See Appendix Table B for regression results.) This translates to an effect on corn prices because ethanol quantity is such an important driver of price changes.

Finally, results published in journal articles find that corn price results are smaller on average than those found in working papers, government documents, or international organization reports, but the effect is not statistically significant in any of the three specifications, suggesting minimal, if any, publication bias.

Overall, our findings confirm the significance of several key factors identified in the literature in explaining seemingly disparate results across studies of the impact of biofuels on crop prices. Particularly important are differences in projected corn ethanol expansion volumes. Modeling framework, projection year, assumptions about ethanol co-products, and inclusion of non-corn biofuels help explain much of the remaining variation across estimates.

For analysts interested in predicting the corn price effects of additional expansion in corn ethanol, it would be appropriate to hold other types of biofuel production constant across the baseline and policy scenarios, to account for ethanol co-products, and to focus on corn as the commodity of interest; failure to do so could yield misleading estimates. Using the results from the corn price per percentage increase in ethanol equation (column 3 of Table 4), we find that increasing corn ethanol production in the year 2015 from 15 to 16 billion gallons would increase corn prices by two to four percent (with a 95 percent confidence interval spanning one to five percent). The variation in the estimated price effect stems from whether we use estimates from a general equilibrium or partial equilibrium model and from a published or unpublished source.

4. Short-run effects of U.S. ethanol expansion on corn prices

When agricultural markets are shocked exogenously by a change in policy or other factors such as drought or high oil prices, they typically do not instantaneously adjust to a new, long-run equilibrium. An examination of the adjustment process allows researchers to gain insight into the magnitude and duration of short-run impacts in response to the shock. How long this adjustment takes and the implications for prices depend on the ability of firms to modify production practices to accommodate this new information. When farmers have less flexibility in the near term, we expect larger increases in corn prices initially than occur in the long run.

To evaluate the short-run implications of demand or supply shocks, researchers rely on different estimation techniques than typically used for evaluating long-run effects. Stochastic partial equilibrium models relax the assumption that individuals have perfect foresight. Farmers form expectations about the most likely realization of outcomes, but uncertainty in the market results in volatility; shocks or new information can increase this volatility. The effects of these shocks can be examined by simulating different scenarios and then comparing the results to a counterfactual. Another method that has been used to gain insight into the adjustment processes of markets to shocks is the structural variance autoregression approach. These models rely on time series data and include lags in the model to allow for less-than-instantaneous adjustment to a new long-run equilibrium after an exogenous shock.[18]

There are far fewer papers in the literature that examine short-run impacts of corn ethanol policy and many of those that are available have not been published. Thus, while we summarize the papers that are available and calculate metrics that normalize by changes in ethanol production, we do not conduct a meta-analysis to examine the influence of various assumptions and modeling approaches on corn prices.

Stochastic partial equilibrium approaches

We find six recent studies that empirically investigate the short-run implications of ethanol expansion or contraction using stochastic partial equilibrium approaches. While none of

[18] See Almirall et al. (2012) for further explanation for how these models work.

these studies has been published in a peer-reviewed journal, we feel it is important to highlight their main findings. The six studies explore a total of 56 scenarios (see Table 5). Similar to our summary of long-run studies, we present the crop price changes in Table 5 in absolute terms because some studies focus on relaxing the mandate, while others examine the imposition of the mandate.

All of the studies focus on the implications of U.S corn ethanol policy—specifically RFS2—for agricultural commodity prices. Unlike the long-run studies discussed in the previous section, they almost all focus exclusively on corn ethanol and do not consider changes in the production of biofuels from other feedstocks concurrently. Five of the six studies report the impacts of RFS2 on U.S. corn prices. Four of these studies examine the implications of relaxing the mandate under various drought conditions. Babcock (2012a, 2012b) and Tyner et al. (2012) examine the effects of a waiver during the 2012 drought. Roberts and Tran (2013) compare how markets react to an expected versus unexpected waiver of the ethanol mandate under drought and non-drought conditions. McPhail and Babcock (2008) consider imposing rather than relaxing the mandate under a variety of conditions related to gasoline price volatility, drought, and ethanol policy.

The sixth study, Roberts and Tran (2012), is somewhat of an outlier in both the scenario and commodity considered. The authors assess the impacts of imposing an ethanol mandate if the market has several years to adjust to the new equilibrium versus a scenario in which the mandate is imposed instantaneously with no prior warning.[19] They examine a calorie-weighted average world price of corn, rice, wheat, and soy as the commodity of interest. While this analysis is distinct from the others and considers some extreme scenarios unlikely to occur in a

[19] Roberts and Tran's long-run equilibrium results are discussed in the previous section.

real-world setting, we include it in our review due to the dearth of studies on the short-run effects of ethanol policy.

As is the case with the long-run studies discussed previously, there is considerable variability across estimates of the short-run price effects resulting from a change in ethanol production. At the low end, McPhail and Babcock (2008) find almost no effect of imposing the mandate under bumper crop conditions because it is largely non-binding. The high end from studies examining a waiver of the mandate is 28 percent. On the extreme high end, Roberts and Tran (2012) estimate short-run price effects of imposing a mandate ranging from 54 to almost 400 percent even though they use an aggregate commodity rather than corn alone. However, as already noted this study differs from the others in examining the effect of a sudden, unexpected ethanol mandate. Also, price effects are largest when the demand elasticity for food is not allowed to adjust over time and the use of ethanol co-products to feed livestock are not included in the model. When consumers can reduce their caloric intake, change the types of foods they consume, or make up some portion of their calories via distiller's grains, price impacts are somewhat mitigated. The authors expect that when grain storage is available and relatively inexpensive, the effect that unexpected demand shocks have on prices will be ameliorated over time by available inventories of grains. They find this to be the case, but when the full mandate is immediately binding, world commodity prices increase markedly in the first year before slowly declining to the new equilibrium long-run price.

As is true for the long-run studies discussed in section 3, one reason for the wide range of predicted price effects in the short run is that the ethanol production changes evaluated differ markedly across scenarios. For instance, Roberts and Tran (2012) consider an 11.1 billion gallon increase in ethanol production. Babcock (2012a) and Babcock (2012b) examine a complete waiver of a 13.6 billion gallon corn and advanced ethanol requirement as well as a partial waiver of 2.4 billion gallons (by allowing the use of carry-over RINs from previous years). Tyner et al. (2012) examine ethanol waivers of between 2 billion and 6.05 billion gallons. Roberts & Tran (2013) examine waiving between 1.5 and 7.5 billion gallons of a 15 billion gallon corn ethanol mandate. Finally, McPhail and Babcock (2008) consider the imposition of an approximately 10 billion gallon ethanol mandate, which represents an increase in ethanol production relative to a baseline ranging from almost 0 (when there is a bumper crop) to almost 7 billion gallons (in the case of drought).

Table 5. Studies Examining Short-Run Impact of Corn Ethanol Expansion on Corn Prices

Study	Ethanol Scenarios	Policy Instrument	Conditions Examined	Absolute Crop Price Change
Babcock (2012a)	2	RFS2	Relaxing mandate; drought	15 - 21%†
Babcock (2012b)	2	RFS2	Relaxing mandate; drought	20 - 26%†
McPhail & Babcock (2008)	4	RFS2, tax credit	Mandate imposed, drought; bumper crop; no tax credit	0.3 - 28%
Roberts & Tran (2012)*	9	RFS2	Unexpected increase in mandate; co-products; demand & supply elasticities	54 - 383%
Roberts & Tran (2013)	30	RFS2	Expected vs. unexpected relaxing of mandate; drought	2 – 26%†
Tyner et al. (2012)	9	RFS2	Relaxing mandate; drought	8 - 28%†

* Roberts and Tran (2012) use a calorie-weighted average price of corn, rice, wheat and soy (i.e., price of buying one year of calories for one person in 2010) instead of U.S. corn price.
† 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.

Table 6 normalizes the short-run price change results from the six stochastic partial equilibrium studies by expressing them in terms of the percent change in the corn price for every billion gallon increase in ethanol and the percent change in corn price per one percent increase in the quantity of ethanol. As previously mentioned, the studies vary with regard to whether they model the RFS2 as the reference or policy case. While the calculations are affected by whether the ethanol mandate is treated as the reference or policy case, these differences are generally small. The change in corn price per billion gallon increase in ethanol ranges from about 1.2 percent to almost 35 percent, while the change in price per one percent increase in ethanol ranges from 0.1 percent to 2 percent. Taking the study-weighted average across all scenarios, each billion gallon increase in corn ethanol raises corn prices by 8.65 percent in the short run. Similarly, a 10 percent increase in corn ethanol production increases corn prices by an average of 9.2 percent. If we exclude Roberts & Tran (2012) from the study-weighted averages because the scenarios differ substantially from those in other papers, it lowers the study-weighted average semi-elasticity to 7.65 percent and increases the price change per 10 percent change in ethanol slightly to 10 percent. As expected, the short-run effects on corn price are substantially higher than those from the long-run studies summarized in Table 3. (Recall that the long-run study-weighted average price per billion gallons is about 2.9 percent, while the average price per 10 percent increase is about 2.4 percent.)

While variation within a study is generally much smaller when price changes are normalized by ethanol production changes, Roberts and Tran (2012) have semi-elasticities that range from 4.8 percent to 34.6 percent and elasticities that range from 0.2 percent to 1.4 percent. Roberts and Tran (2013) have a somewhat smaller range, though it is still larger than for the remaining four studies: semi-elasticities range from 1.2 percent to 11.9 percent, while elasticities range from 0.2 percent to 1.8 percent. These wider ranges reflect the large number of sensitivity analyses included in these studies. In the case of Roberts and Tran (2012), the authors examine how estimates change with the inclusion of co-products and changes in the elasticities of supply and demand. Roberts and Tran (2013) examine alternate yield assumptions and vary whether the waiver is expected or unexpected.

Table 6. Short-Run Impact of Corn Ethanol Expansion on Absolute and Normalized Corn Prices

Study	Absolute crop price change	Price change per billion gallon change in ethanol	Price change per 1% change in ethanol
Babcock (2012a)	15-21%†	10.3 - 10.7%	1.5%
Babcock (2012b)	20-26%†	14.2 - 15.1%	1.9 - 2.0%
McPhail & Babcock (2008)	0.3-28%	4.0 - 8.0%	0.1 - 0.9%
Roberts & Tran (2012)*	54-383%	4.8 - 34.6%	0.2 - 1.4%
Roberts & Tran (2013)	2-26%†	1.2 – 11.9%	0.2 – 1.8%
Tyner et al. (2012)	8-28%†	3.7 - 4.6%**	0.5 - 0.7%**
Study-weighted average	39.28%	8.65%	0.92%

* Roberts and Tran (2012) use a calorie-weighted average price of corn, rice, wheat and soy.
**Relaxing the mandate by 2 BG had no effect on 2012-2013 ethanol production in two scenarios, so it was not possible to calculate elasticities in these cases.
† 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.

There also continues to be a certain amount of variability across studies. Table 7 shows that the models differ in their treatment of co-products, inclusion of the oil market, yields assumed, and how the commodity is defined. As expected, given the near-term focus of the studies, the range of baseline and policy ethanol scenarios considered is much narrower than in the long-run studies.

One of the largest sources of variation across and (in some cases, within) studies is the baseline yield assumption. This is due, in part, to the fact that the main objective of the majority of these studies is to examine how drought conditions combined with ethanol policy affect corn prices. Babcock (2012a) estimates impacts assuming corn yields are well below average due to drought and that there is a low buffer stock (i.e., accumulated inventory) of corn. Babcock (2012b) leaves all assumptions and scenarios unchanged from Babcock (2012a) except for assuming even lower crop yields and harvested acres. Tyner et al. (2012) also examine how an ethanol waiver might affect corn prices under a variety of drought conditions. Tyner et al.'s weaker drought conditions correspond most closely to the yield assumptions in Babcock (2012a), while Tyner et al.'s median and stronger drought conditions fall on either side of the yield assumption made in Babcock (2012b). McPhail and Babcock (2008) have the highest and lowest yield assumptions across all of the studies, to capture severe drought and bumper crop conditions. Back calculating the corn yield in bushels per acre from Roberts and Tran (2012) indicates that their mean yield assumption is roughly equivalent to Tyner et al.'s (2012) weak drought condition. Roberts and Tran (2013) examine a range of yield assumptions, from the very low corn yield used by Babcock (2012b) to yields closer to the pre-drought historic norm.

Table 7. Key Variations across Short-Run Ethanol Studies

	Mean*	Std. dev.	Min	Max	Obs
Baseline corn ethanol (bgal)	11.37	4.55	3.15	15	56
Policy scenario corn ethanol (bgal)	11.87	2.27	7.5	15	56
Ethanol co-products included (1 = yes, 0 = no)	44%	0.51	0	1	43
Projection year	2012	2.28	2008	2015	56
Baseline yield (bushels/acre)**	133.42	9.51	113	169	56
Gasoline/oil prices (Y/N)	67%	0.52	0	1	56
Corn (vs. aggregate commodity) (1 = yes, 0 = no)	83%	0.41	0	1	56

*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.
** Yield per acre for Roberts and Tran (2012) is back-calculated from the information available in the paper.

Yield is also a key source of stochasticity in many of the models. For instance, stochasticity in the Babcock (2012a, 2012b) studies originates from uncertainty regarding corn and soybean yields and demand for ethanol in the U.S. (which is determined by the quantity of ethanol available and gasoline prices). Corn supply stochasticity in McPhail and Babcock's model is also based on uncertainty in planted acres and corn yields, while stochasticity in corn demand is based on uncertainty about export demand, gasoline prices, and corn ethanol capacity in the U.S.[20] Roberts and Tran (2012) and Roberts and Tran (2013) use a stochastic competitive

[20] McPhail and Babcock (2008) also report the coefficients of variation with respect to corn and gasoline prices. Results demonstrate that elimination of the mandate reduces corn price variability. In a case where there is a negative shock to corn yields (i.e., a drought), corn prices increase by less than they would have with an ethanol mandate. Oil prices also matter: when oil prices are low, it is more likely that the mandate is binding, so that its elimination would have a greater effect on corn prices.

storage model where storage is used as a buffer against weather shocks and other sources of uncertainty. Demand and supply of grains are separately identifiable since harvest and cultivated land decisions are a function of expected (and therefore, uncertain) future prices and yields, while demand is a function of current price. Interaction with oil markets is not considered in either version of the model.

The findings of Tyner et al. (2012) echo those of Babcock (2012a, 2012b), but are noticeably smaller, even after normalizing by ethanol production. Tyner et al. point to greater short-run responsiveness of ethanol demand to new information in their model as one source of the differences. In particular, they state that Babcock's model only allows limited flexibility in how blenders and refiners respond to shocks. Thus, while relaxing the mandate slightly—to about 10 billion gallons—may garner some response, further reductions do not. In other words, Babcock does not assume a constant elasticity of demand.[21] Tyner et al. (2012) note that the effect of a waiver in alleviating corn price increases will be small or zero if farmers and refiners have limited flexibility to adjust production practices in the short run, in particular if the market is not able to move away from a 10 percent blend of ethanol in fuel. In addition, if corn production is fixed in the short run, oil prices could push up ethanol and, thus, corn prices. Roberts and Tran (2013) also highlight the importance of assumptions regarding the responsiveness of ethanol demand in determining short-run impacts of an RFS waiver. They note an ongoing debate in the literature about whether the market is currently operating on the elastic or inelastic portion of the ethanol demand curve. If the U.S has limited ability to substitute away from ethanol as an oxygenate in gasoline, even without the ethanol mandate or blend wall issues, it is on the inelastic portion of ethanol demand. In this case, a shift in ethanol supply from a short

[21] McPhail and Babcock (2012) find that corn demand is more inelastic when either RFS or the blend wall is binding, which means that corn prices will increase more in response to a negative corn supply shock than they would without these constraints.

term waiver will have little or no impact on corn prices. If, however, the U.S. is on the elastic portion of the ethanol demand curve, a waiver will have a noticeable effect on corn prices.

While oil markets are considered in the majority of papers – the exception being the papers by Roberts and Tran - and are often treated stochastically (e.g., McPhail and Babcock 2008, Babcock 2012a, and Babcock 2012b), they are not endogenous to the models. In addition, Babcock (2012a, 2012b), and McPhail and Babcock (2008) reflect a narrow range of prices - they assume a wholesale gasoline price ranging from $2.50 to $2.78 per gallon – while Tyner et al. do not report their oil or gasoline price assumption. The lack of complexity in the representation of energy markets is a weakness across all of the short-run studies. Thus, the way that the interaction between oil and corn ethanol markets affects commodity prices in the short run remains largely unanswered by these studies.

Structural vector autoregression approaches

Macro-econometric time-series approaches such as structural variance autoregression also have been used to examine short-run agricultural market responses to ethanol shocks. However, these approaches do not yield enough information to calculate price effects per unit of ethanol production. Instead, these models are typically used to answer two types of questions: what proportion of the variance in the error term comes from a specific shock to the system (referred to as forecast error variance decomposition), and how does the shock affect the variables of interest over time (referred to as tracing out the impulse response function)?

Zhang et al. (2009) examine how much ethanol policies have contributed to short-run price spikes for corn using econometric techniques that capture interactions across markets over time. They find that ethanol prices in 2000-2007 do not explain any of the variation in prices for corn in the short run. Impulse response functions demonstrate that one reason for this is that a shock to corn prices does not persist: corn prices return to their long-run equilibrium value within 10 weeks of an ethanol price shock. Qiu et al. (2012) find that exogenous shocks in the demand for ethanol between 1994 and 2010 explain about four percent of the variation in corn prices in the short run. Unlike Zhang et al. (2009), this small effect persists over many months in their model. Gardebroek and Hernandez (2012) find evidence that energy and corn markets have become more inter-related: returns on corn and ethanol are more strongly correlated after ethanol replaced MTBE as an oxygenate in gasoline in 2006. However, they do not find evidence that shocks in ethanol prices affect corn prices (i.e., they find no mean or volatility spillovers from ethanol to corn markets via price).

These results contrast with other time series-based studies by Hausman et al. (2012) and Carter et al. (2012) that find a stronger association between ethanol and corn prices. However, it is important to note that neither of these studies separate out the effect of ethanol policy from market-driven effects. Hausman et al. (2012) find about 30 percent of the corn price rise from 2006 to 2007 was due to expanded ethanol production. Using an impulse response function, they also examine the effect of taking one million acres of corn out of food production (i.e., it is instead used to produce ethanol). They find that it is associated with a four cent per bushel increase in the price of corn in the first year, but that this effect does not persist.[22] When there are repeated negative shocks to corn acreage (for instance, from a continued buildup of ethanol production), Hausman et al. (2012) show a continued increase in corn prices from four cents per bushel to a peak of 10 cents per bushel in years two and three. Carter et al. (2012) also find that corn prices would have been 30 percent lower for the 2006-2010 period if ethanol production

[22] To compare this result to those from stochastic partial equilibrium models, we would need to know what a loss in acreage means for corn production. We cannot calculate this unless we impose assumptions about corn yield.

had been kept at 2005 levels (i.e., absent inventory supply or demand shocks over this time period).

Zilberman et al. (2012) note that the directional relationship between ethanol prices and food prices is theoretically ambiguous, making it unsurprising that this strand of literature has found mixed results. They argue that researchers should examine the relationship between biofuel production (rather than biofuel prices) and food prices to identify the effects of biofuel policies on commodity markets. Thus, these studies do not yield direct insights about the effect of corn ethanol expansion on food crop prices.

4. Ethanol Production and Global Food Security

Higher agricultural commodity prices due to increased ethanol production are of particular concern in developing countries. First, the majority of developing countries are net importers of food, which means that they often face world prices for agricultural commodities (Valdes 2012). Second, the world's poor are disproportionately affected by higher commodity prices due to inelastic demand for agricultural staples. Populations in developing countries rely heavily on raw agricultural products and spend a far greater portion of their income on staple food expenditures relative to consumers in the developed world (Roberts and Schlenker 2013; Zhang et al. 2013; Runge and Senauer 2007).[23] As a result, even a relatively small increase in agricultural prices has potentially dramatic implications for consumers in these countries (Chakravorty et al. 2012a). Poor households are likely to respond to increases in food prices by reducing food consumption, which may lead to caloric and nutritional deficiencies; and by spending less of their income on other goods and services, such as education, savings, and

[23] The poorest quintile of most developing countries spend well over 50 percent of their income on food, with some spending greater than 70 percent on food expenditures (FAO 2011a).

investment. It is important to note that offsetting positive effects can occur for farmers in these countries, who are expected to benefit from higher prices by earning additional income if they are net food producers (Swinnen and Squicciarini 2012).

Food security is a real issue for large numbers of people, absent consideration of increased ethanol production. The FAO (2011b) estimates that about 850 million people in developing countries–about 16 percent of the total population in these countries–were undernourished in 2007-2009, with Asia and Sub-Saharan Africa making up the majority. Overall, the number of undernourished has remained essentially unchanged for 2011-2012, though this masks sizable regional shifts (i.e., 20 percent decline in Asia; 38 percent increase in Sub-Saharan Africa) that the FAO attributes to the varying ability of countries to limit or mitigate the effects of food price shocks that occurred in 2006-2008.

Future biofuel expansion has the potential to exacerbate this situation. It can contribute to commodity price volatility, which increases uncertainty regarding food availability (McPhail and Babcock 2012). Future food consumption trends in developing countries are particularly dependent upon how much corn is diverted to non-food uses.[24] Loss of agricultural productivity due to climate change also affects yield trends and may make it harder to meet food and fuel objectives (NRC 2012), while biofuel production can further exacerbate food price volatility due to climate change (Diffenbaugh et al. 2012).

While many studies have estimated the commodity price effects of biofuel expansion, fewer researchers have examined the implications of biofuels for food security in developing counties by translating commodity price hikes into changes in the number of people in poverty or

[24] Demand-side shifts, such as changes in consumption and dietary preferences also generate unpredictable effects in global markets. Population and income growth in the major developing countries have the potential to induce large increases in the demand for food, energy, and land. Roberts and Schlenker (2013) point out that China's population has doubled over the past 50 years, but aggregate meat consumption has increased by 33 times over the same period.

suffering from hunger.[25] That said, most experts agree that short-run effects of biofuel expansion on food security are more severe than long-run effects; in the long run, adjustments in land conversion and improvements in technology will likely mitigate some effects (Chakravorty 2012a). There is also an existing literature estimating the short- and long-run poverty implications of food price increases generally (i.e., not resulting from biofuel production *per se*). For instance, a recent World Bank report (Ivanic et al. 2011) indicates that short-run impacts vary widely by country, depending on the degree to which global prices are transmitted into the local market and differences in the ways that households consume and produce goods across countries. Even accounting for these differences, they estimate that substantial price increases in a variety of commodities between June and December 2010 (73 percent increase in global corn prices, 76 percent in sugar prices, 54 percent in oil prices, and 17 percent increase in rice prices) raised the number of people living in extreme poverty by 43.7 million on net, after accounting for countries where poverty is estimated to decline because they are net sellers of food.

Two of the studies covered in Section 3 empirically estimate the long-run impacts of ethanol expansion on global or regional food security (Rosegrant et al. 2008 and Roberts and Schlenker 2013). We also identified three additional studies that examine the impact of biofuels expansion on food security or poverty but were excluded from Section 3 because they do not report estimates of either the change in corn prices or US corn ethanol production (Fischer et al. 2009, Bryant et al. 2010, Chakravorty et al. 2012a). Still two more studies consider the effects of food price changes on welfare in developing countries, though they do not provide estimates of food security or poverty metrics (Huang et al. 2012 and Timilsina et al. 2012).[26] As shown in

[25] There is a large qualitative literature in this area, however. See Timilsina et al. (2012).
[26] Huang et al. (2012) is included in the review of long-run studies in Section 3, but Timilsina et al. (2012) is excluded because it focuses on global biofuel production and does not provide information on biofuel production by feedstock.

Table 8, some of these studies take a global approach, while others focus on specific low- or middle-income countries.

Table 8: Studies Estimating Impact of Ethanol Expansion on Food Security

Study	Model	Countries /regions	Policy scenarios	Crop price change *
Bryant et al. (2010)	Static GE model	9	RFS2	-
Chakravorty et al. (2012a)	Dynamic multi-market model	India	RFS2 and Indian biofuel mandates	12%
Fischer et al. (2009)	GE model + PE agricultural model	34	2008 global biofuel policy; doubling of existing targets	8%-35%
Huang et al. (2012)	CGE model + PE ag. model	China	RFS2, EU, and Brazil biofuel policy; market-driven expansion	15% - 50%
Roberts & Schlenker (2013)	Supply and demand model		RFS2	20% - 30%
Rosegrant et al. (2008)	PE agricultural model	115	RFS2, EU, and Brazil biofuel policy; doubling existing targets	26% - 72%
Timilsina et al. (2012)	Dynamic CGE model + PE land and biofuel sector models	112	Announced global biofuel policies; doubling of those targets	1%– 3.7%

* Fischer et al. (2009) report changes in cereal prices out to 2050. They do not report changes in corn production or prices separately. For comparability to results from other models, we report the effects in 2020. Roberts and Schlenker (2013) use a calorie-weighted average of corn, soy, rice, and wheat. Bryant et al. (2010) do not report change in crop prices.

Most of the studies examine the combined effect of ethanol expansion policies from the United States and other world regions on food security, the exceptions being Roberts and Schlenker (2013) and Bryant et al. (2010), who examine the impact of U.S. policy only. Rosegrant et al. (2008) compare a 2020 world where biofuel policies in the U.S., Europe, and Brazil are maintained at 2010 levels to moderate biofuel expansion based on already announced plans and more drastic expansion. Similarly, Timilsina et al. (2012) examine the implementation of announced biofuel policies in more than 18 countries, and a doubling of announced targets within the same timeframe.[27] Fischer et al. (2009) examine the impacts of global biofuel expansion using first-generation biofuels on food security out to 2050 based on current biofuel policy only (as of 2008), and on a doubling of the amount in the first scenario.[28] Huang et al. (2012) evaluate biofuel expansion scenarios in which market forces drive further biofuel expansion, and where U.S., EU, and Brazilian ethanol mandates for 2020 are binding, focusing on impacts in China. Chakravorty et al. (2012a) examine the impact of US and Indian biofuel mandates on household welfare and poverty in India. Roberts and Schlenker (2013) and Bryant et al. (2010) both examine the reduction in calories available for food consumption worldwide when RFS2 is in place.

The seven papers summarized in Table 8 differ in their use of partial equilibrium or multi-market models representing the agriculture and biofuel sectors, versus pairing these types of detailed models with a general equilibrium approach. Studies that make use of general equilibrium modeling have the advantage of allowing changes in the biofuels and agricultural markets to affect financial and commodity flows in other related markets such as the oil market. Bryant et al. (2010), Timilsina et al. (2012) and Huang et al. (2012) make use of an expanded GTAP database with an explicit link between agricultural and energy markets. Fischer et al. (2009) also use a general equilibrium approach, though they do not include an explicit representation of the oil market in their model. Chakravorty et al. (2012a) use a multi-market modeling approach that includes as a final consumption good energy for transportation from both

[27] Timilsina et al. (2012) note that there are significant food price effects in the baseline. For instance, existing biofuel policies coupled with substantial oil price increases in the baseline result in corn prices increasing 31 percent by 2020. As expected, processed food prices see little effect since agricultural products represent a relatively small share of its cost.

[28] Sensitivity analyses also are carried out to examine the role of technology–specifically the availability of second-generation fuels. We focus on the year 2020 to make findings more readily comparable to other studies.

gasoline and biofuels. Roberts and Schlenker (2013) and Rosengrant et al. (2008) do not consider impacts of changes in ethanol policy outside of the agricultural sector.

Changes in crop prices reported in Table 8 are for 2020 in most cases (Chakravorty et al. and Roberts and Schlenker report impacts in 2015). The absolute crop price changes reflected in these studies are consistent with the larger body of long-run estimates discussed in section 3: they range from one percent (Timilsina et al.) to 72 percent (Rosegrant et al.). Fischer et al. (2009) find that cereal prices increase by about 10 percent in 2020 relative to the baseline under the more moderate biofuel expansion scenario. In the more aggressive biofuel expansion scenario, cereal prices increase by about 30 percent in 2020 if slower deployment of second-generation fuels is assumed; optimistic assumptions regarding availability lead to lower price impacts. Roberts and Schlenker find that ethanol expansion reduces world caloric production of these commodities for other uses by about five percent and results in about a 20 to 30 percent increase in the calorie-weighted price, depending on assumptions about ethanol co-products. Huang et al. (2012) find world corn price increases ranging from 15 to 50 percent but that only about a quarter of this is passed through to the Chinese market. Chakravorty et al. (2012a) find that biofuel policies result in world price increases of seven percent for rice, 12 percent for wheat, less than one percent or sugar, and 12 percent for "other crops" (including other cereals, starches, and oils) in 2015; the effects on prices in India depend on the degree of pass-through.

When translated into change in corn price per billion gallon increase in corn ethanol (see Table 9), the range across these studies is narrower than what is represented in Section 3: 0.4 to 2.7 percent (as opposed to -0.3 to 8.7 percent). Timilsina et al. (2012) and Huang et al. (2012) do not provide enough information to calculate how many additional people are affected per billion gallon increase in ethanol and therefore are not included in Table 9. Information on biofuel production by feedstock was not provided in Fischer et al. (2009), so we included global biofuel production from all feedstocks in the denominator for this study. This difference could help explain why the normalized crop price impacts in Fischer et al. are substantially lower than the other studies in Table 9.

Table 9: Implications of Ethanol Expansion for Food Security

Study	Crop price change	Price change per billion gallon increase in ethanol	Additional people affected (millions)	Additional people affected per billion gallon increase in ethanol (millions)	Food security metric
Bryant et al.*	-	-	0.8-1.2	0.3-0.8	Risk of hunger
Chakravorty et al.**	12%	2%	16-42	2.7-7	Extreme poverty in India
Fischer et al.*	8%-35%	0.4-0.8%	40-140	2.1-3	Risk of hunger
Roberts & Schlenker	20% - 30%	1.8% - 2.7%	132	12	Risk of hunger
Rosegrant et al.	26% - 72%	2.1% - 2.5%	4.4-9.6	0.3-0.4	Preschooler malnourishment

* Fischer et al. (2009) report percent change in cereal prices but do not separate out the change in corn price nor do they specify what proportion of changes in biofuels production are from cereal based biofuels vs. other sources (e.g., sugarcane). Bryant et al. (2010) do not report changes in corn prices.
**Chakravorty et al. (2012a) do not report baseline ethanol production in their paper. From the information available, we have assumed it is 6 billion gallons absent additional ethanol policy in the U.S. and India.

The studies use a variety of food security metrics. Three studies (Bryant et al., Fischer et al, and Roberts and Schlenker) report the increase in the number of people who will be at risk of hunger (i.e., are below minimum caloric requirements) globally. Rosegrant et al. (2008) estimate the number of malnourished children under age five in developing countries. Chakravorty et al. (2012a) only examine impacts in India and project the number of people in extreme poverty (i. e., living on less than $1.25 per day) rather than an explicit measure of hunger. While we cannot express these numbers in percentage terms–few of these studies report the risk of hunger in the baseline–we can express the results from several of the papers in terms of billion gallons of ethanol production to make them more readily comparable (see Table 9).

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

[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.

countries. Similar to the Bryant et al. result, wide availability of second-generation fuels beyond 2020 substantially reduces the number of people at risk of hunger under the aggressive biofuel expansion scenario (from 140 million to 80 million). South Asia accounts for the vast majority (75 to 90 percent) of the increase in those at risk of hunger worldwide.

At the high end, Roberts and Schlenker (2013) find that developing countries that are largely net food importers are negatively impacted. The authors do a back of the envelope calculation that the estimated reduction in food consumption is equivalent to the caloric requirements to feed about 132 million people. However, because this is not a modeled result, it does not account for the ability of individuals to substitute to cheaper foodstuffs: it assumes they will adapt to higher prices only by eating less.

While the studies by Timilsina et al. (2012) and Huang et al. (2012) are excluded from the tables above because they do not provide quantitative estimates comparing baseline and expansion scenarios, their results are worth mentioning. Timilsina et al. (2012) find that, even for the relatively moderate price increases experienced in the announced target scenario, impacts on food supply are significant in some developing countries such as India (0.5 percent reduction in food supply) and sub-Saharan Africa (0.2 percent reduction). They report that a decline in gasoline and diesel prices, though not large enough to outweigh agricultural commodity price increases, offset the higher cost of processed foods in which agricultural commodities are an input. However, processed foods are consumed in lower proportions in developing countries and in particular by households at the bottom of the income distribution in these countries. Huang et al. (2012) find that production and exports of feedstock crops grown in China increase due to higher prices, but production of many other crops decline. As a result, farmers in China tend benefit from biofuel expansion, with relatively more of this benefit accruing to poorer farmers because the share of their income from agriculture is higher. Huang et al. (2012) do not estimate the effect of biofuel expansion on Chinese consumers, but expect they are negatively affected since they experience higher commodity prices without an offsetting increase in income.

The results of these studies are so disparate that it is difficult to draw any quantitative conclusions about the welfare impacts of ethanol expansion on food security. The one common thread across all the studies is the finding that higher crop prices resulting from biofuels expansion leads to net increases in hunger or poverty. While increased agricultural profits and potentially lower fuel prices could also benefit some consumers in developing countries, any such gains are likely to be regressive, benefitting middle-income consumers and landowners rather than the poor (Chakravorty 2012a; Huang et al. 2012).

5. Conclusions

Economic theory suggests that diverting a sizable share of corn production to ethanol for fuel will put upward pressure on corn prices. While several empirical analyses confirm this finding, the literature has reported price effects from biofuel expansion ranging from nil to over 70 percent. We scrutinize these divergent results to determine whether they are more comparable once we control for the quantity of ethanol production and other scenario differences and assumptions.

Our review of long-run analyses released between 2008 and 2013 shows that the study-weighted average effect of an additional billion gallons of corn ethanol on corn prices is approximately two to three percent. A meta-analysis finds that modeling framework, baseline and policy scenario ethanol production, inclusion of ethanol co-products, projection year, and non-corn biofuel production explain much of the divergence among estimates. Due to sparse data about the elasticity of substitution between biofuels and petroleum fuels, as well as elasticities of crop supply and demand, we are unable to assess to what extent these factors might help explain the remaining variation in estimates. We urge authors to report these and other key assumptions in future analyses of biofuel impacts to foster transparency and comparability among studies.

We also examine recent literature highlighting the short-run price impacts of ethanol production. While the literature is unpublished, the findings confirm that short-run effects of increases in ethanol production on corn price are substantially higher than those from long-run studies. Key to predicting the effects of a short-term ethanol waiver on corn prices is the elasticity of ethanol demand. Study authors note an ongoing debate in the literature about whether the market is currently operating on the elastic or inelastic portion of the ethanol demand curve.

A limited number of studies also relate crop price increases caused by biofuel production to food security and poverty in developing countries. Farmers in these countries who are net food sellers could see a boost in their incomes, but on balance biofuel policies are expected to increase the numbers of people at risk of hunger and poverty. While short-run price swings due to weather or unanticipated policy shocks seem particularly relevant for low-income consumers in developing countries, the food security studies included in our review are all based on long-run economic models. A direction for future research might be to combine analysis of short-run price impacts with modeling that projects numbers of people at risk of hunger to gain a fuller picture of potential food security impacts associated with biofuel expansion policies.

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Appendix

Table A. Data from Long-Run Ethanol Studies

Study	Policy scenario	Commodity price change	Baseline corn ethanol (bgal)	Policy scenario corn ethanol (bgal)	Commodity	Projection year
Anderson & Coble	RFS2	6.8%	8.5	9.5	corn	2008
Bento et al.	RFS2 (VEETC discontinued)	11.7%	11.6	13.1	corn	2012
	RFS2 (VEETC continued)	12.6%	11.6	13.2	corn	2012
	RFS2 (VEETC discontinued)	24.5%	12.0	15.0	corn	2015
	RFS2 (VEETC continued)	25.2%	12.0	15.0	corn	2015
Chakravorty et al.	RFS2 & EU biofuel policy	18.6%	7.3	13.8	cereals	2022
	RFS2 & EU biofuel policy	0.5%	8.1	8.2	cereals	2007
Chen and Khanna	RFS2	23.5%	3.9	11.5	corn	2022
	RFS2, tax credits	36.8%	3.9	15.0	corn	2022
	RFS2, tax credits, tariff	37.1%	3.9	15.0	corn	2022
	RFS2, tax credits, tariff; SC	52.4%	3.9	13.9	corn	2022
	RFS2, tax credits; SC	42.3%	3.9	12.3	corn	2022
	RFS2; SC	35.4%	3.9	10.1	corn	2022
Cui et al.	first-best policy	17.0%	6.0	13.9	corn	2009
	no ethanol policy	-23.0%	6.0	0.1	corn	2009
	optimal biofuel subsidy	38.2%	6.0	16.0	corn	2009
	optimal fuel tax & biofuel subsidy	36.3%	6.0	15.5	corn	2009
	optimal mandate	43.8%	6.0	17.5	corn	2009
	status quo (RFS2)	18.0%	6.0	10.8	corn	2009
Fernandez-Cornejo et al.	RFS2 with additional yield increases	23.0%	4.9	15.0	corn	2015
	RFS2 with basic yield increases	23.0%	4.9	15.0	corn	2015
Gelhar et al.	RFS2, tax credits eliminated	3.2%	8.0	15.0	corn	2022
	RFS2, tax credits eliminated	3.1%	8.0	15.0	corn	2022

	RFS2, tax credits halved	3.9%	8.0	15.0	corn	2022
	RFS2, tax credits halved	4.1%	8.0	15.0	corn	2022
	RFS2, tax credits retained	4.7%	8.0	15.0	corn	2022
	RFS2, tax credits retained	4.8%	8.0	15.0	corn	2022
Hayes et al.	Biofuel tax credits	19.2%	16.6	25.5	corn	2022
	RFS2, tax credits, import tariffs	22.0%	9.2	16.9	corn	2022
	RFS2	16.3%	1.8	15.0	CG	2007
	RFS2 with fixed food consumption	17.6%	1.8	15.0	CG	2007
Hochman et al.	100% decrease in biofuels	-7.3%	3.9	0.0	corn	2005
	100% decrease in biofuels	-12.2%	6.5	0.0	corn	2007
Huang et al.	Mandate-driven expansion (RFS2)	15.0%	4.9	15.0	corn	2020
	Market-driven expansion	49.6%	4.9	40.0	corn	2020
Mosnier et al.	deviations from RFS2 (125%)	5.0%	13.0	16.2	corn	2010
	deviations from RFS2 (150%)	13.0%	13.0	19.4	corn	2010
	deviations from RFS2 (50%)	-7.0%	13.0	6.5	corn	2010
	deviations from RFS2 (75%)	-4.0%	13.0	9.7	corn	2010
	deviations from RFS2 (125%)	3.0%	15.0	18.8	corn	2020
	deviations from RFS2 (150%)	9.0%	15.0	22.5	corn	2020
	deviations from RFS2 (50%)	-7.0%	15.0	7.5	corn	2020
	deviations from RFS2 (75%)	-5.0%	15.0	11.3	corn	2020
	deviations from RFS2 (high corn)	11.0%	15.0	21.4	corn	2020
	deviations from RFS2 (125%)	0.0%	15.0	18.8	corn	2030
	deviations from RFS2 (150%)	0.0%	15.0	22.5	corn	2030
	deviations from RFS2 (50%)	-1.0%	15.0	7.5	corn	2030
	deviations from RFS2 (75%)	1.0%	15.0	11.3	corn	2030
	deviations from RFS2 (high corn)	0.0%	15.0	21.4	corn	2030
Meyer & Thompson	RFS2 with partial cellulosic waiver	-0.2%	15.5	15.6	corn	2016-2020

	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