Biofuels and Vertical Price Transmission: The Case of the U.S. Corn, Ethanol, and Food Markets

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Abstract
This is the first paper to analyze the impact of biofuels on the price transmission along the food chain. Specifically, we analyze the U.S. corn sector and its vertical links to food and ethanol markets. The key result of this paper is that the presence of biofuels affects the price transmission elasticity only when the blender's tax credit is binding and the shock originates in the food market. Our another important result is that the response of corn and food prices to exogenous shocks in the corn or food markets is always lower in the presence of biofuels when the tax credit is binding. However, the results are mixed for the binding mandate. The sensitivity analyses indicate that our results are robust to different assumptions about the model parameters.

Key words: price transmission, food chain, biofuels, prices
JEL classification: Q11, Q21

1. Introduction

A renewed interest in the issue of price transmission among researchers and policy makers stems from two sources. First, the recent structural changes in food and retail sectors have led to higher concentration of these sectors. And second, the global agricultural commodity and energy prices have surged recently, increasing not only the price levels but also volatility. The pass-through of the price shocks from world to domestic markets and from agricultural commodities to food prices can have significant income distributional and welfare implications. Especially, poor consumers are adversely affected by the rise in food prices and farmers' real incomes depend heavily on commodity prices which makes the issue of price transmission very relevant from the political economy perspective.

The transmission of changes from commodity to food prices and *vice versa* varies by commodity, time span considered, and countries. These factors have been well documented in the rich literature on the topic (e.g., Gardner 1975; Reagan and Weitzman 1982; Kinnucan and Forker 1987; Ball and Mankiw 1994; McCorriston et al. 1998; von Cramon-Taubadel 1998, Azzam 1999; Gohin and Guyomard 2000; McCorriston et al. 2001; Lloyd et al. 2006; Nakajima, 2011; Rezitis and Reziti 2011; Simioni et al. 2012; Rajcaniova and Pokrivcak 2013). The general finding of the literature is that changes in the relative prices in one market are transmitted to other markets in the agri-food chain through input-output linkages between vertically integrated up- and downstream industries.

Despite the numerous studies on price transmission in the agri-food supply chain, we are not aware of any that would analyze either theoretically or empirically the impact of the recent phenomenon of biofuels on the price transmission. This topic is of high importance given the significant impact of biofuels' expansion on the world agricultural commodity markets through creation of a direct link between energy and crop prices (e.g., de Gorter an Just 2009a; Ciaian and Kancs 2011; Drabik 2011; Wright 2011; Mallory et al. 2012; de Gorter et al. 2013).

In this paper, we ask a simple but very important question: how did biofuels under different biofuel policy regimes and exogenous market shocks affect the price transmission between agricultural commodity and food markets? More specifically, we analyze the U.S. corn sector and its vertical links to food and ethanol markets. We consider the following biofuel

[1] For space limitation, all appendices refered to in the text are available upon request.

policy regimes: (1) a binding blend mandate (with or without a tax credit), (2) a binding blender's tax credit, and (3) no biofuel policy. These three policy regimes are compared to our benchmark which is no biofuel production. The price transmission between agricultural and food prices is evaluated for exogenous shocks in: (1) domestic corn supply, (2) foreign demand for corn, and (3) domestic demand for food.

2. Theoretical Model

In this section, we develop an analytical model for the corn sector and its vertical linkages with food and ethanol markets to analyze price transmission elasticities under several settings. In order to better identify the impact of biofuels on the price transmission along the food chain, we abstract from modeling the linkages of the fuel market with the food sector (e.g., higher transportation cost) and the indirect linkages with the corn sector in the form of changing input costs for corn production.

We start with the benchmark scenario, entitled *no biofuel*, in which there is no linkage between corn and ethanol markets and where only the corn-food market chain is considered. The food market is represented by a competitive processing sector which buys and processes corn and sells corn-based food to final consumers. Next, we analyze how the benchmark price transmission elasticity is affected by the presence of biofuel production which creates a link between corn and ethanol quantities and, especially, prices. In addition to the no biofuel benchmark, in this section we consider three policy regimes: (1) a binding blend mandate, (2) a binding blender's tax credit, and (3) no biofuel policy. The link between corn and ethanol prices when ethanol is produced is modeled as in de Gorter and Just (2008), Drabik (2011), and Mallory et al. (2012).

No Ethanol Production

In the absence of ethanol production,[2] the total U.S. corn supply, $S_C\left(P_C\right)$, at price P_C is used for (*i*) domestic food (e.g., corn syrup) and feed production (e.g., feed for hogs), collectively denoted by *x*, and (*ii*) exports, with the export demand curve facing the U.S. corn market denoted by $\bar{D}\left(P_C\right)$. The equilibrium in the corn market thus requires

(1) $$S_C\left(P_C, Z_1\right) = x + \bar{D}\left(P_C, Z_2\right)$$

where Z_i , i = {1, 2}, denotes an exogenous shifter of the corn supply curve (e.g., due to the 2011/12 drought in the United States) and of the foreign corn demand (e.g., higher incomes in the rest of the world), respectively. There are no shocks in the initial equilibrium, hence $Z_1 = Z_2 = 0$. A positive shock implies a rightward shift in a supply or a demand curve.

Domestic corn is processed by a competitive industry into food/feed according to a well-behaved production function $f\left(x\right)$, i.e., the function satisfies: $f\left(0\right)=0$, $f_x > 0$, and $f_{xx} < 0$. The subscript denotes the derivative of the production function with respect to the argument.

Denoting $D_f\left(p\right)$ as the demand for food at price *p* and Z_3 as an exogenous food demand shifter (e.g., due to higher incomes or population growth), the equilibrium in the food market is given by

(2) $$D_f\left(p, Z_3\right) = f\left(x\right)$$

[2] The term "no ethanol production" is not a synonym for "no ethanol policy". It is because under some conditions, specified in the section *No Biofuel Policy,* ethanol production can occur even without any biofuel policy.

The first-order condition for profit maximization in the food processing industry implicitly defines the demand for corn

(3) $$pf_x = P_C$$

Totally differentiating the system of equations (1) through (3), we arrive at

(4)
$$\begin{aligned} \left(S_{CP_C} - \bar{D}_{P_C}\right)dP_C + S_{CZ_1}dZ_1 &= dx + \bar{D}_{Z_2}dZ_2 \\ D_{fp}dp + D_{fZ_3}dZ_3 &= f_x dx \\ f_x dp + pf_{xx}dx &= dP_C \end{aligned}$$

where the subscripts on the market supply and demand curves denote partial derivatives with respect to individual arguments. With the system of equations (4), we are in a position to derive price transmission elasticities in the absence of ethanol production pertaining to individual market shocks.

A shock in the corn supply of dZ_1 ($dZ_2 = dZ_3 = 0$) changes the corn price by dP_C/dZ_1 and the food price by dp/dZ_1. Following McCorriston et al. (2001), we calculate the price transmission elasticity, ε_{Z_1}, of a shock in the corn supply as[3]

(5) $$\varepsilon_{Z_1} = \frac{\Delta p}{\Delta P_C}\frac{P_C}{p} = \frac{dp/dZ_1}{dP_C/dZ_1}\frac{P_C}{p}$$

Setting $dZ_3 = 0$ in the second equation of the system (4), and solving the system for dp/dZ_1 obtains

(6) $$\frac{dp}{dZ_1} = \frac{f_x}{f_x^{\,2} + pf_{xx}D_{fp}}\frac{dP_C}{dZ_1}$$

Substituting expression (6) into the formula (5), using the expression for the term f_{xx} derived in Appendix 1, invoking that $f_x = P_C/p$ (from equation (3)), and converting the price derivative D_{fp} into its elasticity form ($D_{fp} = \eta_f^D D_f/p$), we obtain

(7) $$\varepsilon_{Z_1}^{NP} = \frac{\eta_f^S}{\eta_f^S - \eta_f^D} \le 1$$

where η_f^S denotes a price elasticity of food supply (derived in Appendix 2), and η_f^D is a price elasticity of food demand.

Applying an analogous procedure, we obtain an identical expression for the price transmission elasticity of a shock in the foreign corn export demand, ε_{Z_2}

(8) $$\varepsilon_{Z_2}^{NP} = \frac{dp/dZ_2}{dP_C/dZ_2}\frac{P_C}{p} = \frac{\eta_f^S}{\eta_f^S - \eta_f^D} \le 1$$

Intuitively, elasticities (7) and (8) are expected to be identical because the shock occurs in the same (corn) market and leads to the same corn price change. It should, however, be noted that the elasticity formulas in this theoretical section are derived using marginal analysis and therefore might differ from the empirical results, especially for non-marginal shocks.

[3] The change in the corn price is in the denominator because the primary effect of the corn supply shock is to affect the corn price, which in turn has an effect also on the food price.

The price transmission elasticity ε_{Z_3} relates to the price shock in the food market (due to a shift in the food demand curve), which causes a subsequent change in the corn price (see Appendix 3 for details)

(9) $$\varepsilon_{Z_3}^{NP} = \frac{dP_C/dZ_3}{dp/dZ_3}\frac{p}{P_C} = \frac{\eta_f^S}{\eta_f^S + \phi\eta_C^S - \rho\bar{\eta}_C^D} \leq 1$$

where η_C^S and $\bar{\eta}_C^D$ denote elasticities of the corn supply and export demand curves, respectively, and $\phi = P_C S_C/pf$ and $\rho = P_C \bar{D}_C/pf$ denote the shares of the value of corn supply and corn exports, respectively, in the value of food production (or equivalently food expenditures).

A close inspection of elasticities (7), (8), and (9) shows that the transmission elasticity stemming from a shock in the corn market can be smaller, equal, or greater than the elasticity of a food demand shock, depending on the relative supply and demand elasticities and value shares. For example, a shock in the corn market results in smaller transmission elasticity than the shock in the food market as long as $\eta_f^D \leq \rho\bar{\eta}_C^D - \phi\eta_C^S$. Empirically, we find the transmission elasticities under no ethanol production (benchmark) be equal to 0.84 and 0.61 for the corn and food market shocks, respectively.

Binding Blend Mandate[4]

Under a binding blend mandate α, ethanol has to constitute at least α[x100] percent of the final fuel blend. The fuel (blend of ethanol and gasoline) price, P_F, is equal to the weighted average of the ethanol and gasoline prices, P_E and P_G, respectively, adjusted for the fuel tax, t, and the ethanol tax credit, t_c, (if any) (de Gorter and Just 2009; Drabik 2011)

(10) $$P_F = \alpha\left(P_E + t/\lambda - t_c/\lambda\right) + (1-\alpha)\left(P_G + t\right)$$

The term λ = 0.7, denotes miles per gallon of ethanol relative to gasoline (de Gorter and Just 2008), and is used to consistently convert all prices and quantities into gasoline energy-equivalent terms (Cui et al. 2011; Lapan and Moschini 2012).

The zero marginal profit condition for ethanol production implies a link between corn and ethanol prices (de Gorter and Just 2008; Drabik 2011, Lapan and Moschini 2012)

(11) $$P_C = \frac{\lambda\beta}{1-r\gamma}\left(P_E - c_0\right)$$

where β = 2.8 denotes gallons of ethanol per bushel of corn; r denotes the relative price of Dried Distillers Grains with Solubles (DDGS)[5] and corn; γ = 17/56 is the share of DDGS per bushel of corn; and c_0 denotes (constant) processing cost per gasoline energy-equivalent gallon of ethanol.

The ethanol supply curve S_E is determined by the horizontal difference between the corn supply and the demand for corn for domestic food/feed use and corn exports

(12) $$S_E\left(P_E\right) \equiv \frac{\lambda\beta}{1-r\gamma}\left[S_C\left(P_C, Z_1\right) - x - \bar{D}\left(P_C, Z_2\right)\right]$$

In the presence of ethanol production, the term x does not represent solely yellow corn (as it was the case in the previous section where ethanol was not produced) but rather the corn-equivalent quantity of corn and DDGS that is used in food production. This does not pose a problem for our

[4] Although the U.S. Renewable Fuel Standard (RFS) stipulates a quantitative mandate for ethanol, in practice it is implemented as a blend mandate. Therefore, we do not analyze price transmission elasticities under a quantity mandate.

[5] DDGS, a valuable co-product of ethanol production, is returned into the corn market and is used for feeding animals. Drabik (2011) provides details on the economics of this co-product and further explanation of equation (12).

analysis as we measure the food production and associated corn inputs in dollar terms. The dollar value terms make it possible to accommodate a possibly separate use of DDGS (e.g., as a hog feed, where the meat is subsequently counted as food) and yellow corn (e.g., directly used for pop-corn) for food production.

For later use, we write the corn use identity as

$$S_C \equiv x + \bar{D} + S_C^E \tag{13}$$

where S_C^E denotes the amount of corn *initially*[6] allocated to ethanol production. Identity (13) can be converted into

$$\frac{P_C x}{pf} \equiv \phi - \rho - \mu \tag{14}$$

where $\mu = P_C S_C^E / pf$ denotes the share of the value of corn diverted to ethanol in the value of food production.

The equilibrium in the ethanol market requires that ethanol supply be equal to ethanol demand; the latter is proportional to the fuel demand

$$S_E\left(P_E\right) = \alpha D_F\left(P_F\right) \tag{15}$$

Total fuel demand has to also equal total fuel supply

$$D_F\left(P_F\right) = S_G\left(P_G\right) + S_E\left(P_E\right) \tag{16}$$

Total differentiation of equations (2), (3), (10), (11), (15), and (16) (with the substitution identity (12) into equations (15) and (16)), yields

$$\begin{gathered} D_{fp}dp + D_{fZ_3}dZ_3 = f_x dx \\ f_x dp + pf_{xx}dx = dP_C \\ dP_F = \alpha dP_E + \left(1-\alpha\right)dP_G \\ dP_C = kdP_E \\ \alpha D_{FP_F}dP_F = k\left(S_{CP_C} - \bar{D}_{P_C}\right)dP_C + kS_{CZ_1}dZ_1 - kdx - k\bar{D}_{Z_2}dZ_2 \\ D_{FP_F}dP_F = S_{GP_G}dP_G + k\left(S_{CP_C} - \bar{D}_{P_C}\right)dP_C + kS_{CZ_1}dZ_1 - kdx - k\bar{D}_{Z_2}dZ_2 \end{gathered} \tag{17}$$

where we use a short-hand notation $k = \lambda\beta/\left(1-r\gamma\right)$, and the prime (') to denote the derivative with respect to a sole argument.

Because the first two equations in the system (17) are identical to the last two equations in system (4), it must be that the functional forms of the transmission elasticities with blend mandate (denoted by the superscript BM) related to the supply/foreign demand shocks in the corn market are the same

$$\varepsilon_{Z_1}^{BM} = \varepsilon_{Z_2}^{BM} = \frac{\eta_f^S}{\eta_f^S - \eta_f^D} \leq 1 \tag{18}$$

The magnitudes of elasticities in (18) in general differ from their counterparts with no corn-ethanol linkage in (7) and (8). The reason is that both sets of elasticities pertain to different market equilibria.[7] However, the difference will be rather small and we expect almost equal

[6] We stress the word *initially* because this is not the final quantity of yellow corn used in ethanol production. It is because ethanol production yields DDGS as a co-product which is almost a perfect substitute for yellow corn for animal feed. Therefore, the yellow corn that DDGS replaces can be further used for ethanol production.

[7] This point is explained in a greater detail in the section on data and calibration.

elasticities with and without ethanol.

The price transmission elasticity for the shock in the food demand under the blend mandate takes the form (Appendix 3)

(19) $$\varepsilon_{Z_3}^{BM} = \frac{\eta_f^S}{\left(\eta_f^S + \phi\eta_C^S - \rho\bar{\eta}_C^D\right) - \frac{\alpha\mu}{\omega m}\eta_G^S\eta_F^D\frac{P_F}{P_G}} \le 1$$

where $\omega = P_F S_E / P_C S_C^E$, and $m = \eta_G^S \frac{P_F}{P_G} - (1-\alpha)\eta_F^D$; η_G^S denotes gasoline supply elasticity, and η_F^D denotes fuel demand elasticity.

Binding Blender's Tax credit

Because under a binding blender's tax credit, fuel consumers are not mandated to consume ethanol, they will only do so if the consumer price of ethanol, inclusive of the reduced tax due to the tax credit (t_c), is the same as the consumer price of gasoline, i.e., $P_G + t$ (de Gorter and Just 2008; Cui et al. 2011; Lapan and Moschini 2012). For the market price of ethanol, we then have

(20) $$P_E = P_G - \left(\frac{1}{\lambda} - 1\right)t + \frac{t_c}{\lambda}$$

And the consumer fuel price is given by

(21) $$P_F = P_G + t$$

Totally differentiating the system of equations (2), (3), (21), (22), (11) , and (16) (with the substitution of equation (12) into (16)), which constitute the market equilibrium under a binding tax credit, we arrive at

(22) $$\begin{gathered} D_{fp}dp + D_{fZ_3}dZ_3 = f_x dx \\ f_x dp + p f_{xx} dx = dP_C \\ dP_E = dP_G \\ dP_F = dP_G \\ dP_C = k dP_E \\ D_{FP_F} dP_F = S_{GP_G} dP_G + k\left(S_{CP_C} - \bar{D}_{P_C}\right)dP_C + kS_{CZ_1}dZ_1 - kdx - k\bar{D}_{Z_2}dZ_2 \end{gathered}$$

The first two equations in the system (23) are the same as the last two equations in (4), hence the expressions for the price transmission elasticity of shocks in the corn market must be the same as in the case of no biofuels and with a binding blend mandate.

(23) $$\varepsilon_{Z_1}^{TC} = \varepsilon_{Z_2}^{TC} = \frac{\eta_f^S}{\eta_f^S - \eta_f^D} \le 1$$

where the super script TC denotes the case of a tax credit. The intuition why the price transmission elasticity is close to the no biofuel benchmark is the same as for the binding blend mandate provided above for equation (18).

The price transmission elasticity of a shock in the food demand under the tax credit is given by (Appendix 3)

(24) $$\varepsilon_{Z_3}^{TC} = \frac{\eta_f^S}{\left(\eta_f^S + \phi\eta_C^S - \rho\bar{\eta}_C^D\right) + \frac{\mu}{\omega}\left(\theta\eta_G^S - \sigma\eta_F^D\right)} \le 1$$

where $\theta = P_F S_G / P_G S_E$ and $\sigma = P_G D_F / P_G S_E$.

The last term in the denominator in equation (24), $\mu/\omega\left(\theta\eta_G^S - \sigma\eta_F^D\right)$, is unambiguously positive which implies that the price transmission elasticity with the binding tax credit should generally be smaller than the elasticity with no biofuel. For the extreme case of a perfectly elastic gasoline supply and/or fuel demand curve, the expression (24) reduces to $\varepsilon_{Z_3}^{TC} = 0$. In this case, the corn price does not respond to food demand shocks; the corn price is directly linked to the exogenous gasoline price - through the ethanol price given in (21) - and is thus insensitive to any shock in the food market. This implies that the linkage between corn and ethanol markets makes the corn price less responsive to food price changes when the tax credit is binding.

No Biofuel Policy

Corn ethanol production can also take place without biofuel policy. This is possible in several cases. First, with increased corn productivity the availability of crop may expand, leading to lower feedstock prices thus making ethanol production profitable even in the absence of biofuel policy. Second, if gasoline prices are sufficiently high, then the free market ethanol price increases according to equation (21) with the tax credit set to zero as is the case with no biofuel policy) and thus potentially making ethanol production profitable. Third, a technological change can also result in ethanol production without a policy.

In all three cases above, the consumer is not mandated to consume ethanol and will do so only when the final price of ethanol per mile is lower than the final price of gasoline. Hence, this is the same case as for the tax credit. Therefore, the model set-up for the market equilibrium with the tax credit (set to zero) applies for the no biofuel policy case as well. Consequently, the formulas for price transmission elasticities are the same as well. The only difference between the binding tax credit and the no biofuel policy is in the size of the ethanol sector. With tax credit the ethanol sector is expected to be larger because the tax credit improves ethanol profitably, leading to a higher ethanol production.

3. Data and Calibration

We calibrate the model to the data describing the U.S. corn, food, and fuel markets in 2009. The demand and supply curves exhibit constant price elasticity. We adopt some parameters and raw data from a well-established paper by Cui et al. (2011) as their corn-ethanol model is also calibrated to the year 2009. We provide an explanation for cases when our data differ from theirs. A self-explanatory documentation of the data used is presented in Appendix 5. All fuel price and quantity data are converted into gasoline energy-equivalents to consistently model the linkages in the fuel market. We calibrate our model to a binding mandate combined with a tax credit; we refer to this model as the *baseline*.

Demand and supply elasticities play an important role in our analysis. We use the central estimates for elasticities of corn supply, foreign corn import demand, and gasoline supply as reported in Cui et al. (2011); the lower and upper limits for the sensitivity analyses are also very similar (see the bottom part of Appendix 5) to Cui et al. (2011)'s. The elasticity of food/feed corn demand is calculated as per equation (A4.6) and is equal to -0.23, which is very close to the value reported by Cui et al. (2011) (-0.20).

The elasticity of food demand comes from Seale et al. (2003) and is equal to -0.09, which is consistent with the empirical observation that demand for food is very inelastic. Central estimate of the fuel demand elasticity of -0.26 comes from Hamilton (2009), and the lower and upper limits reflect the low and upper estimates of the recent meta-analysis by Havránek et al. 2012.

4. Simulation results

We use the baseline parameters to construct equilibria for the no biofuel benchmark and four policy regimes: (1) a binding mandate combined with a tax credit (same as the baseline), (2) a binding mandate alone, (3) a binding blender's tax credit, and (4) no biofuel policy.

In the benchmark and each regime, we (separately) introduce three exogenous shocks (Z_1, Z_2, Z_3) to calculate price transmission elasticities related to each shock. The magnitude of each shock is equal to 10 percent of the consumption/production corresponding to the no-shock case. Thus, for example, the (negative) corn supply shock under the binding tax credit regime is equal to 10 percent of the corn supply in the shock-free equilibrium for that policy regime. The price transmission elasticities are then calculated from the simulated changes in corn and food prices relative to the no-shock prices.

We perform a Monte Carlo analysis to check the robustness of our results to the exogenous elasticities. To that end, we vary elasticities of corn supply, food corn demand, foreign corn import demand, food demand, fuel demand, and gasoline supply. We make 5000 random draws for each of the elasticities from a beta distribution whose parameters are derived from the lower, central, and upper values of the elasticities specified in Appendix 5, using the PERT method (Davis 2008).

Price transmission elasticities

Table 1 presents a summary for the price transmission elasticities obtained from Monte Carlo simulations. We limit ourselves to the discussion of the central estimates of the transmission elasticities (the heavy font). For the no biofuel benchmark, the price transmission elasticity is 0.84 for corn market shocks (Z_1 and Z_2) and 0.61 for the food demand shock (Z_3).

For the binding mandate (with or without the tax credit), the transmission elasticities corresponding to individual shocks are very similar to the benchmark elasticities. To understand this stability, it is important to realize that at the current mandate levels the ethanol market – the only link in our model between corn and food markets on the one hand and the gasoline market on the other – is small relative to the gasoline market. As a result, the simulated market shocks have a minimal impact on the fuel price which, in connection with the inelasticity of fuel demand, implies minimal changes in the fuel consumption. Therefore, given the blend mandate – implemented as a fixed share of ethanol in fuel consumption – the amounts of ethanol and corn dedicated to ethanol production are not very sensitive to the market shocks. Under the binding mandate, the effects of the market shocks mostly materialize in the allocation of the residual amount of corn for non-ethanol uses. For example, the more the corn supply contracts (e.g., due to bad weather), the less corn is available for domestic food/feed use and for exports[8] but the amount of corn for ethanol does not change much.

Since for a given mandate the amount of ethanol does not response significantly to the market shocks, the corn price is effectively determined in the corn market.[9] In order to produce the mandated quantity of ethanol, ethanol producers need to pay for corn at least as much as the food sector is willing to pay. This mechanism of price formation under the mandate means that

[8] The allocation between the two corn uses depends on relative demand elasticities of the food/feed and export demand curves.

[9] The corn price would be completely determined in the corn market if the mandate were implemented as a fixed quantity mandate.

biofuels do not significantly affect the price transmission of shocks between corn and food prices. A change in the food (corn) price will be transmitted to the corn (food) price at the same rate both with the binding mandate and with no biofuels. This is documented by almost identical transmission elasticities in the first three columns in Table 1.

We observe a partially different result structure when the tax credit is binding as well as when no biofuel policy is in place. The asymmetric effect of biofuels on price transmission along food chain occurs with the food demand shock. As reported in Table 1, under a binding tax credit the presence of biofuels significantly reduces the price transmission elasticity with the food demand shock – a decrease in the transmission elasticity from 0.61 to 0.35. The elasticities associated with the remaining shocks are largely the same as in the benchmark case.

With the binding tax credit (or no biofuel polices), consumers are not mandated to consume ethanol. They will only do so if the (hypothetical)[10] consumer price of ethanol, inclusive of the reduced tax due to the tax credit (if any), is lower or the same as the consumer price of gasoline. This implies that now the corn price is determined by the gasoline price (through the ethanol price) and not in the corn market as it was the case under the binding mandate. Consequently, a shock in the food market will affect the corn price only to the extent to which it can affect the gasoline price. Given the small size of the ethanol market relative to the gasoline market, the price transmission from the food to corn market is also small (empirically only about 35 percent).

For a shock originating in the corn market, the price transmission elasticity is not affected by the presence of biofuels. It is because biofuels do not affect the price linkages in the processing or food markets, hence any change in the corn price is transmitted to the food price at the same magnitude with or without biofuels.

In order to identify the effects of the exogenous model parameters on the price transmission elasticities, we regress (separately for each shock and scenario) the transmission elasticities obtained from the 5000 simulations on the five elasticities (corn supply, foreign corn import demand, food demand, fuel demand, and gasoline supply). To ease the interpretation of the results, the demand elasticities were converted into positive values in all regressions.

The results in Table 2 show that the food demand elasticity is by far the strongest determinant of price transmission elasticities for all shocks except for the shock in the food demand in which case the corn supply elasticity affects the transmission elasticities most. The price transmission elasticities increase with the elasticities of corn supply and foreign corn demand for most shocks and scenarios. The only exception is again the food demand shock in which case the relationship is reversed. This is because the formula for the price transmission elasticity for a food demand shock is the reciprocal of the formula for the corn shock.

The sensitivity analysis for the fuel demand and the gasoline supply elasticities shows some heterogeneity across shocks and model scenarios. For corn supply, corn export, and food demand shocks (Z_1, Z_2, Z_3), the price transmission elasticities do not respond statistically significantly to the changes in fuel demand/gasoline supply elasticities when the mandate is binding (Table 2). For all other cases, fuel demand/gasoline supply elasticities generally do significantly affect the magnitude of price transmission elasticities. This heterogeneity is due to the different ways – described above – through which the shocks are transmitted to and interact with the fuel market and corn market.

Price level changes

[10] This price is hypothetical because the consumption of pure ethanol is very rare.

In addition to analyzing how biofuel policies have affected the price transmission, which is a relative measure, it is also important to investigate to what extent biofuel policies affect the price changes under various market shocks. To that end, in we report a summary for percentage changes in food and corn prices for the benchmark and four policy regimes.[11] We limit our discussion to the central estimates of these changes.

Biofuel's impact on the magnitude of the corn and food price responses to market shocks strongly depends on the biofuel policy. Compared to the no biofuel scenario, both food and corn price responses are not affected significantly when the mandate is binding. These results are qualitatively similar to price transmission elasticities reported in Table 1 where biofuels did not affect price transmission when mandate was the binding policy.

However, when the tax credit is binding (or when the free market would support biofuel production), both food and corn price changes are lower relative to the no biofuel scenario for all shocks. This is in contrast to the results for price transmission elasticities reported in Table 1, where the transmission elasticity was reduced by the presence of biofuels only for the food price shock. The reason is that fuel market absorbs (through biofuels) the major share of corn price shocks. With tax credit or in the absence of biofuel policies corn price is determined by the gasoline price. Because ethanol's share in the total fuel is small, corn and/or food market shocks have a limited impact on the gasoline price, thus making the corn price responding little to the shocks. As derived in the theoretical analysis, in an extreme situation with a perfectly elastic gasoline supply or fuel demand curves, the corn price response to any corn or food market shocks is zero, implying that also the food price change is reduced significantly relative to no biofuel situation.

Conclusions

The key result of this paper is that the presence of biofuels affects the price transmission elasticity only when the blender's tax credit is binding (or when ethanol is produced without any policy) and the shock originates in the food market. Our another important result is that the response of corn and food prices to exogenous shocks in the corn or food markets is always lower in the presence of biofuels when the tax credit is binding (or when ethanol would be produced without any policy). However, the results are mixed for the binding mandate.

The contribution of our study is to provide a theoretical basis for the often mixed results of many empirical studies on price transmission in the food chain. This means that the empirical studies need to consider whether biofuels are produced in the period covered and if so, which policy is binding.

Our results have also important policy implications. The price transmission along food chain recently attracted a lot of attention among policy makers (e.g., Areté 2012; European Commission 2009; Vavra and Goodwin 2005). It is often argued that the cause of low transmission of food prices to agricultural producer prices is market power of processing the industry and/or supermarkets. We show that under certain conditions biofuels are an additional cause for the reduced prices transmission in the food chain.

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[11] Of course, by dividing the corn and food price changes reported in **Error! Reference source not found.**, one obtains price transmission elasticities reported in .

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Table 1. Price transmission elasticities (summary statistics for 5000 simulations)

		No biofuel (benchmark)	Binding mandate & tax credit**	Binding mandate	Binding tax credit	No biofuel policy
Corn supply shock (Z_1)	Central	**0.84**	**0.83**	**0.83**	**0.84**	**0.84**
	Min	0.79	0.79	0.79	0.80	0.80
	Max	0.98	0.98	0.98	0.98	0.98
Corn export shock (Z_2)	Central	**0.84**	**0.84**	**0.84**	**0.84**	**0.84**
	Min	0.80	0.80	0.80	0.80	0.80
	Max	0.98	0.98	0.98	0.98	0.98
Food demand shock (Z_3)	Central	**0.61**	**0.63**	**0.63**	**0.35**	**0.35**
	Min	0.49	0.53	0.53	0.27	0.27
	Max	0.74	0.80	0.80	0.45	0.45

Note: * Standard deviation in each case is between 0.03 and 0.04. ** At the calibration point.

Table 2. The effect of model supply and demand elasticities on the price transmission elasticities

		Elasticity of corn supply	Elasticity of foreign corn import demand	Elasticity of food demand	Elasticity of fuel demand	Elasticity of gasoline supply
Corn supply shock (Z_1)	No biofuel (benchmark)	0.0103***	0.00248***	-1.572***	n.a.	n.a.
	Binding mandate and tax credit	0.0188***	0.00196***	-1.582***	-0.00038	-0.000187
	Binding mandate	0.0188***	0.00196***	-1.582***	-0.00038	-0.000188
	Binding tax credit	0.00221***	0.000231***	-1.544***	0.00457***	0.00497***
	No biofuel policy	0.00221***	0.000231***	-1.544***	0.00457***	0.00497***
Corn export shock (Z_2)	No biofuels (benchmark)	0.00322***	0.000404***	-1.530***	n.a.	n.a.
	Binding mandate and tax credit	0.00269***	0.000302***	-1.527***	-0.000343	-0.000157
	Binding mandate	0.00269***	0.000302***	-1.527***	-0.000343	-0.000157
	Binding tax credit	0.000517**	8.81E-06	-1.521***	0.000421	0.000632**
	No biofuel policy	0.000517**	8.81E-06	-1.521***	0.000421	0.000632**
Food demand shock (Z_3)	No biofuels (benchmark)	-0.325***	-0.0893***	0.234***	n.a.	n.a.
	Binding mandate and tax credit	-0.484***	-0.0439***	0.0598***	-0.00118	-0.000575
	Binding mandate	-0.484***	-0.0439***	0.0598***	-0.00121	-0.000558
	Binding tax credit	-0.131***	-0.0167***	0.00592***	-0.320***	-0.349***
	No biofuel policy	-0.131***	-0.0167***	0.00592***	-0.320***	-0.349***

Notes: Coefficients are estimated by OLS regression. The demand elasticities were converted to positive values for an easier interpretation.
*** p<0.01, ** p<0.05, * p<0.1; n.a. – not available

Table 3. Food and corn price changes due to market shocks under various policy regimes (%)*

		No biofuel (benchmark)		Binding mandate and tax credit		Binding mandate		Binding tax credit		No biofuel policy	
		Food	Corn	Food	Corn	Food	Corn	Food	Corn	Food	Corn
Corn supply shock (Z_1)	Central	**10.6**	**12.7**	**13.6**	**16.3**	**13.6**	**16.3**	**4.6**	**5.4**	**4.6**	**5.4**
	Stand. dev.	1.9	2.1	2.8	3.1	2.8	3.1	0.6	0.7	0.6	0.7
	Min	6.5	8.2	8.8	11.0	8.8	11.0	3.0	3.7	3.0	3.7
	Max	22.2	25.2	34.3	39.1	34.3	39.1	7.6	8.5	7.6	8.5
Corn export shock (Z_2)	Central	**2.6**	**3.1**	**2.0**	**2.3**	**2.0**	**2.3**	**0.7**	**0.8**	**0.7**	**0.8**
	Stand. dev.	0.5	0.5	0.4	0.4	0.4	0.4	0.1	0.1	0.1	0.1
	Min	1.7	2.1	1.3	1.6	1.3	1.6	0.5	0.6	0.5	0.6
	Max	5.6	6.3	4.4	4.9	4.4	4.9	1.1	1.3	1.1	1.3
Food demand shock (Z_3)	Central	**46.4**	**28.2**	**48.4**	**30.3**	**48.4**	**30.3**	**28.2**	**9.7**	**28.2**	**9.7**
	Stand. dev.	6.6	5.5	8.3	7.1	8.3	7.1	2.1	1.4	2.1	1.4
	Min	33.4	16.8	35.8	19.4	35.8	19.4	23.8	6.4	23.8	6.4
	Max	87.0	64.4	110.0	87.1	110.0	87.0	38.7	16.7	38.7	16.7

* Summary statistics for 5000 simulations