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The effect of ethanol policies on the vertical price transmission in corn and food markets☆

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ABSTRACT

This paper analyzes the impact of ethanol policies on price transmission along the food supply chain. We consider the US corn sector and its vertical links with food and ethanol (energy) markets. We find that ethanol is a source of imperfect price transmission in the food supply chain. Ethanol, however, alters price transmission only under a binding blender's tax credit and only from food to corn (not vice versa). Our results indicate that ethanol weakens the response of corn and food prices in terms of their level changes to shocks occurring in agricultural (corn and food) markets. The results are robust to different assumptions on the model parameters. Although market power has previously been identified as a source of imperfect price transmission in the food supply chain, our findings show that in the presence of ethanol, the imperfect price transmission may occur even if markets are perfectly competitive. This warrants careful evaluation of markets before any policy intervention.

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 the food and retail sectors have led to their higher concentration. Second, the global agricultural and energy sectors became more interdependent due to the surge in biofuel production in the last two decades, with both sectors exhibiting high price 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 for farmers and consumers; this makes the issue of price transmission very relevant from the political economy perspective.

The pass-through of price changes along the food supply chain is commonly found to be imperfect, meaning that a price change at the producer (consumer) level is not fully transmitted to consumers (producers). Literature often finds price transmission to be asymmetric, that is, a price decrease at the producer level is slowly and not fully transmitted to consumers while a price increase at the producer level is transmitted more quickly and fully to consumers prices. Two main causes of imperfect price transmission were identified in the theoretical literature: the market power (e.g., McCorriston et al., 1998) and the existence of adjustment or menu costs (e.g., Ball and Mankiw, 1994). Other causes of imperfect price transmission include, among others, agricultural policies (Gardner, 1975; Serra and Goodwin, 2003), inventory behavior (Reagan and Weitzman, 1982; Wohlgenant, 1985), dynamics (Azzam, 1999), the share of commodity costs in the final product (Bettendorf and Verboven, 2000), and accounting methods (Balke et al., 1998).

Besides theoretical studies, there is a large empirical literature investigating the price transmission in the food supply chain (e.g., Goodwin and Harper, 2000; Mohanty et al., 1995; Miller and Hayenga, 2001; Rezitis and

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Reziti, 2011; Bakucs et al., 2012, 2014; Rajcaniova and Pokrivcak, 2013; Pokrivcak and Rajcaniova, 2014). Although the studies significantly differ in their estimation methodology and regional and commodity coverage, they tend to confirm imperfect price transmission. The main shortcoming of the empirical studies, however, is their failure to provide theoretical underpinnings and a plausible interpretation of the estimated results.

A flourishing empirical literature has analyzed the effects of biofuels on the price transmission between biofuels and feedstock prices. An extensive literature review by Serra and Zilberman et al. (2013) concludes that energy prices drive long-run agricultural price levels and that instability in energy markets is transferred to food markets. Kristoufek et al. (2014) study price transmission between biofuel markets and related commodities. They find that both ethanol and biodiesel prices are responsive to their production factors (ethanol to corn and biodiesel to diesel). The strength of transmission between both significant pairs increased remarkably during the food crisis of 2007–2008.

This paper contributes to the previous literature by developing a stylized structural theoretical model for the corn sector and its vertical linkages with food and ethanol markets to analyze the impact of ethanol and ethanol policies on price transmission in the food supply chain (and not only between ethanol and corn prices) (Fig. 1).

This topic is of high importance given the significant impact of biofuels' expansion on the world agricultural commodity markets (e.g., de Gorter and Just, 2008, 2009a; Ciaian and Kancs, 2011a, 2011b; Drabik, 2011; Serra et al., 2011; Yano et al., 2010; Zilberman et al., 2013; de Gorter et al., 2013). In the period 2007–2010, world ethanol production almost doubled but leveled-off after that, reaching 21.8 to 24.6 billion gallons in the period 2011–2014 (US Department of Energy, 2015). A significant share of corn and sugarcane production is used to produce fuel. Several studies have shown that the surge in biofuel production due to biofuel policies was the major cause of the recent spikes in the global grains and oilseed prices and that a strong and direct link between energy and commodity prices has been created (e.g., Wright, 2011; Mallory et al., 2012; de Gorter et al., 2015).

This paper provides an answer to a question on whether the introduction of corn ethanol has affected the price transmission between the agricultural commodity (corn) and food markets. Because the biofuel production is policy-driven, we also analyze how different policy regimes affect the price transmission. More precisely, we analyze the US corn sector and its vertical links to food and ethanol markets. We consider two policy regimes: (1) a blend mandate and (2) a blender's tax credit. We compare these policy regimes to the no biofuel production benchmark. The blend mandate and the blender's tax credit are historically the most relevant policies used in the United States, and other countries alike, to support biofuel production. We evaluate the price transmission both from corn to food and from food to corn.

We build a tractable partial equilibrium model where corn is used to produce food (and feed) and ethanol by competitive firms, and is also exported abroad. We are aware that the US food processing industry exhibits a significant concentration; however, by assuming a competitive market environment, we can better identify the effects of ethanol (and the role of different policy regimes) on price transmission in the food chain. More importantly, however, it appears that the assumption of a competitive industry is inconsequential to the question whether ethanol has affected the price transmission, as long as the same market structure exists before and after the introduction of ethanol.

In our model, the corn market is vertically linked to a food industry that produces final goods for consumers. When ethanol production is introduced, corn prices become linked to ethanol prices through a zero-profit condition following the models of de Gorter and Just (2008), and Mallory et al. (2012).

The key finding from our simulation results based on the 2009 data is that when ethanol production is due to a blender's tax credit, a price shock originating in the food market transmits to the corn market at a smaller rate compared to a situation without ethanol production (i.e., the transmission becomes more imperfect). However, when the ethanol production is due to a blend mandate, or the price shock originates in the corn market (regardless of the biofuel policy), the price transmission does not change. These differences stem from different effects biofuel policies have on the corn price formation. Importantly, our results also show that the response of corn and food prices (in absolute terms) to shocks in the corn or food markets is lower in the presence of biofuels.

The public media and policy documents often claim that the imperfect price transmission is caused by market failures, such as market power. This argument is often used to justify policy intervention in the agricultural markets (Meyer and von Cramon-Taubadel, 2004). The results of our paper show that such arguments need to be evaluated with caution and that the market environment needs to be understood well before a policy intervention. It is because, as we showed earlier, the imperfect price transmission can occur even if markets are perfectly competitive. The presence of biofuels may thus result in an imperfect adjustment of farm gate prices to shocks occurring in the food sector.

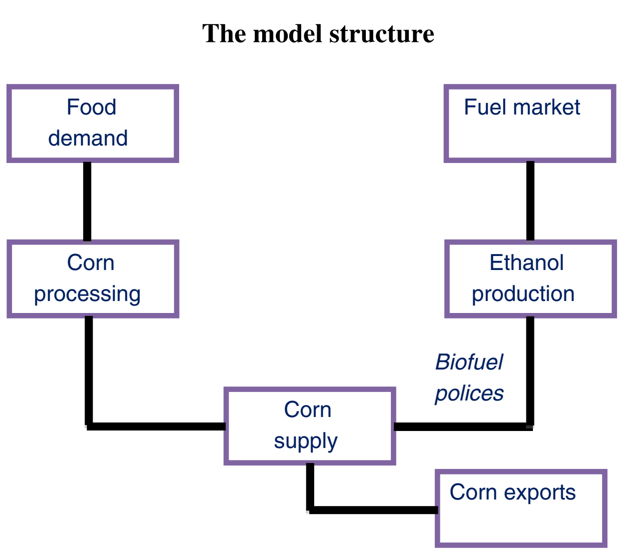

Fig. 1. The model structure.

2. The theoretical model

In order to better identify the direct impact of biofuels on the price transmission, we abstract from modeling the linkages of the fuel market with the food sector (e.g., through higher transportation costs) and with the corn sector in the form of changing input costs for corn production. Furthermore, we also abstract from other issues already investigated in the literature, such as market power, adjustment costs, inventory behavior, size of commodity costs in the final product, or accounting method. However, because biofuels production has historically heavily depended on governmental interventions, we consider a policy dimension in our model.

In our benchmark scenario, entitled *no biofuel*, only the corn–food market supply chain is considered and corn and ethanol markets are delinked. The food market is represented by a competitive processing sector that buys and processes corn and sells corn-based food. We then analyze how biofuels affect the benchmark price transmission by creating a direct link between corn and ethanol prices and quantities. The ethanol production and the price links are primarily determined by biofuel policies. Therefore, we consider two policy regimes: (1) a binding blend mandate and (2) a binding blender's tax credit. These biofuel policies have historically been used in the United States. We follow the approach developed by de Gorter and Just (2008), Drabik (2011), and Mallory et al. (2012) to model the link between corn and ethanol prices (Fig. 1).

2.1. The no biofuel benchmark

In the absence of ethanol production, the total US corn supply, $S_C(P_C)$, 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 US market denoted by $\overline{D}(P_C)$. The equilibrium in the corn market thus requires that corn supply be equal to corn food/feed demand and exports

$$S_C(P_C, Z_1) = x + \overline{D}(P_C, Z_2), \tag{1}$$

where Z_i, $i = \{1, 2\}$, denotes an exogenous shifter of the corn supply curve (e.g., due to the 2011–2012 drought in the United States) and of the foreign corn demand (e.g., hoarding of corn during periods of price spikes), respectively. These exogenous shifters are used to derive transmission elasticities (see below). Since there are no shocks in the initial equilibrium, we initially set $Z_1 = Z_2 = 0$. A positive shock implies a rightward shift in a supply or demand curve.

Domestic corn is processed by a competitive representative firm into food/feed according to a well-behaved production function $f(x)$ that satisfies: $f(0) = 0$, $f_x > 0$, and $f_{xx} < 0$. The subscript denotes the derivative of the production function with respect to the argument. The produced food is directly consumed; that is, we do not model the retail sector.

Denoting $D_f(p)$ as the total (i.e., domestic and export) demand for food at price p and Z_3 as an exogenous food demand shifter, the equilibrium in the food market is given by

$$D_f(p, Z_3) = f(x). \tag{2}$$

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

$$pf_x = P_C. \tag{3}$$

Eqs. (1) through (3) represent market equilibrium conditions that allows us to derive price transmission elasticities in the absence of ethanol production pertaining to individual market shocks.

First, we consider price transmission elasticities from the corn to the food market. We derive these elasticities by introducing exogenous shocks in the corn supply, Z_1, and the corn export demand, Z_2. A shock in the corn supply or corn export demand of dZ_i changes the corn price by dP_C/dZ_i and the food price by dp/dZ_i, for $i = \{1, 2\}$. Following McCorriston et al. (2001), we calculate the price transmission elasticity, ε_{Z_i}, of a shock in the corn market as

$$\varepsilon_{Z_i} = \frac{dp/dZ_i}{dP_C/dZ_i}\frac{P_C}{p} \quad \text{for } i = \{1, 2\}. \tag{4}$$

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

Totally differentiating the system of Eqs. (1) through (3) and solving for price transmission elasticities corresponding to the corn supply (Z_1) and corn export demand (Z_2) shocks we obtain

$$\varepsilon_{Z_i}^{NB} = \frac{\eta_f^S}{\eta_f^S - \eta_f^D} \leq 1 \quad \text{for } i = \{1, 2\}, \tag{5}$$

where η_f^S denotes a price elasticity of food supply (derived in Drabik et al., 2014), and η_f^D is a price elasticity of food demand. Note that because the corn supply shock and the corn export demand shock occur in the same (corn) market, their corresponding price transmission elasticity turns out to be identical, given by Eq. (5).

Second, we consider the price transmission elasticity from food to corn, $\varepsilon_{Z_3}^{NB}$. We can derive this elasticity from the system of Eqs. (1) through (3) by introducing an exogenous shock, Z_3, to the food demand

$$\varepsilon_{Z_3}^{NB} = \frac{\eta_f^S}{\eta_f^S + \phi\eta_C^S - \rho\overline{\eta}_C^D} \leq 1, \tag{6}$$

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

2.2. Biofuels

The price transmission elasticities derived in Eqs. (5) and (6) represent the benchmark situation with no biofuels in place. Next, we introduce ethanol and link them to the corn–food supply chain defined above.

We assume a Leontief production technology, where a bushel of corn results in $\beta = 2.8$ gal of ethanol (Eidman, 2007). In addition, each bushel of corn processed into ethanol yields $\gamma = 17/56$ bushels of an ethanol co-product that is returned to the corn market as an animal feed (dried distillers grains with solubles—DDGS). The ethanol supply curve, $S_E(P_E)$, is determined by the horizontal difference between the corn supply and demand for domestic food/feed use and exports, adjusted by conversion coefficients

$$S_E(P_E) \equiv \frac{\lambda\beta}{1 - r\gamma}\left[S_C(P_C, Z_1) - x - \overline{D}(P_C, Z_2)\right], \tag{7}$$

where P_E denotes the ethanol price; r denotes the relative price of DDGS and corn; and the coefficient $\lambda = 0.7$ denotes miles traveled per gallon of ethanol relative to gasoline (de Gorter and Just, 2008), and is used to consistently convert all quantities and prices into gasoline energy-equivalent terms (Cui et al., 2011; Lapan and Moschini, 2012).

In the presence of ethanol production, the term x does not represent solely yellow corn (as it is the case when ethanol is not produced) but rather the corn-equivalent quantity of corn and DDGS used in food production. The dollar value in which we measure the food production makes it possible to accommodate a possibly separate use of DDGS (e.g., as a hog feed, where the pork is subsequently counted as food) and yellow corn (e.g., directly used for pop-corn) in food production.

To simplify the analysis, we assume a constant processing cost, c_0, per gallon of ethanol produced. The zero marginal profit condition for ethanol production then implies a link between corn and ethanol prices (de Gorter and Just, 2008; Drabik, 2011; Lapan and Moschini, 2012)

$$P_C = \frac{\lambda\beta}{1 - r\gamma}(P_E - c_0). \tag{8}$$

The equilibrium in the fuel market is obtained by setting the gasoline supply, $S_G(P_G)$, and the ethanol supply [Eq. (7)] equal to the fuel demand, $D_F(P_F)$

$$D_F(P_F) = S_G(P_G) + S_E(P_E), \tag{9}$$

where P_G and P_F denote the gasoline and the fuel price, respectively.

The corn and ethanol price formation depends on the policy regime. Therefore, we next consider a blend mandate and a blender's tax credit.

2.2.1. A binding blend mandate

Although the US 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. Under a binding blend mandate, α, ethanol has to constitute at least $\alpha[\times 100]$ percent of the final fuel blend. Therefore, when the mandate is binding, ethanol and gasoline are complements. The fuel price, P_F, is equal to the weighted average of the ethanol and gasoline prices, adjusted for the fuel tax, t, and the ethanol tax credit, t_c (if any) (de Gorter and Just, 2009b; Drabik, 2011)

$$P_F = \alpha(P_E + t/\lambda - t_c/\lambda) + (1-\alpha)(P_G + t). \tag{10}$$

The blend mandate requires that ethanol supply be proportional to the fuel demand

$$S_E(P_E) = \alpha D_F(P_F). \tag{11}$$

Because the fuel demand is price-inelastic (Havránek et al., 2012), the right-hand side of Eq. (11) essentially determines the amount of ethanol to be produced for a given mandate. In combination with Eq. (7), the amount of ethanol in (11) also determines the amount of corn to be processed. As a result, with a binding ethanol mandate, the corn and ethanol prices are determined solely on the corn market (except for the small impact of the corn market on the gasoline market under an endogenous gasoline price. But this does not make much difference conceptually. The corn market feedback on gasoline through ethanol is minimal because the ethanol share in the US total fuel is rather small, around 7% in 2009 and 10% currently). The intuition is that when ethanol blending is mandatory, ethanol processors are “forced” to acquire corn from the corn market at any price. This implies that a shock occurring on the corn market will be absorbed by the residual corn used for food/feed.

The market equilibrium conditions when the ethanol price is determined by a blend mandate [given by (2), (3), (7), (8), (9), (10), and (11)] can be used to derive for price transmission elasticities corresponding to the corn supply (Z_1), corn export demand (Z_2), and food demand (Z_3) shocks

$$\varepsilon_{Z_1}^{BM} = \varepsilon_{Z_2}^{BM} = \frac{\eta_f^S}{\eta_f^S - \eta_f^D} \le 1 \tag{12}$$

$$\varepsilon_{Z_3}^{BM} = \frac{\eta_f^S}{\left(\eta_f^S + \phi\eta_C^S - \rho\overline{\eta}_C^D\right) - \frac{\alpha\mu}{\omega m}\eta_G^S\eta_F^D\frac{P_F}{P_G}} \le 1 \tag{13}$$

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 and η_F^D denote gasoline supply and fuel demand elasticities, respectively.

The magnitudes of elasticities in (12) in general differ with no corn–ethanol linkage Eq. (5). The reason is that both sets of elasticities pertain to different market equilibria.[1]

Formula (13) differs from formula (6) by a term that captures the parameters of the fuel market. Since the term is positive, the transmission elasticity for a food demand shock under a blend mandate should generally be smaller than the transmission elasticity with no biofuels. Note, however, that because the market equilibria corresponding to formulas (6) and (13) are not the same, the magnitudes of the (endogenous) terms ϕ and ρ differ between the formulas, making the two elasticities not exactly comparable.

2.2.2. A binding blender's tax credit

Under a binding blender's tax credit, fuel consumers are not mandated to consume ethanol; therefore, 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 or lower than the consumer price of gasoline, that is, $P_G + t$ (de Gorter and Just, 2008; Cui et al., 2011; Lapan and Moschini, 2012). This results in the equilibrium equation of the market price of ethanol given by

$$P_E = P_G - (1/\lambda - 1)t + t_c/\lambda, \tag{14}$$

whereas the consumer fuel price is given by

$$P_F = P_G + t. \tag{15}$$

Then, Eqs. (8) and (14) imply the following price formation for corn

$$P_C = \frac{\lambda\beta}{1 - r\gamma}[P_G - (1/\lambda - 1)t + t_c/\lambda - c_0]. \tag{16}$$

Eq. (16) implies a direct link between corn and gasoline prices. The corn price is fully linked to the gasoline price, meaning that a change in the gasoline price is fully transmitted to the corn price. Naturally, given the relative sizes of the corn and gasoline markets, a shock in the corn price will have a minimal (if any) effect on the gasoline price.

The equilibrium conditions (2), (3), (7), (8), (9), (14), and (15) can be used to solve for price transmission elasticities corresponding to the corn supply (Z_1), corn export demand (Z_2), and food demand (Z_3) shocks

$$\varepsilon_{Z_1}^{TC} = \varepsilon_{Z_2}^{TC} = \frac{\eta_f^S}{\eta_f^S - \eta_f^D} \le 1 \tag{17}$$

$$\varepsilon_{Z_3}^{TC} = \frac{\eta_f^S}{\left(\eta_f^S + \phi\eta_C^S - \rho\overline{\eta}_C^D\right) + \frac{\mu}{\omega}\left(\theta\eta_G^S - \sigma\eta_F^D\right)} \le 1, \tag{18}$$

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 Eq. (18), $\mu(\theta\eta_G^S - \sigma\eta_F^D)/\omega$, 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, expression (18) 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 (14) 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.

Note that assuming a zero tax credit [i.e., $t_c = 0$ in Eq. (14)] and a sufficiently high gasoline price, the model collapses to a situation of no biofuel policies, that is, ethanol production in the absence of a policy intervention. Because the market equilibrium does not change qualitatively in this special case, the price transmission elasticities are the same as under the tax credit. For this reason, we do not analyze the no biofuel policy scenario further.

2.2.3. Corn price formation: a graphical illustration

Because the corn price formation is key to understanding the intuition behind the price transmission elasticities simulated in a later section, Figs. 2 and 3 graphically (and in a simplified manner) illustrate how the corn price is determined under a blender's tax credit and a biofuel mandate. Because biofuels interact with the food supply chain through corn, this new linkage can potentially alter the price transmission between food and corn as compared to the no biofuels benchmark. To simplify the graphical exposition, we assume a fixed gasoline price and all corn is supplied to the domestic market (these assumptions are relaxed later in the paper). The horizontal axis shows the quantity of corn, Q, and the vertical axis measures the corn price, P_C. With no ethanol and no shock, the derived food demand for corn is given by the downward sloping curve D_f^o and the corn supply is represented by

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

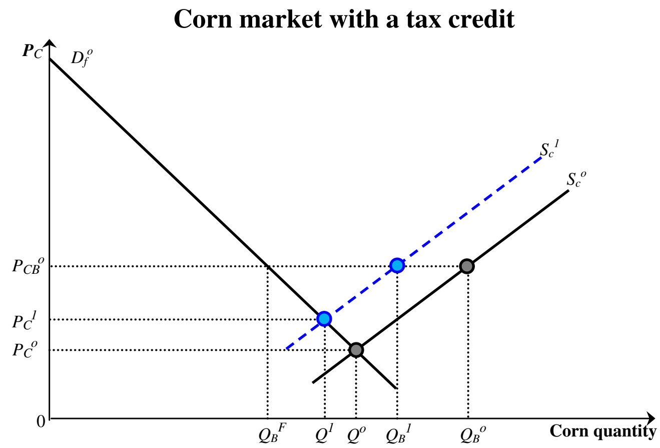

Fig. 2. Corn market with a tax credit.

the upward sloping curve S_C^o. Hence, the corn market equilibrium with no biofuels and no shock is (Q^o, P_C^o) in both figures, meaning that all corn, Q^o, is processed for food at price P_C^o.

Now assume a tax credit is introduced that makes ethanol production profitable. As a result, the new corn market price is P_{CB}^o in Fig. 2, and it is linked to the ethanol price as given by Eq. (8). The equilibrium with the tax credit shifts from (Q^o, P_C^o) to (Q_B^o, P_{CB}^o). The new quantity of corn supplied to the food production is Q_B^F and the residual, $Q_B^o - Q_B^F$, goes to the ethanol production.

Next, assume an exogenous corn supply shock that shifts the corn supply curve from S_C^o to S_C^1. With no biofuels, the equilibrium would shift from (Q^o, P_C^o) to (Q^1, P_C^1). However, because with the tax credit the corn price is directly linked to the gasoline price [given by Eq. (16)], any shock occurring on the corn market is absorbed by the fuel market via a reduction in the corn destined for ethanol $(Q_B^o - Q_B^1)$, with no impact on the corn price (it stays at P_{CB}^o). Note that the corn-food use is unaltered at Q_B^F. Overall, comparing the change in market equilibria due to a shock with and without biofuels, we observe that biofuels reduce the corn price change under the tax credit, implying that we can expect lower (i.e., more imperfect) price transmission elasticities between food and corn markets relative to the (no biofuels) benchmark.

Another biofuel policy we consider is an ethanol mandate. Although in the paper we model a blend mandate (which specifies a fixed share of ethanol in the fuel blend and the quantity of ethanol may vary, depending on the total fuel consumption), for ease of exposition and with no effect on the qualitative results, we consider a quantity mandate (which

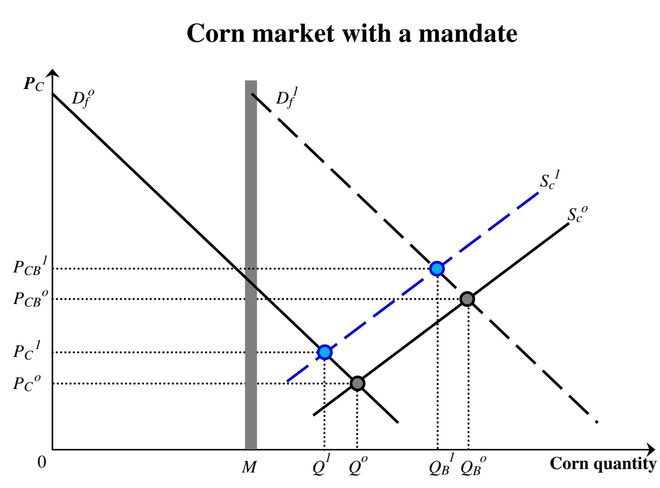

Fig. 3. Corn market with a mandate.

specifies a fixed quantity of ethanol and the share of ethanol may vary) in Fig. 3.[2] We denote the quantity of corn dedicated to ethanol production under the mandate by M. Because the ethanol mandate creates additional demand for corn, the original corn demand curve D_f^o shifts horizontally out to the right by distance M to achieve D_f^1. The market equilibrium shifts from (Q^o, P_C^o) to (Q_B^o, P_{CB}^o). In equilibrium, the residual quantity of corn, $Q_B^o - M$, is used in food production. In contrast to the tax credit (where the corn price is determined by the fuel market), with the mandate the corn price is determined on the corn market by the intersection of the total corn demand curve, D_f^1, and the corn supply curve, S_C^o.

Like above, we assume a corn supply shock that shifts the corn supply curve from S_C^o to S_C^1 (Fig. 3). The corn price and quantity both adjust to the shock with and without biofuels. With biofuels, the equilibrium shifts from (Q_B^o, P_{CB}^o) to (Q_B^1, P_{CB}^1), whereas without biofuels the equilibrium relocates from (Q^o, P_C^o) to (Q^1, P_C^1). In either case, all adjustments to the shock take place on the corn-food market. Similar results hold for the food demand shock. Overall, these results indicate that with a mandate in place, biofuels do not affect the corn price formation, implying that under a biofuel mandate we expect no change in the price transmission cause due to biofuel production.

3. Data and calibration

We calibrate the model to the data describing the US 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. Where our data differ from theirs, we explain why that is the case. A self-explanatory documentation of the data used is presented in Table 2. All fuel price and quantity data are converted into gasoline energy-equivalents to consistently model the linkages in the fuel market.

Two principal corn ethanol policies were in place in the United States in 2009: the blender's tax credit and the blending (share) mandate. Because only one biofuel policy can determine the biofuel price at a time (de Gorter and Just, 2009b), it is crucial to determine the binding policy in order to properly calibrate the model. Cui et al. (2011) calibrate their model to the blender's tax credit arguing (in footnote 36) that "because ethanol production for 2009 exceeds the mandate level, […] the mandate does not bind, and […] it is the fuel tax and ethanol subsidy policies that affect equilibrium values." However, de Gorter and Just (2010) show that the comparison of the observed quantity of ethanol with the mandated level does not reliably determine which policy is binding and argue for comparing the observed ethanol market price with what the price would have been if the tax credit had been binding. de Gorter and Just (2010)'s empirical analysis shows that the binding policy in 2009 was the mandate. An indication that the blender's tax credit was not a binding policy in 2009 is the gasoline price. Cui et al. (2011) calculate it to be \$2.11/gal, which is 35 cents more than the observed wholesale price of \$1.76/gal. Thus, we calibrate our model to a binding mandate combined with a tax credit.

The upper part of Table 2 presents parameters that describe the link between corn and ethanol prices and quantities; we also recognize that one gallon of corn ethanol yields only approximately 70% of the mileage compared to gasoline. The returns-to-scale parameter of the food production function is estimated to be $\varepsilon = 0.33$, which corresponds to the food supply elasticity of $\eta_f^S = 0.48$ (Drabik et al., 2014).

[2] Given that for illustration purpose we assume an exogenous gasoline price in Fig. 3 (no impact of ethanol on gasoline market), the quantity mandate and the blend mandate have equivalent implications for the corn market (the ethanol quantity is equal in both cases). In simulations, we relax the assumption of an exogenous gasoline price. However, because of the small size of the ethanol production relative to the size of gasoline market, the intuition of the effects illustrated in Fig. 3 also holds for the endogenous gasoline price and blend mandate as considered in the simulations.

To be consistent with observed market data, we calculate the mandate $\alpha = 0.057$ as the share of the (energy) amount of ethanol in the (energy) amount of total fuel. In 2009, a corn ethanol blender's tax credit of $0.45/gal and the (federal and state average) gasoline tax of $0.39/gal were also in place.

The gasoline and ethanol wholesale (rack) prices come from Omaha, Nebraska. The price of fuel is equal to the weighted average of ethanol and gasoline prices adjusted for the fuel tax and the tax credit, and amounts to $2.17 per gasoline energy-equivalent gallon (GEEG). Corn and ethanol prices are linked through a zero marginal profit condition for ethanol production. The price of food is normalized to unity, which makes it possible to use the dollar value of the food production as the food quantity.

The US ethanol production (equal to consumption in our model) in 2009 amounted to 10.76 billion gallons (corresponding to 7.53 billion GEEGs), and the total fuel (i.e., gasoline and ethanol) consumption was 134.74 billion gallons. Therefore, the gasoline consumption equals 134.74–10.76 = 123.61 billion gallons, making the total fuel consumption in energy terms be equal to 131.14 GEEGs.

Corresponding to the 10.76 billion gallons of ethanol is 2.84 billion bushels of yellow corn; this estimate does, however, not take into account the amount of the ethanol co-product, DDGS (dried distillers grains with solubles) that is returned to the corn market. Taking the DDGS into consideration, the total quantity of yellow corn diverted to ethanol production is 3.84 billion bushels. The difference between 3.84 billion bushels and 2.84 billion bushels thus gives the amount of DDGS placed on the market. Following Hoffman and Baker (2011), we assume 81% of DDGS is consumed domestically and the rest is exported.

The total yellow corn supply in the United States in 2009 was 13.15 billion bushels, of which 1.86 billion bushels were exported. We estimate the quantity of yellow corn used in food/feed as the residual after the export and ethanol markets have been satisfied, that is, $13.15 - 3.84 - 1.86 = 7.45$ billion bushels. However, the total amount of corn equivalent used in the food/feed sector is equal to $7.45 + 0.81 \times 1.00 = 8.26$ billion bushels, reflecting that 81% of DDGS stayed in the domestic market in 2009. We made a similar adjustment for the corn-equivalent amount of exports.

We use the Annual Survey of Manufacturers (ASM) from the US Census Bureau to estimate the value of food production that is related to corn.[3] The total value of food production where corn is used is $94.85 billion. The items included in this amount are presented in Table 1. Because more than 80% of US corn ethanol plants are dry mills due to lower capital costs,[4] we do not include products of wet milling into the value of food production.

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 analysis are also very similar (see the bottom part of Table 2) to Cui et al. (2011)'s. The elasticity of food/feed corn demand is calculated as per Eq. (A4.6) and is equal to −0.23, which is very close to −0.20, a value reported by Cui et al. (2011).

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 meta-analysis by Havránek et al. (2012).

4. Simulation results

We calibrate the model to a binding mandate combined with a tax credit using the data for 2009 and parameters reported in Table 2.

[3] http://www.census.gov/manufacturing/asm/historical_data/index.html
[4] http://www.afdc.energy.gov/fuels/ethanol_production.html

Table 1
Products included in the value of food production using corn.

Products and service codes	Meaning of products and service codes	Sum of products shipment value ($1000)
3112117	Corn mill products	1,830,037
3112211	Corn sweeteners	6,070,174
3112214	Manufactured starch	2,189,667
3112218	Corn oil	992,574
311611A	Pork, not canned or made into sausage, slaughtering plants	16,379,772
311611G	Pork, processed, not made into sausage, slaughtering plants	2,137,591
3116121	Pork, processed/cured, purchased carcasses	8,296,984
311615	Poultry processing	51,150,442
3119194	Corn chips and related products	5,807,472
	Total	94,854,713

Source: The Annual Survey of Manufactures (ASM), US Census Bureau.

Then we use the calibrated model to simulate the benchmark of no biofuels as well as the equilibrium with binding mandate (without tax credit) and a binding blender's tax credit. These three policy regimes (i.e., no biofuels, a binding mandate, and a binding blender's tax credit) are considered for simulations to derive the price transmission elasticities. We have also run the model to derive the price transmission elasticities where we assume binding mandate with tax credit in place. Because the results are identical to the case of the mandate only, we do not report them further. This is because mandate determines the equilibrium in the corn and biofuel markets. The tax credit affects only the ethanol price level with no impact on the interlinkages between markets.

To derive price transmission elasticities, we separately introduce exogenous shocks in corn supply, corn export demand, and corn food demand, denoted as Z_1, Z_2, and Z_3, respectively. The first two shocks allow us to identify the price transmission elasticity from the corn to the food market because they introduce exogenous changes in the corn market. The corn food demand shock induces changes in the final consumer demand, which allows as to identify the price transmission elasticity from food to corn. The magnitude of each shock is equal to 10%[5] of the consumption/production corresponding to the no-shock equilibrium. Thus, for example, the (negative) corn supply shock under the binding tax credit regime is equal to 10% of the corn supply in the shock-free equilibrium. The price transmission elasticities are 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, 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 Table 2, using the PERT method (Davis, 2008).

4.1. Price transmission elasticities

Table 3 presents a summary of results for the price transmission elasticities obtained from Monte Carlo simulations. We focus on the central estimates of transmission elasticities (the bold font). The price transmission elasticity from corn to food in the no biofuels benchmark is 0.84 (for corn market shocks Z_1 and Z_2), meaning that a 10% increase in the corn price causes an 8.4% increase in the price of food. On the

[5] We have also simulated the model with 1-, 5-, 25-, 50-, and 75% shocks. Because the price transmission elasticities are largely unaffected we do not report these results. Only for the 50- and 75% shocks, the elasticities differ slightly relative to the 10% shock. This is expected given that the magnitude of shocks is relatively large and thus effects may depart, to a certain extent, from the comparative static results derived in Section 2. However, the overall results of the paper are not affected by the size of the shocks; the results are robust across all simulated shocks.

Table 2
Data sources (2009).

Variable/parameter	Symbol	Value	Unit	Source
Parameters				
Miles per gallon of ethanol relative to gasoline	λ	0.70		de Gorter and Just (2009a)
Ethanol produced from one bushel of corn	β	2.80	Gallon/bushel	Eidman (2007)
DDGS production coefficient	γ	17/56		Eidman (2007)
DDGS relative price to corn	r	0.86		$r = (P_{DDGS}*56)/(P_C*2000)$
Price and quantity link between corn and ethanol market	k	2.65	GEEG/bushel	$k = \lambda\beta/(1 - r\gamma)$
Ethanol processing cost	c_0	1.14	$/GEEG	$c_0 = P_E - P_C/k$
Returns to scale parameter of the food production function	ε	0.33		$\varepsilon = P_C x/pf$
Share of domestic consumption of DDGS	ω	0.81		Hoffman and Baker (2011)
Value of corn supply in value of food production	ϕ	0.52		$\phi = P_C S_C/pf$
Value of corn equivalent exports in value of food prod.	ρ	0.08		$\rho = P_C \overline{D}_C/pf$
Value of (initial) corn used in ethanol in value of food production	μ	0.11		$\mu = P_C S_C^E/pf$
Policy variables				
Blend mandate [a]	α	0.06		$\alpha = E/F$
Ethanol tax credit	t_c	0.45	$/gallon	RFS2 [b]
Fuel tax	t	0.39	$/gallon	Cui et al. (2011)
Prices				
Gasoline price	P_G	1.76	$/gallon	Gasoline average rack price in Omaha, Nebraska[c]
Ethanol market price (volumetric)	P_e	1.79	$/gallon	Ethanol average rack price in Omaha, Nebraska[c]
Ethanol market price (energy)	P_E	2.56	$/GEEG	$P_E = P_e/\lambda$
Fuel price	P_F	2.17	$/GEEG	Eq. (10)
Food price	p	1.00		Normalized
Corn market price	P_C	3.74	$/bushel	Cui et al. (2011)
DDGS price	P_{DDGS}	114.38	$/ton [d]	Cui et al. (2011)
Quantities				
Fuel demand (volume)	$\tilde{F}$	134.37	Billion gallons	Cui et al. (2011)
Fuel demand (energy)	F	131.14	Billion GEEGs	$F = G + E$
Ethanol consumption (volume)	e	10.76	Billion gallons	Cui et al. (2011)
Ethanol consumption (energy)	E	7.53	Billion GEEGs	$E = \lambda e$
Gasoline supply	G	123.61	Billion gallons	$G = \tilde{F} - e$
Corn supply	S_C	13.15	Billion bushels	Cui et al. (2011)
Consumption of yellow corn for food/feed	$\tilde{x}$	7.45	Billion bushels	$\tilde{x} = S_c - \tilde{S}_C^E - \tilde{D}$
Consumption of corn-equivalent for food/feed	x	8.26	Billion bushels	$x = \tilde{x} + DDGS^H$
Foreign yellow corn import demand	$\tilde{D}$	1.86	Billion bushels	Cui et al. (2011)
Foreign corn equivalent import demand	$\overline{D}$	2.05	Billion bushels	$\overline{D} = \tilde{D} + DDGS^F$
Corn used in ethanol production (initial) [e]	S_C^E	2.84	Billion bushels	$S_C^E = E/k$
Corn used in ethanol production (equilibrium)[f]	$\tilde{S}_C^E$	3.84	Billion bushels	$\tilde{S}_C^E = S_C^E/(1 - r\gamma)$
DDGS supply	DDGS	1.00	Billion bushels	$DDGS = r\gamma\tilde{S}_C^E$
Domestic DDGS consumption	$DDGS^H$	0.81	Billion bushels	$DDGS^H = \omega*DDGS$
DDGS exports	$DDGS^F$	0.19	Billion bushels	$DDGS^F = (1 - \omega)*DDGS$
Food production	f	94.85	Billion dollars	The Annual Survey of Manufactures (ASM), US Census Bureau [g]
Elasticities		Central	(low, high)	
Elasticity of corn supply	η_C^S	0.30	(0.00, 0.50)	Cui et al. (2011)
Elasticity of food/feed corn demand	η_C^D	−0.23	(−0.29, 0.00)	Eq. (A4.8)
Elasticity of foreign corn import demand	$\eta_C^{\overline{D}}$	−1.50	(−3.00, −1.00)	Cui et al. (2011)
Elasticity of food demand	η_f^D	−0.09	(−0.12, 0.00)	Seale et al. (2003)
Elasticity of fuel demand	η_F^D	−0.26	(−0.31, −0.09)	Hamilton (2009)
Elasticity of gasoline supply	η_G^S	0.20	(0.10, 0.50)	Cui et al. (2011)

Notes:
[a] The blend mandate is expressed in energy terms.
[b] Renewable fuel standard.
[c] http://www.neo.ne.gov/statshtml/66.html.
[d] Short ton (= 2000 lb).
[e] This quantity of corn does take into account the market effects of DDGS.
[f] This quantity of corn takes into account the market effects of DDGS.
[g] http://www.census.gov/manufacturing/asm/historical_data/index.html.

other hand, for the reverse direction (i.e., from food to corn) the price transmission elasticity (for food demand shock Z_3) is smaller, at 0.61: a 10% increase in the price of food has corn prices increase only by 6.1%. The price transmission from the corn market to the food market is greater than the other way around because we consider larger elasticities of corn supply and export demand relative to the elasticity of food demand which causes smaller corn price responses than food price responses to a given shock [see Table 2 and Eqs. (5) and (6)].

For the binding mandate, the price transmission elasticities in both directions are very similar to the benchmark elasticities. Note that a binding mandate generates the same results as when a mandate is combined with tax credit. As illustrated in Fig. 3, this result is expected. With the mandate in place, biofuels do not, in principle, affect the corn price formation. Note 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 inelastic fuel demand, implies minimal changes in the fuel consumption. Therefore, given the blend mandate—implemented as a fixed share of ethanol in the fuel consumption—the amounts of ethanol and corn dedicated to ethanol production are not very sensitive to the market shocks. With

Table 3
Price transmission elasticities*.

		No biofuel (benchmark)	Mandate	Tax credit
Price transmission elasticity from corn to food				
Corn supply shock (Z_1)	Central	**0.84**	**0.83**	**0.84**
	Min	0.79	0.79	0.80
	Max	0.98	0.98	0.98
Corn export shock (Z_2)	Central	**0.84**	**0.84**	**0.84**
	Min	0.80	0.80	0.80
	Max	0.98	0.98	0.98
Price transmission elasticity from food to corn				
Food demand shock (Z_3)	Central	**0.61**	**0.63**	**0.35**
	Min	0.49	0.53	0.27
	Max	0.74	0.80	0.45

Source: Own calculations.
* Summary statistics for 5000 simulations; the standard deviation in each case is between 0.03 and 0.04.

the mandate, the effects of the market shocks are absorbed in the residual corn-food market. 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 (the allocation between the two corn uses depends on relative demand elasticities of the food/feed and export demand curves), which increases corn prices but the amount of corn for ethanol does not change much.

Since for a given mandate the amount of ethanol does not respond significantly to the market shocks, the corn price is effectively determined in the corn market. 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 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 mandate and with no biofuels. This is documented by almost identical transmission elasticities in the first two columns in Table 3.

As expected, we observe partially different results when the tax credit is binding, leading to imperfect price transmission in the food supply chain.[6] A significant effect of biofuels along the food supply chain occurs for the price transmission from food to corn (i.e., for the food demand shock). In this case, the transmission elasticity decreases significantly, from 0.61 to 0.35, as compared to the no biofuel benchmark (Table 3). The reverse elasticity from corn to food (associated with the remaining shocks) is largely the same as in the benchmark case.

With the binding tax credit, consumers are not mandated to consume ethanol. They will only do so if the consumer price of ethanol is lower than the consumer price of gasoline. This implies that under a binding tax credit the corn price is determined by the gasoline price (through the ethanol price) and not on the corn market as it was the case under the binding mandate (Fig. 2). 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.

The price transmission from corn to food (induced by the shocks originating in the corn market) is not affected by biofuels because, biofuels do not affect the price linkages in the processing or food markets, thus any change in the corn price is transmitted to the food price at the same magnitude with or without biofuels.

The reader might have noticed that the transmission elasticities in our model are relatively high and do not reflect the fact that corn accounts for less than 8% of the retail value of food. For example, we have shown that a 10% shock in the corn price results in an 8.4% increase in the food price (assuming corn is the only variable input into food production) in the absence of biofuels. The high price transmission elasticities in our model are primarily due to assuming that consumers consume the food directly; that is, we do not model the retail sector. Taking into account the 8% share of corn in the retail price of food, a 10% shock in the corn price is then in reality expected to cause only a 0.67% ($= 0.84 \times 10 \times 0.08$) increase in the food price. We argue, however, that this adjustment does not affect our qualitative results as the effects of the retail sector are independent of the binding biofuel policy.

The sensitivity analysis indicates that our results are robust to different assumptions about the model parameters. Fig. 4 reports box plot results for the transmission elasticities obtained from the 5000 simulations where we varied exogenous model parameters. Similar to results reported in Table 3, the figure clearly indicates that the price transmission elasticities from corn to food exhibit similar magnitudes and variation across different shocks and policy regimes. On the other hand, the price transmission elasticity from food to corn with the tax credit deviates significantly (in terms of level and variation) from the elasticities for the benchmark and the binding mandate (as in Table 3).

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

The results in Table 4 show that the food demand elasticity is by far the strongest determinant of the corn to food price transmission elasticities. The food demand elasticity has a smaller and reverse impact on the transmission elasticities from food-to-corn. The price transmission elasticities from corn to food (food to corn) increase (decrease) with the elasticities of corn supply and corn export demand. However, both elasticities affect stronger the transmission elasticities from food to corn than the other way around. Note that the relationship between the price transmission elasticities and the food demand elasticity is reversed compared to the relationship for the corn supply and corn export elasticities (Table 4). This is because the formula for the price transmission elasticity for a food demand shock is the reciprocal of the formulas for other elasticities.

The sensitivity analysis for the fuel demand and the gasoline supply elasticities shows some heterogeneity across the price transmission elasticities. For each of the shocks, the price transmission elasticities

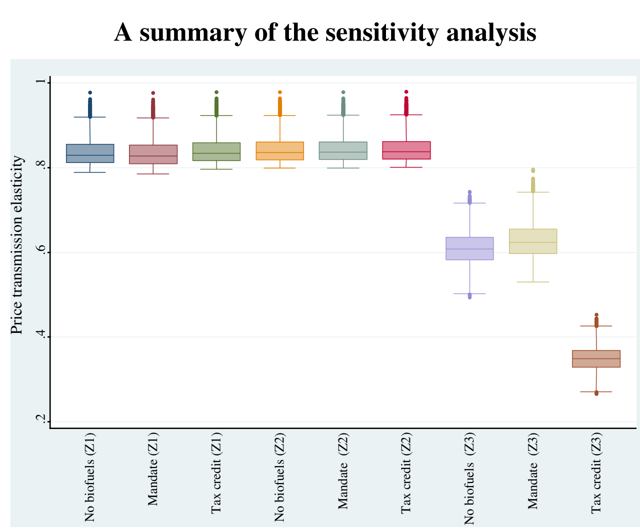

Fig. 4. A summary of the sensitivity analysis.

[6] Same results hold for zero tax credit and ethanol production in equilibrium (i.e., no biofuel policies). Because the results and the intuition do not differ qualitatively we do not report these results.

Table 4
The effect of model supply and demand elasticities on the price transmission elasticities[†].

		Elasticity of				
		Corn supply	Corn export demand	Food demand	Fuel demand	Gasoline supply
Price transmission elasticity from corn to food						
Corn supply shock (Z_1)	No biofuel	0.0103***	0.00248***	−1.572***	n.a.	n.a.
	Mandate	0.0188***	0.00196***	−1.582***	−0.00038	−0.000188
	Tax credit	0.00221***	0.000231***	−1.544***	0.00457***	0.00497***
Corn export shock (Z_2)	No biofuel	0.00322***	0.000404***	−1.530***	n.a.	n.a.
	Mandate	0.00269***	0.000302***	−1.527***	−0.000343	−0.000157
	Tax credit	0.000517**	8.81E-06	−1.521***	0.000421	0.000632**
Price transmission elasticity from food to corn						
Food demand shock (Z_3)	No biofuel	−0.325***	−0.0893***	0.234***	n.a.	n.a.
	Mandate	−0.484***	−0.0439***	0.0598***	−0.00121	−0.000558
	Tax credit	−0.131***	−0.0167***	0.00592***	−0.320***	−0.349***

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$; n.a., not available.
Source: own calculations.
[†] Coefficients estimated by OLS. The demand elasticities were converted to positive values for an easier interpretation.

do not respond statistically significantly to the changes in fuel demand/gasoline supply elasticities when the mandate is binding (Table 4). 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 through which the shocks are transmitted to and interact with the fuel and corn market.

4.2. Price level changes

In addition to analyzing how biofuel policies affect the price transmission, which is a ratio of two relative measures, it is also important to investigate to what extent biofuels affect the price level changes in the food supply chain under various market shocks. The elasticities capture only the relative importance of corn–food prices responses to market shocks; they ignore the magnitude of the level changes. To that end, in Table 5 we report a summary of percentage changes in food and corn prices for the benchmark and the two policy regimes. These changes indicate the adjustment in price levels to a given shock over the different policy regimes. We focus on the central estimates of these changes.

Ethanol'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 benchmark, both food and corn price responses are not affected significantly when the mandate is binding. These results are similar to price transmission elasticities reported in Table 3, where biofuels did not affect price transmission when mandate was the binding policy.

Table 5
Food and corn price level changes due to market shocks under various policy regimes (%)*.

		No biofuel (benchmark)		Mandate		Tax credit	
		Food	Corn	Food	Corn	Food	Corn
Price transmission elasticity from corn to food							
Corn supply shock (Z_1)	Central	**10.6**	**12.7**	**13.6**	**16.3**	**4.6**	**5.4**
	Min	6.5	8.2	8.8	11.0	3.0	3.7
	Max	22.2	25.2	34.3	39.1	7.6	8.5
Corn export shock (Z_2)	Central	**2.6**	**3.1**	**2.0**	**2.3**	**0.7**	**0.8**
	Min	1.7	2.1	1.3	1.6	0.5	0.6
	Max	5.6	6.3	4.4	4.9	1.1	1.3
Price transmission elasticity from food to corn							
Food demand shock (Z_3)	Central	**46.4**	**28.2**	**48.4**	**30.3**	**28.2**	**9.7**
	Min	33.4	16.8	35.8	19.4	23.8	6.4
	Max	87.0	64.4	110.0	87.1	38.7	16.7

Source: Own calculations.
* Summary statistics for 5000 simulations; the standard deviation in each case is between 0.1 and 8.3.

However, when the tax credit is binding, both food and corn price changes are lower relative to the no biofuel scenario for the corn and food market shocks Z_1, Z_2, and Z_3. This is in contrast to the price transmission elasticities reported in Table 3, where only the transmission elasticity from food to corn was reduced by biofuels (i.e., for the food price shock). The reason is that fuel market absorbs (through biofuels) the major share of the shocks. With the tax credit, the corn price is determined by the gasoline price. The only exception is the food price change for the food demand shock, Z_3, which is similar to the change in no biofuel benchmark. The reason is that the food demand shock induces a direct effect on the food market, causing a corresponding adjustment in food price. However, when this shock is transmitted on the corn market, it is largely absorbed by the corn quantity adjustment, with the corn price changing much less than in the benchmark case.

5. Conclusions

The rise of the biofuel sector has created an important outlet for agricultural commodities. Biofuel production absorbs a significant amount of corn, sugarcane, wheat, sugar beet, and oilseeds. The increasing interdependence between the agricultural commodity markets and energy markets may reduce the dependence of agricultural production on food markets, which in turn may reduce the price responsiveness along the whole food supply chain.

The key finding from our simulation results based on the 2009 data is that when ethanol production is due to a blender's tax credit, a price shock originating in the food market transmits to the corn market at a smaller rate compared to a situation without ethanol production (i.e., the transmission becomes more imperfect). However, when the biofuel production is due to a blend mandate, or the price shock originates in the corn market (regardless of the biofuel policy), the price transmission does not change. These differences steam from different effects biofuel policies have on the corn price formation.

A second implication of our study is that the response of corn and food prices in terms of their level changes to exogenous market shocks is smaller in the presence of biofuels, indicating that—in some situations—biofuels may reduce the magnitude of the price adjustments in food markets. This is the case when the tax credit is binding. In this situation, most of the shock in the food market is absorbed by the fuel market because of the corn price's direct link to the gasoline price effectuated through ethanol. However, this does not hold when mandate is binding. The mandate directly determines the volume of the ethanol production and, therefore, also the amount of ethanol-dedicated corn. Any shock in the corn or food market is then absorbed by the residual corn and food markets and not by the fuel market. This is because corn dedicated for ethanol production is essentially fixed while the residual corn market remains exposed to market shocks at the same level as in the case of no biofuels.

Our results have important policy implications. The price transmission along the food chain has recently attracted a lot of attention among policy makers (Areté, 2012; European Commission, 2009; Vavra and Goodwin, 2005). It is often argued that the imperfect price transmission from food to agricultural producer prices is caused by market failure such as market power of processing industry and/or supermarkets. For example, in the European Union, the strong interest of the European Commission in the price formation along the food supply chain was confirmed by the establishment of the High Level Group on the Competitiveness of the Agro-Food Industry in 2008. The group identified, among others, that the “lack of market transparency, inequalities in bargaining power, and anti-competitive practices have led to market distortions with negative effects on the competitiveness of the food supply chain as a whole” (European Commission, 2009). One of the key policy instruments applied in the European Union to strengthen farmers market position in the supply chain is the support for creation of agricultural producer organizations (or marketing cooperatives) (Bijman et al., 2012). The results of our paper indicate that imperfect price transmission in the agri-food chain may emerge even in a situation of no market power existing in the downstream industry if agricultural markets are linked to biofuels. That is, biofuels might be an additional cause of the reduced price transmission in the food supply chain.

A second policy implication of our analysis is that biofuels may result in lower adjustment of food prices to market shocks. The magnitude of food price changes is often argued to be a serious concern particularly for developing countries due to the large share of food expenditures in total income of poor consumers and the sizable share of agriculture as a source of income for many poor farmers (OECD, 2011). It is often argued that biofuels are one of the causes of the recent increase in food prices (Babcock, 2011; FAO, 2012). Contrary to this argument, our results indicate that biofuels may reduce the magnitude of price adjustments along the agri-food chain. The fact that biofuels link the agricultural commodity prices to fuel prices makes them more resistant to different shocks occurring in agricultural markets.

A third policy implication of our analysis is that the biofuels induce important income distributional effects among the agricultural market agents along the agri-food chain. Because ethanol reduces price transmission from food to corn, farmers will tend to benefit less from a higher food price but lose less when food prices decrease. The reverse price transmission (i.e., from corn to food) is not affected by ethanol, hence the changes in farm level prices will be fully reflected in food prices and thus also in consumers' gains/losses.

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