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On the (De)Stabilization Effects of Biofuels: Relative Contributions of Policy Instruments and Market Forces

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Ethanol production has recently surged in response to biofuel policies and increased fossil oil prices. We develop a partial equilibrium model focused on U.S. corn-based ethanol production with downside risk-averse farmers to assess the consequences of ethanol production on agricultural volatility. We report substantial effects on the distribution of corn prices with increases in the variance of prices received by farmers. Risk-averse corn farmers still benefit due to the higher mean price effect. From a methodological perspective, this analysis reveals that downside risk aversion may be important.

Key words: biofuels, policy, risk

Introduction

World production and consumption of biofuels has surged over recent years. This development has been partly caused by higher prices for fossil fuel, which has stimulated research and also provided incentives for developing new energy sources. The development of biofuel production also has been spurred by public policies. These have taken the form of either price incentives (e.g., tax exemptions) or quantitative objectives (e.g., mandatory blending, incorporation targets, etc.).

Recent assessments of the impact of biofuel policies on the farm sector offer some useful results as well as some contradictory findings. For instance, de Gorter and Just (2009) found that U.S. corn-based ethanol production is not viable without the ethanol tax credit; hence, there is some water in the tax credit. On the other hand, Elobeid and Tokgoz (2008) concluded that U.S. production of corn-based ethanol would represent more than 4% of U.S. gasoline consumption even if the ethanol tax credit and the accompanying tariff on imports were to be removed. The difference in these results stems mainly from the fact that these two studies are set in different time periods and involve different assumptions about oil prices.

While assumptions about oil prices play a crucial role in analyses of biofuel policies (Tokgoz et al., 2007), most studies of biofuel models have not accounted for uncertainty on the part of market participants about those prices. Some studies introduce variability and risk at the farm production level, but assume that farmers are risk neutral (Baker, Hayes, and Babcock, 2008; McPhail and Babcock, 2008; Westhoff, Thompson, and Meyer, 2008; Hochman, Sexton, and Zilberman, 2008). Accordingly, the primary objective of this study is to extend previous analyses on the impact of biofuel programs by taking into account

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uncertainties about fossil oil prices and risk aversion on the part of farmers. This approach allows us to explore two important questions. First, do biofuel production and biofuel programs tend to reduce the volatility in agricultural markets? Second, what relative roles do market forces and public incentives play in that respect?

To address these questions, we start with a simple model of the corn market and a farm policy that includes a price floor for corn producers (e.g., a loan rate). The introduction of biofuel production creates a new source of demand for corn, causing the total demand for corn to become more price elastic. The increase in price elasticity (in absolute terms) depends on the elasticity of ethanol production with respect to the price of corn. Biofuel policy potentially has a role here. If the additional demand is completely policy driven, the slope of the total demand curve remains the same. The additional demand will mainly increase corn prices but may still affect the variance of the corn producer price if the public price floor is not always binding.

If biofuel production is market driven (e.g., stimulated by higher oil prices), then total demand for corn is more price elastic. The result is an increase in the average price of corn and a reduction in its variance. The final situation, however, may be more complex. Indeed, the additional demand may be affected by the linkage with prices and subject to its own sources of fluctuation. In other words, biofuels may pass volatility in energy markets to the corn market.

We assess these issues by developing an empirical partial equilibrium model focusing on U.S. ethanol production made from corn. As in most previous analyses, we develop a static equilibrium displacement model with parameters calibrated on 2006 data and elasticities obtained from previous studies. The model includes two innovations. First, we introduce downside risk-aversion behavior by corn farmers, which has been identified in some econometric analyses (e.g., Holt, 1994). This feature is important because the biofuel market may provide a floor for the corn price without preventing very high prices when production mandates are binding (Elam, 2008). Accordingly, the distribution of corn prices may be skewed to the right. Hence, the model focuses on the third moment of the corn price distribution and downside risk aversion on the part of farmers. Second, we develop a new model of ethanol demand to capture the role of ethanol and to model biofuel policy instruments. Up to a certain level of demand, ethanol is a complement to standard gasoline as an oxygenated and octane enhancer. Above that level, it becomes a substitute as an energy provider. We capture this feature by developing a mixed complementarity model of ethanol demand, where the threshold level of demand is price dependent.

The model simulations indicate that the variance of corn producer price increases when biofuel demand is introduced because the public price floor becomes less binding. As expected, corn farmers benefit because the mean price increases enough to offset the negative impact of higher variance. We also find that the quantity effects of biofuels are reduced once we introduce downside risk aversion for corn farmers.

Intuitive Effects with Simple Analytical and Graphical Frameworks

A Simple Analytical Framework

Consider a simple framework with one product (corn), one country (the world), and initially one source of demand and one risk-neutral supplier. Corn supply (Y) and food demand (FD) are assumed to be linear forms of price:

$$Y = a + bP,$$

$$FD = c - dP.$$

The market equilibrium is written as follows, where *a*, *b*, *c*, and *d* are parameters:

$$Y = FD = \frac{ad + bc}{b + d} ,$$

$$P = \frac{c - a}{b + d} .$$

We introduce price variability by assuming that corn demand is uncertain.[1] Thus, the parameter *c* is a normally distributed random variable.

$$\text{Var}(P) = \frac{\text{Var}(c)}{(b + d)^2} .$$

Now, let ethanol demand for corn (*ED*) enter the market:

$$ED = e - f(P - S),$$

where *S* is a per unit subsidy which takes the form of a tax credit, and *e* and *f* are parameters. If *ED* is policy determined (a mandate), then its slope is zero ($f = 0$) and the constant (*e*) represents the mandated level. If ethanol demand for corn is not completely policy determined, uncertainty in the ethanol market is captured by assuming the intercept *e* is a random variable (which, for example, depends on oil prices) independent of the corn random variable. The new market equilibrium is characterized by:

$$Y = \frac{ad + bc + af + be + bfS}{b + d + f},$$

$$FD = \frac{ad + bc + cf - de - dfS}{b + d + f},$$

$$ED = \frac{eb + ed + bfS + dfS + fa - fc}{b + d + f},$$

$$P = \frac{c + e + fS - a}{b + d + f},$$

$$\text{Var}(P) = \frac{\text{Var}(c)}{\left(b + d + f\right)^2} + \frac{\text{Var}(e)}{\left(b + d + f\right)^2} .$$

As expected, a per unit ethanol subsidy (tax credit) causes an increase in corn prices. Assuming an interior solution (ethanol demand for corn is positive), the new market equilibrium leads to higher corn prices and output, but lower use of corn for feed and food.

[1] Focusing on uncertain corn demand (rather than on supply) avoids unnecessary complexity. Considering an uncertain supply would call for a risk framework encompassing both price and production risks. Nevertheless, this simplification does not alter the main insights.

The impact on the variance of corn prices is ambiguous. If the demand for corn for ethanol production is fixed [$\text{Var}(e) = 0$)] and price elastic ($f > 0$), then the variance of corn prices decreases. In contrast, if ethanol demand for corn is totally price inelastic but its variance is positive, then the corn price variance increases.

A Simple Graphical Exposition

Figures 1 and 2 illustrate the two additional impacts of the ethanol market on corn price volatility. In both figures, *S* represents the corn supply function, *FD* denotes food demand for corn, and *D* is total demand for corn. First, consider food-only demand. Uncertainty about *FD* (which may vary within a range ΔFD_0) will cause food demand to shift, as shown in both figures. Because the corn supply function is assumed to be fixed, variability in food demand will cause the corn market price to vary within the range ΔP^{ref}.

The central question addressed in this paper is how variability in the corn market prices changes with the additional ethanol demand for corn. In figures 1 and 2, we consider the two most extreme cases. In figure 1, total corn demand is more price elastic than food demand, and energy demand for corn is nonstochastic. Hence, the total demand shifter ΔD_0^l is equal to the food-only demand shifter ΔFD_0. Consequently, corn market price variability declines, i.e., $\Delta P^l < \Delta P^{ref}$. The introduction of ethanol demand for corn leads to less price variability.

In figure 2, ethanol demand for corn is assumed to be stochastic. Thus, total corn demand is more variable than in the previous case ($\Delta D_0^h > \Delta D_0^l$) and market price becomes more variable, i.e., $\Delta P^h > \Delta P^{ref}$.

Specification of the Empirical Framework

The empirical model accounts for corn production, intermediate processing, and ethanol demand. The model's innovative features include (*a*) the assumption that farmers are risk averse, and (*b*) the stochastic nature of the demand for ethanol. The model's other components are similar to those of previous analyses (see Gardner, 2007; Babcock, 2008).

The Production of Corn

We consider a representative farmer who uses a fixed amount of labor and two variable inputs, land (x_L) and an aggregate input (x_I) to produce one good, corn (y). The two variable inputs are combined in a constant elasticity of substitution (CES) production function that exhibits decreasing returns to scale. The farmer faces only one source of risk: the price of corn ($\tilde{p}$) is a random variable with expectation μ_p, standard deviation (σ_p), and third central moment (σ_p^3). Input prices are nonstochastic and known by the corn farmer prior to their use (including fuel pricing). We also assume the farmer does not use futures markets. The modeling of farm policy instruments is simplified by assuming that the farm receives a direct payment (κ) based on its acreage and an output subsidy if the market price is lower than the loan rate.[2] The farmer is

[2] In addition to the price support and direct payment programs, many other U.S. policies directly affect corn production, including crop insurance subsidies, the Conservation Reserve Program, or the Acreage Crop Revenue Election (ACRE) instituted with the 2008 Farm Bill. Adoption of the latter by farmers is presently low because farmers are required to forego part of their certain direct payments and part of their total uncertain countercyclical payments. In this paper, we do not consider the optimal choice of income support instruments by farmers, and thus assume that they stay with old instruments. How the biofuel policy influences this choice is left for future research.

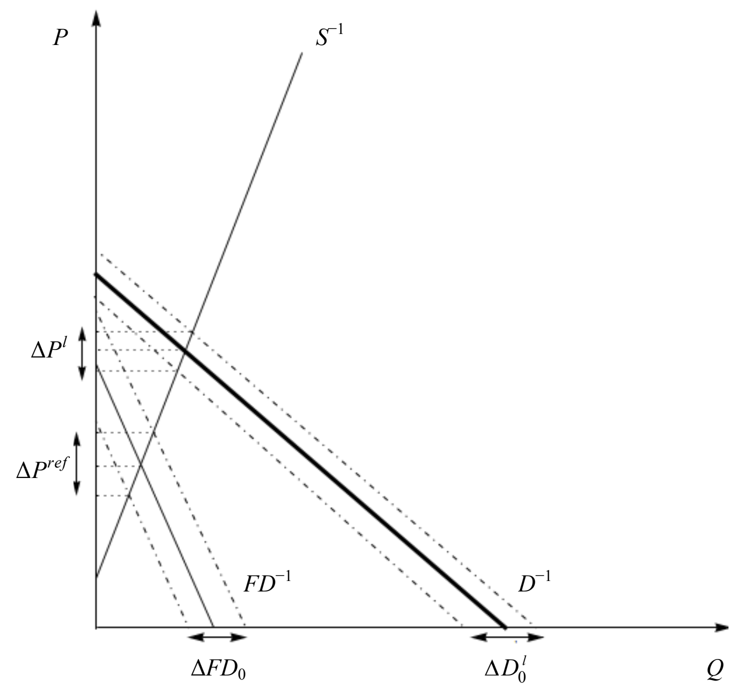

Figure 1. The higher price elasticity of corn demand outweighs the higher volatility "imported" from the energy market, leading to a smaller corn market price volatility with respect to the food-only benchmark ($\Delta P^l < \Delta P^{ref}$)

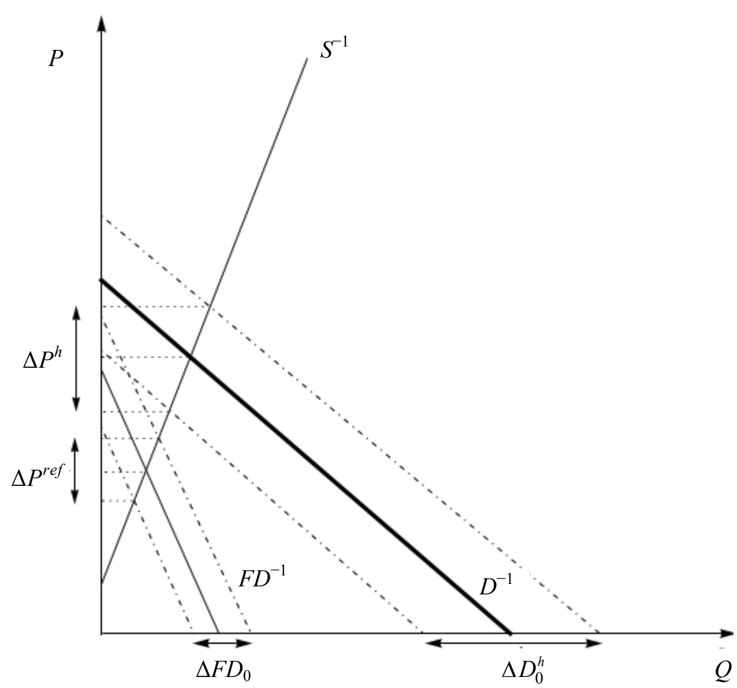

Figure 2. The higher volatility "imported" from the energy market outweighs the higher price elasticity of corn demand, leading to a higher corn market price volatility with respect to the food-only benchmark ($\Delta P^h > \Delta P^{ref}$)

assumed to exhibit downside risk aversion, with preferences represented by constant relative risk aversion (CRRA) in a power utility function.[3] Following Femenia, Gohin, and Carpentier (2010), we also assume that initial wealth (W_0) has two components: land values and off-farm assets.

These assumptions imply that the agricultural household's constrained objective is as follows:

$$\text{(1)} \quad \max_{Y} \mathbf{E}U(W_0+\tilde{\pi}),$$
$$\text{s.t.:} \begin{cases} \tilde{\pi} = \tilde{p}y - w_I x_I - (w_L - \kappa)x_L \\ y = \alpha_0\left(\alpha_1 x_I^{(\sigma-1)/\sigma} + (1-\alpha_1)x_L^{(\sigma-1)/\sigma}\right)^{\sigma\theta/(\sigma-1)} \\ W_0 = W_{NF} + \frac{w_L}{\tau}x_{LP} \end{cases},$$

where $\tilde{\pi}$ is current period profit; ρ is the relative risk-aversion coefficient (assumed different from 1); α_0, α_1, θ, and σ are the CES function parameters; x_L denotes the quantity of land; w_L is the land rental rate; x_I represents other inputs; w_I is the price of these inputs; and τ is the discount rate. W_{NF} represents nonfarm assets held by the representative farm household, and the second part of the household's wealth is given by the value of its farm land (x_{LP}). Maximizing expected utility is equivalent to maximizing the certainty equivalent of final wealth, defined as the expectation of final wealth less the risk premium R:

$$\max \mathbf{E}U(W_0+\tilde{\pi}) \Leftrightarrow \max CE = \mathbf{E}(W_0+\tilde{\pi}) - R(W_0+\tilde{\pi}).$$

Most risk analyses use Taylor expansions to obtain a second-order (Arrow-Pratt) approximation of the risk premium. This approximation is relevant if there is no asymmetry in the price (wealth) distribution. Here, we represent the risk premium with a third-order approximation because of potential skewness in the corn price distribution, i.e.:

$$\text{(2)} \quad R(W_0+\tilde{\pi}) \simeq -\frac{1}{2}\frac{U''(W_0+\mathbf{E}(\tilde{\pi}))}{U'(W_0+\mathbf{E}(\tilde{\pi}))}\sigma^2(W_0+\tilde{\pi}) - \frac{1}{6}\frac{U'''(W_0+\mathbf{E}(\tilde{\pi}))}{U'(W_0+\mathbf{E}(\tilde{\pi}))}\sigma^3(W_0+\tilde{\pi}).$$

Consider the form of this risk premium in relation to the concept of downside risk aversion. Assume that the corn price distribution is skewed to the left (i.e., $\sigma^3 < 0$), which means there is a downside risk exposure.[4] Then, with decreasing absolute risk aversion (DARA) preferences (which imply $U''' > 0$), the willingness to pay to avoid risk exposure (as measured by the risk premium) would rise. Conversely, upside risk exposure (i.e., $\sigma^3 > 0$) would decrease the risk premium.

Given the assumptions about sources of risk for the corn producer and the form of the utility function, this risk premium can be approximated by:

$$\text{(3)} \quad R(W_0+\tilde{\pi}) \simeq \frac{1}{2}\frac{\rho}{W_0+\mathbf{E}(\tilde{\pi})}y^2\sigma_{p_y}^2 - \frac{1}{6}\frac{\rho(\rho+1)}{(W_0+\mathbf{E}(\tilde{\pi}))^2}y^3\sigma_{p_y}^3.$$

[3] CRRA implies decreasing absolute risk aversion (DARA) (see Chavas, 2004).

[4] Following Menezes, Geiss, and Tressler (1980), downside risk aversion is defined as a positive willingness to pay to avoid downside risk.

The optimal production quantity is therefore implicitly determined by the first-order condition:[5]

(4)
$$\left(\mu_p - C_y(w_I,\, w_L - \kappa, y)\right)\left(1 + \frac{1}{2}\frac{\rho y^2 \sigma_p^2}{(W_0 + \mathbf{E}(\tilde{\pi}))^2}\right) - \frac{\rho y \sigma_p^2}{W_0 + \mathbf{E}(\tilde{\pi})}$$
$$+ \frac{\rho(\rho+1) y^2 \sigma_p^3}{(W_0 + \mathbf{E}(\tilde{\pi}))^2}\left(\frac{1}{2} - \frac{1}{3}\frac{\left(\mu_p - C_y(w_I, w_L - \kappa, y)\right) y}{W_0 + \mathbf{E}(\tilde{\pi})}\right) = 0,$$

where

(5)
$$C_y(w_I, w_L - \kappa, y) = \frac{1}{\theta y}\left(\frac{y}{\alpha_0}\right)^{1/\theta}\left(\alpha_1^{\sigma} w_I^{1-\sigma} + (1-\alpha_1)^{\sigma}(w_L - \kappa)^{1-\sigma}\right)^{1/(1-\sigma)}.$$

This implicit supply function merits some comment. Note that if the relative risk-aversion coefficient equals zero, then the optimal output is determined by equating the output price with marginal cost. This marginal cost increases with the input prices and decreases with the direct payment. If the relative risk-aversion coefficient is positive and there is no asymmetry, then total differentiation of the supply function implies that the optimal level of production is decreasing in the variance of corn prices and increasing in the mean price. When the corn price distribution is asymmetric, the effects of changes in the variance and average level of corn prices are ambiguous.

The supply side of the corn market is "closed" by specifying the supply functions for land (x_L) and other variable inputs (x_I). We use constant elasticity functions:

(6)
$$x_L = \beta_L w_L^{\varepsilon_L},$$

(7)
$$x_I = \beta_I w_I^{\varepsilon_I},$$

where β_L, β_I, ε_L, and ε_I are parameters.

From the Supply of Corn to the Demand for Ethanol

The demand for corn has three components: domestic demand for food/feed use (d_f), export demand (d_x), and demand for ethanol production (d_e). The first two sources of total demand are specified as linear functions, assuming a fixed price for other goods and risk-neutral consumers:

(8)
$$d_f = \alpha_f - \beta_f p,$$

(9)
$$d_x = \alpha_x - \beta_x p.$$

The demand for corn for ethanol production is the result of profit-maximization behavior by ethanol producers. We assume a representative ethanol producer is risk neutral. Arnade and Gopinath (1998) found that capital adjustment in U.S. food processing is much more rapid than in the agricultural sector, suggesting food processors are better able to cope with economic risk. Ethanol production technology is captured by a Leontief function on both the input side (corn d_e and other variable inputs z_i) and the output side (ethanol y_e and dried distillers grains with solubles z_d). These assumptions are reflected in the following equations:

[5] Second-order conditions of the maximization program are automatically satisfied.

(10) $$d_e = \delta_e y_e ,$$

(11) $$z_i = \delta_i y_e ,$$

(12) $$z_d = \delta_d y_e ,$$

(13) $$pd_e + w_i z_i = p_d z_d + p_e y_e ,$$

where w_i, p_d, and p_e denote, respectively, the prices of variable inputs, dried distillers grains with solubles (DDGS), and ethanol. Equation (10) is the demand function for corn used in ethanol production while equation (11) is the demand function for variable inputs. Equation (12) specifies the supply of DDGS. Finally, equation (13) is the zero profit condition for the ethanol industry, and implicitly defines the U.S. supply of ethanol (given the prices of all inputs and outputs). The price of DDGS (p_d) is assumed to be perfectly correlated with the price of corn (following Tokgoz et al., 2007), while the supply function for other inputs is linear:

(14) $$p_d = \gamma p ,$$

(15) $$z_i = \alpha_i + \beta_i w_i .$$

Demand for Domestic Ethanol and the Role of Biofuel Policy

Ethanol can serve two purposes. It is an additive that has now replaced methyl tertiary butyl ether (MTBE), and it is a substitute for gasoline. We begin by assuming ethanol has no additional value as an additive. In that case, to be used by blenders, ethanol's price must be less than or equal to the price of gasoline (adjusted for energy content and the tax credit). More precisely, the blender's objective consists of minimizing the purchasing cost of different gasoline sources to meet any given amount of gasoline demand ($\overline{d}$):[6]

(16) $$\min_{y_e, y_f} \; p_e y_e + (p_f + t) y_f , \quad \text{s.t.: } \overline{d} = y_e + y_f ,$$

where y_f denotes the supply of standard gasoline. The solution to the blender's optimization problem is as follows:

(17) $$\begin{cases} p_e \geq p_f + t \perp y_e > 0 \\ \overline{d} = y_e + y_f \\ \overline{p} = p_f + t \end{cases} .$$

The first condition identifies the demand for U.S. ethanol by U.S. blenders. This formulation, with complementarity conditions, allows ethanol demand to be zero if it is too expensive. The second and third conditions implicitly define the amount of standard gasoline purchased

[6] We disregard the possibility of buying ethanol from the world market (from sugarcane-based ethanol made in Brazil, for instance). Including this possibility would clearly create an extension to the present paper and should be considered to obtain more realistic figures. However, adding sugarcane-based ethanol would entail the need to cope with the dependence between the corn and sugar markets, which would complicate an already complex agricultural supply module.

by blenders. The system is closed by the (linear) specification of oil-based gasoline supply and total gasoline demand ($\bar{d}$):

(18) $$y_f = \alpha_f + \beta_f p_f ,$$

(19) $$\bar{d} = \bar{\alpha} - \bar{\beta}\bar{p} .$$

Production and consumption of ethanol in the United States were boosted by the ban on MTBE as well as by the mandate in the federal biofuel policy. Ethanol production may therefore benefit from a rent. In a representative U.S. market model, it is not possible to capture the effects of state-level policies. Here, we assume U.S. demand for ethanol is determined by solving the following optimization problem:

(20) $$\min_{y_e, y_f} \; p_e y_e + (p_f + t) y_f ,$$

$$\text{s.t.:} \begin{cases} \bar{d} = y_e + y_f \\ y_e \geq \varphi \bar{d} \end{cases} ,$$

where φ represents the U.S. mandatory level of ethanol use. First-order conditions for this problem are expressed as:

(21) $$\begin{cases} p_e \geq p_f + t + \chi \perp y_e > 0 \\ y_e \geq \varphi \bar{d} \perp \chi > 0 \\ \bar{d} = y_e + y_f \\ \bar{p}\bar{d} = p_e y_e + (p_f + t) y_f \end{cases} .$$

This model specification allows for two types of ethanol demands. If ethanol demand exceeds the mandatory rate multiplied by total gasoline demand, then ethanol demand is determined by its energy value and the rent (χ) is zero (as implied by the second condition). Otherwise, ethanol serves as an additive, and there is a difference between the tax-included gasoline price and the ethanol price (reflected in the rent). As a result of this specification, total ethanol demand is not completely policy driven because total gasoline demand depends on the average gasoline price. Accordingly, the price elasticity of total ethanol demand is never zero ($\bar{\beta} > 0$).

Calibration of the Empirical Framework

We calibrate the parameters of the model to 2006 data using elasticities obtained from various sources (Abler, 2001; Gardner, 2007; Rajagopal et al., 2007). More precisely, we assume an initial level of corn production of 12 billion bushels produced on 80 million acres and an initial corn price of \$3 per bushel. Using USDA production cost estimates, we assume variable costs of \$300 per acre and land costs of \$100 per acre.[7] Farmers receive \$25 in direct payments, so profit per acre is \$75. In the corn production function, we assume an elasticity of substitution of 0.4 between land and other variable inputs (Abler, 2001). The initial wealth of a representative corn farmer is assumed to be \$120 billion, which is estimated as follows.

[7] See http://www.ers.usda.gov/Data/CostsAndReturns/testpcik.htm.

Land is valued at $2,000 per acre, and the representative farm household is assumed to own 60% of a total of 80 million acres of land planted to corn. Thus, the wealth of the representative farm household resulting from land ownership equals $96 billion. Furthermore, 80% of farmer wealth is assumed to result from land ownership. Hence, the representative corn farm has a total net worth of $120 billion.[8] Finally, the assumed supply elasticities for land and the aggregate variable input, 0.1 and 1, were obtained from Abler (2001).

A critical element in any risk analysis is the farmer's level of risk aversion. While there is a general consensus in the literature that farmers are risk averse, the precise level of risk aversion is highly disputed. For instance, Lence (2009) argues that typical production data do not contain enough information to allow econometric identification of the structure of risk aversion. An additional issue concerns the choice of arguments in the utility function. Because econometric studies use either final wealth, profit, or consumption, estimated absolute levels of risk aversion are not comparable (Meyer, 2002). We calibrate the risk-aversion coefficient by using the risk premium estimate of $24 per acre reported by Bontems and Thomas (2000) for U.S. corn producers. This results in an estimated risk-aversion coefficient of 11.75, which we round down to 10. The resulting risk premium for the representative farmer's operation is $1.73 billion, representing 4.5% of 2006 corn farm receipts.

An alternative way to assess the appropriateness of this calibration procedure is to compute supply responses to price changes. Under the above assumptions about risk aversion, corn supply elasticities are 0.60 with respect to the expected average price, −0.07 with respect to the expected variance, 0.02 with respect to the expected third central moment, and 0.03 with respect to wealth.[9] By comparison, under risk neutrality, the corn supply elasticity with respect to the average price equals 0.45.

On the demand side for corn, we assume that domestic demand equals 8 billion bushels, exports are 2 billion bushels, and own-price elasticities are −0.2 for domestic consumption and −1 for exports. Ethanol producers initially use 2 billion bushels of corn and produce 5 billion gallons of ethanol. The initial market price of ethanol is $2 per gallon. Following Gardner (2007), we treat the ethanol tax credit as a subsidy of $0.50 per gallon received by ethanol firms. Ethanol by-products are initially valued at $2.3 billion. Thus, ethanol profits net of the cost of corn inputs are $8.8 billion. The initial supply elasticity for the variable input is assumed to be 6 (Gardner, 2007).

In the energy market, total gasoline demand is assumed to be 140 billion gallons, of which 135 billion come from oil. Price elasticities of demand and supply for gasoline are assumed to be −0.25 and 0.25 (Rajagopal et al., 2007). Hence, the price elasticity of demand for ethanol (in the absence of policy) equals −13.7.

Other critical issues in risk analysis include the determination of initial risk levels and how producers form expectations. We introduce risk by making domestic and export demand for corn stochastic, as well as oil-based gasoline supply. We calibrate risks on corn demands whereby, without risk aversion on the part of corn producers, the expected average corn price is $3 per bushel with a standard deviation of $0.6 (and hence, a coefficient of variation of 0.2). Thus, we are able to determine the standard deviation of the constants in the domestic and export demand functions (using a linearization of the supply function and assuming a

[8] The USDA's values are consistent with these net worth estimates.

[9] To compute these elasticities, we must postulate the mean, variance, and asymmetry of corn prices expected by the representative corn producer. These values are assumed to be $3 per bushel, 0.36, and 0.164, respectively, which we obtain from a truncated normal distribution with a coefficient of variation of 0.2 (see text that follows).

fixed ethanol demand). This coefficient of variation corresponds to the historical value for corn prices during periods in which U.S. ethanol production was relatively stable. In energy markets, gasoline prices are normally distributed with an expected value of 2 and a standard deviation of 0.7 (following Schnitkey, Good, and Ellinger, 2007). Corn producers are assumed to be risk averse and (following Holt, 1994) to form rational expectations about the mean, variance, and skewness of corn prices. Hence, we solve the model iteratively until there is convergence on these three moments.[10]

Finally, we introduce the loan rate mechanism, modeled (following Mullen et al., 2001) as the sum of the loan rate and the countercyclical payment as the minimum producer price of \$2.36 per bushel. The biofuel policy instruments are (*a*) \$0.5 per gallon tax credit, and (*b*) a mandated level of use. The federal mandate was 4 billion gallons in 2006. Following Babcock (2008), we assume that the initial level of production is just at the kink in the demand curve in 2006; i.e., initial rent is zero but the mandatory level is just binding in the calibration point.

Simulations

Our primary objectives are to determine empirically whether biofuels will affect the stability of the market for corn and to assess the respective role of market forces and policy instruments. The main simulation results are presented in panel A of table 1, where we examine the effects of downside risk aversion on the part of U.S. corn farmers.

To assess the relative contributions of the biofuel policy and market forces, we first simulate a hypothetical reference scenario without any ethanol production (panel A of table 1). In that case, a substantial difference is observed between the mean producer price (i.e., including the countercyclical payments, \$2.71/bushel) and the market price (\$1.62/bushel). It is worth stressing that this price level is lower than the 2006 observed price since the possibility of transforming corn into ethanol has been removed. It should also be noted that the smaller standard deviation of the producer price with respect to the market price (0.70 compared to 1.57) stems from the fact that the agricultural policy instruments are often binding. The role played by these agricultural policy instruments is also observed in the high level of skewness for the producer corn price (2.31), while there is almost no skewness in the corn market price.

Adding the possibility of biofuel production as well as biofuel support policies leads to a sharp increase in average prices. The producer price rises by 30% from \$2.71 to \$3.53 per bushel, while the market price increases by 104%, from \$1.62 to \$3.31 per bushel. These prices are lower than the peak levels observed in 2008 and 2009. The (de)stabilization effects of biofuel production are as follows: the consumer price standard deviation decreases slightly, while positive skewness has increased only marginally. Hence, the two potential effects of biofuels markets on the corn market discussed above (higher elasticities of demand and reduced volatility in aggregate corn demand shocks) tend to offset each other. As expected, if we assume that energy prices are known with certainty, then corn prices become less volatile following the introduction of ethanol production (the standard deviation of the corn market price decreases to 0.59).

[10] Before large-scale biofuels production, farmers had to consider only the feed/food market in order to understand how corn prices were determined. The rational expectations hypothesis suggests that farmers were able to predict the expected value of corn price. Here, the framework is more complex, since energy markets interact with agricultural markets. However, the rational expectations hypothesis allows us to make the assumption that farmers are also able to correctly anticipate the different moments of the corn price in equilibrium even in the more complex framework involving subtle interactions between energy and agricultural markets.

Table 1. Simulation Results with Three Different Farmer Risk Behaviors (ρ = 10 in the first two scenarios)

Description	Corn Market Price ($/bu.): ▪ Mean ▪ Std. Dev. (σ) ▪ Skewness (σ^3)	Corn Producer Price ($/bu.): ▪ Mean ▪ Std. Dev. (σ) ▪ Skewness (σ^3)	Mean Total Corn Production (mil. bu.)	Mean Corn Production for Ethanol (mil. bu.)
A. With Downside Risk Aversion:				
With biofuel policy	3.31 1.53 0.36	3.53 1.25 1.02	12,593	2,947
Without biofuel policy	2.21 1.57 0.33	2.93 0.92 1.91	12,266	1,311
Without biofuel production	1.62 1.57 0.23	2.71 0.70 2.31	11,785	N/A
B. Without Downside Risk Aversion:				
With biofuel policy	4.00 1.53	4.09 1.41	11,472	2,663
Without biofuel policy	3.26 1.55	3.52 1.25	10,478	780
Without biofuel production	2.71 1.58	3.18 1.08	10,420	N/A
C. Without Risk Aversion:				
With biofuel policy	3.35 0.82 0.50	3.38 0.77 0.87	12,568	2,980
Without biofuel policy	2.58 1.01 −0.18	2.88 0.63 1.48	11,680	1,159
Without biofuel production	2.00 1.10 −0.69	2.61 0.39 1.69	11,212	N/A

In terms of corn producers, the first impression is that biofuel policies tend to destabilize corn prices, since the standard deviation increases from 0.7 to 1.25. However, skewness decreases from 2.31 to 1.02. Hence, the higher variance is a consequence of higher prices which de facto lead to fewer occurrences of binding agricultural policy instruments.

Finally, U.S. corn production increases by 6.1% or 808 million bushels. This increase is lower than the average use of corn for ethanol production (2,947 million bushels) because higher corn prices reduce domestic food/feed consumption by 10.2% and exports by 38.3%.

We now focus on the role played by the U.S. biofuel policy versus market forces in these results. Simulation results obtained in the absence of any biofuel policies are reported in the second row of each scenario in table 1. Biofuel policy is found to be the key driver in the evolution of the distribution of corn prices received by farmers. The 30% increase in the mean producer price can be decomposed into two parts—eight percentage points can be attributed to the market effect and 22 percentage points to biofuel policies. A similar pattern is observed for the increase in the variance of the producer price, as well as for the decrease in the skewness. The contribution of policy relative to market forces is different for corn production (about 60% of the increase is explained by market effects) because production elasticities decrease as quantities increase.

The above results have been obtained in a framework in which the risk premium approximation is expanded to include third-order effects to assess the extent to which downside risk aversion by farmers matters. To address this question, simulations were run by first removing the downside risk aversion and then by excluding risk aversion. Results are reported in panels B and C of table 1.

Some results change dramatically. In particular, when risk-aversion effects on the part of corn farmers are ignored, biofuel policy leads to a 12% increase in corn production, compared to a 6.8% increase when downside risk aversion is taken into account. The increase in mean prices is similar. This result does not stem from the increase in the supply elasticity with respect to the mean price (on the contrary, it has decreased from 0.6 to 0.45). The explanation lies in the role of higher-order moments in the corn price distribution, namely variance and skewness. These results indicate that focusing on the third-order approximation for the risk premium is quantitatively relevant. Restricting the expansion of the risk premium to second-order moments results in attributing increases in corn production almost entirely to the effect of biofuel policies (+10.1%), as the market effects of introducing biofuels increase corn production by only 0.5%. On the other hand, the effects on corn market prices are less significant. Small effects on the standard deviation of the corn market price are observed in both cases.

Finally, we compute welfare effects (with respect to the no-biofuel framework) on the stakeholders involved in biofuel production using certainty equivalent estimates for farmers and standard surplus measures for other economic agents (table 2). The simulations show that farmers and suppliers of inputs to agriculture and ethanol production tend to gain from the policy shift in favor of ethanol production. Conversely, food/feed corn consumers (U.S. and foreign), as well as gasoline producers, lose when ethanol is produced. More interestingly, taxpayers also tend to gain from the implementation of incentives for ethanol production because coupled agricultural subsidies are reduced.[11]

As expected, the aggregate welfare effects of allowing biofuel production are estimated to be positive because the model focuses on market effects and ignores environmental externalities associated with biofuel production. More surprisingly, the introduction of the biofuel policy further increases total welfare. This finding suggests that even if this is not its main purpose, biofuel policy decreases the aggregate cost of risk in agricultural markets.

Conclusion

Biofuel production and consumption have recently surged due to public policies and increased fossil oil prices. In addition to supporting corn prices through a standard demand effect on farm markets, the biofuel outlet may also pass energy volatility to the corn market, thereby destabilizing farm markets and revenues. We developed a partial equilibrium model focused on U.S. corn-based ethanol production where farmers are assumed to be risk averse.

[11] Note that in the reference scenario (i.e., without ethanol production), the coupled payments to agriculture are quite important ($12.4 billion), which explains why the payments to agriculture face such large variations in the two scenarios under scrutiny.

Table 2. Welfare Variations ($ millions) with Respect to the No-Biofuel Framework (hypothesis of downside risk aversion for farmers, ρ = 10)

Description	With Biofuel Policy	Without Biofuel Policy
A. Producers:		
Farmers	+ 22,096	+ 10,968
Nonfarmers/agricultural land owners	+ 658	+ 372
Producers of other agricultural inputs	+ 2,164	+ 1,259
Producers of other inputs used in ethanol production	+ 1,830	+ 666
Gasoline producers	− 28,100	− 11,032
B. Consumers:		
U.S. corn consumers (food/feed)	− 13,927	− 4,987
Foreign corn consumers	− 3,630	− 1,074
DDGS consumers	− 1,296	− 460
Gasoline + ethanol consumers	+ 27,487	+ 11,170
C. Taxpayers:		
Total payments	− 6,229	− 3,851
Agricultural coupled subsidies	− 9,912	− 8,946
Biofuel subsidies (foregone tax)	+ 3,684	0
D. Aggregate:		
Total Welfare	+ 13,469	+ 10,876

A particular focus of the analysis has been the role of biofuel policy, specifically through its significant impact on the price elasticity of ethanol demand. By making farm policy instruments less binding, our findings reveal that the biofuel outlet significantly affects the distribution of corn (producer and market) prices with a higher variance of producer prices. However, corn farmers benefit from higher expected prices. At the same time, biofuels reduce the coefficient of variation of corn market prices. Further, the inclusion of downside risk aversion for corn producers substantially dampens the quantity effects of biofuels. Finally, biofuel policy explains roughly two-thirds of the estimated price impacts reported in the analysis.

This study represents a first effort to unravel the effects of the connection that has developed between agricultural and energy markets, when taking into account risk preferences by farmers. Many uncertainties still linger concerning the future of biofuel programs. However, the increasing interrelatedness of agricultural and energy markets is certain to be a central issue in coming years.

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