Ethanol Production and Food Price: Simultaneous Estimation of Food Demand and Supply

Bree L. Dority[a,*] **Frank Tenkorang**[a]

a *Department of Economics, University of Nebraska-Kearney*
1917 W 24th St, Kearney, NE 68849, USA, Tel: +1 308 865 8343
Email: doritybl@unk.edu, Email: tenkorangf1@unk.edu

Abstract

We investigate the impact of U.S. and Brazilian ethanol production on global food prices. Our analysis is based on a food demand and food supply simultaneous equation model. We control for the increased demand for food by developing countries, the depreciation of the U.S. dollar, energy prices, and technological advancement in agricultural production. Based on our three-stage least squares results, the rapid expansion of ethanol production is unlikely to have been related to the high food prices experienced in the late 2000s. However, we find that world food prices are significantly impacted by energy prices.

1. Introduction

Worldwide ethanol production has more than quadrupled since 2000 with the U.S. and Brazil leading in production (RFA n.d.a). Brazil, who has been a long time global leader in ethanol production, attributes its main reason to the high oil prices in the 1970s (Dias de Moraes 2007). Other countries who boosted their production in the mid-2000 justified their decision based on ethanol's positive impact on rural development, reducing reliance on unfriendly nations for energy, and environmental stewardship (Rosillo-Calle & Johnson 2010), the last of which is often criticized because of the perceived negative energy balance of ethanol. The United States, with the help of government support (e.g., capital investment, blenders' subsidies, and tariffs), surpassed Brazil to become the leading producer of ethanol in 2006. Besides the negative energy balance of ethanol production, one of the major criticisms against ethanol is the impact on food prices. Since 2000, world food prices have more than doubled (World Bank n.d.).

The high food prices, especially in poor countries, led to calls to curtail ethanol production (Grunwald 2008; Sharma 2008), and subsequently triggered many studies to examine the relationship between the ethanol market and the food market. Monteiro, et al. (2012) studied the impact of ethanol production in the U.S. and Brazil on food prices by focusing on the 1980-2007 time period. They found the share of Brazilian ethanol in the world market, the value of the U.S. dollar, and the price of oil have significantly affected food prices. Literature reviewed by Armah, et al. (2009) attributes the rise in food prices to increased energy cost, the devaluation of the U.S. dollar, and the increased energy demand by developing countries such as India and China. Other studies have found the price of ethanol to be influenced by food and energy prices (Serra, et al.

2011a; Serra, et al. 2011b; Kristoufek, et al. 2012), confirming a connection between the food and ethanol markets.

In response to the outcry against ethanol production, policies such as import tariffs and blenders' subsidies have been discontinued in the U.S., and ethanol use mandates have been reduced in the U.S.[1] and Europe (Taylor 2013 & Kenny 2014). Although ethanol production in the U.S. and Brazil has slowed as a result of these policy changes, it increased more than 9% from 2012 to 2014, while food prices dropped by nearly 14% over the same time period. Moreover, from 2012 to 2014, energy prices fell by more than 7%, which begs the question, is ethanol production responsible for high food prices? The purpose of our study is to investigate the impact of U.S. and Brazilian ethanol production on global food prices by estimating food demand and food supply equations simultaneously. We include data from 1980 to 2014 and control for the increased demand for food by developing countries due to improving economies and increasing populations, the depreciation of the U.S. dollar, energy prices, and technological advancement in agricultural production.

2. Ethanol Production in the U.S. and Brazil

The U.S. and Brazil are the leading producers of ethanol in the world, accounting for over 80% of production (RFA). In response to the higher oil prices in the early 1970s, Brazil embarked on a massive ethanol production program. Policies implemented in Brazil include mandatory blending, capital subsidies, flex-fuel vehicle subsidies, and a 20% import tariff (Monteiro et al. 2012). Production has grown from about 0.16 billion gallons in the mid-1970s to 6.2 billion gallons in 2014 (RFA). In addition to the government programs, the success of Brazilian ethanol production is owed to the abundant supply of sugarcane, a very cost- and environmentally-efficient feedstock. Brazil is now a leader in sugarcane-based ethanol production. Currently, pure gasoline (i.e. zero ethanol blend) is no longer available in Brazil (Rico 2008). Only two forms of vehicle fuel are available – Blended with Gasoline (5-25% ethanol) and Pure Ethanol (85-100% ethanol) (Sugarcane.org). The success of ethanol production in Brazil is also attributed to improvement in agricultural technology which allowed Brazil to significantly increase its sugarcane yields in three decades (Goldemberg 2008). An unintended consequence of the ethanol production program was reduced food production. Because sugarcane production is more profitable than traditional food production, land was diverted from food production to sugarcane. The strong demand for land for sugarcane production led to high land prices and consequently high food prices. Also, the strong derived demand for sugarcane is believed to have caused a 200% increase in global sugar prices between May 2005 and May 2006 (UN 2006).

In the U.S., ethanol production can be traced back to the 19th century, but its growth did not occur until the early 2000s when it began to serve as a primary substitute for methyl tertiary butyl ether (MTBE) due to environmental concerns (Goettemoeller & Goettemoeller 2007). Similar to Brazil, but about 40 years later, two energy acts, the Energy Policy Act of 2005 and the Energy Independence and Security Act of 2007,

[1] The proposal to reduce the ethanol use mandate in the U.S. is pending final approval (EPA, 2014).

mandated the reduction of U.S. dependence on foreign oil, and thus, boosted ethanol production. The U.S. policies are similar to those of Brazil: import tariff of $0.54 per gallon, blenders' tax credit of $0.45 per gallon, mandatory blending, capital grants, vehicle subsidies, and import tariffs (Monteiro et al. 2012). These policies have helped the U.S. to surpass Brazil as the leading producer of ethanol in the world. The U.S. accounted for 58% of the 24.6 billion gallons of ethanol produced in 2014 while Brazil accounted for 25% (RFA).

Unlike in Brazil, the main feedstock of U.S. ethanol is corn. While ethanol has benefitted from technological advancement in corn production, it is yet to be seen whether corn productivity has improved because of ethanol. The obvious, however, is a shift in acreage allocation from other crops to corn due to the increased demand for ethanol. Currently, U.S. ethanol production is increasing at a decreasing rate due to the following factors: expiration of the blenders' tax credit and ethanol import tariff in 2011, easing of the mandatory blending, and the abundant supply of oil and low oil prices. The boost in U.S. ethanol production triggered many studies that examine the influence of ethanol on agricultural commodity prices.

3. Review of Ethanol-Food Price Studies

Serra and Zilberman (2013) conducted one of the most extensive literature reviews on the biofuel-food price relationship. Their main findings are that energy prices drive agricultural prices, and volatility transfer from energy markets to food markets has increased with ethanol production. Most of the studies reviewed use time series models which often lack theoretical structure. The most popular models include the vector error-correction model (VECM), the vector autoregressive (VAR) model, and the generalized autoregressive conditional heteroscedastic (GARCH) model, or some variant of them.

According to Wright (2011), the popularity of time series models in biofuel-food price studies is due to the lack of a widely accepted model (in Serra & Zilberman 2013). Other researchers have used simulations through elasticities to study this relationship (Zilberman et al. 2013). However, most studies focus on the price of a specific crop or cereal. Roberts and Schlenker (2013) used calories to convert the four basic staples (corn, rice, soybeans, and wheat) into one core product when examining the U.S. ethanol use mandate and food prices for the period 1961-2007. They find that the mandate increases food prices by 30%, and by 20% if one-third of the commodities used are recycled as feedstock. Their use of a core product is laudable as it simplifies the analysis.

Monteiro et al. (2012) also used a core measure in their examination of how the interaction between ethanol production in Brazil and the U.S. influences food prices. They regressed a world food price index on the share of Brazilian ethanol production, oil price, exchange rate, and land use for the period 1980-2007. They find the share of Brazilian ethanol production is significantly positively related to world food prices and interpret this result as ethanol having a positive effect on relative food prices. However, they failed to note that the share of Brazilian ethanol production *fell* over the period they examined (Fig 1; Monteiro et al. 2012) when interpreting their result. As such, their results imply there would be downward pressure on relative food prices from 1980 to 2007. Moreover, they were surprised to find Brazilian sugarcane ethanol acreage has a negative effect on world food prices. The negative effect of land on food prices could be due to the low-indirect land use change (ILUC) associated with sugarcane-based ethanol production (Nassar & Moreira 2013). A more appropriate measure to capture land or production is yield, which would also allow for the effect of technological advancements in agriculture on food prices to be controlled for.

Overall, most of the reviewed ethanol-food price studies were conducted before the recent peak in food prices. Time has elapsed since 2008, hence it is appropriate to estimate the ethanol production-food price model with updated data.

4. Methods & Data

Agricultural markets are often assumed to be competitive markets because of the large number of market participants. Because price discoveries in such markets are due to the interaction between demand and supply, we estimate demand for and supply of food equations to determine the impact of ethanol production on food prices. To allow for direct estimation of the impact of ethanol production on food prices, the following inverse demand function and supply function are estimated:

$$\text{Demand:} \quad P_F = f(Q_F, G, ER, P_E, E_{GTH}) \tag{1}$$

$$\text{Supply:} \quad Q_F = f(P_F, P_E, Y_C, Y_S, E_{GTH}) \tag{2}$$

where P_F is the world commodity food price index. Q_F is the world gross food production index. Economic theory indicates a relationship between the quantity of food and the price of food; however, food production (e.g., Q_F) is missing in Monteiro et al. (2012). A properly specified demand function requires an income variable. G is China's GDP per capita and is included to proxy income growth in the world's most populous country and second largest economy. It is expected to have a positive impact on food prices. ER is the U.S. real effective exchange rate index. The U.S. dollar is the main currency of exchange in world food transactions, hence its relative value influences the demand for food. If the U.S. dollar depreciates, we would expect higher food prices because of the increased demand for relatively cheaper food.

P_E is the energy price index. Energy and food are essential goods as the world is faced with the challenge of how to produce sufficient quantities of both. The energy price index is included in both functions. In the demand function, high energy prices capture the incentive to produce more ethanol because it is an alternative energy source. The increased ethanol demand in turn creates more demand for feedstocks (e.g., corn and sugarcane); therefore, it expected that energy prices will positively impact of food prices. In the supply function, high energy prices imply high food production costs; thus, decreasing the food supply and increasing food prices. Also, in the supply function, Y_C and Y_S are U.S. corn yields and Brazilian sugarcane yields, respectively. Yields proxy improvement in technology which plays a major role in the food supply (Zilberman et al., 2013). Due to the significant increase in sugarcane yields in Brazil (Goldemberg 2008), Y_S is expected to have a positive effect on Q_F and consequently a negative effect on food prices.

E_{GTH} is the ethanol production growth rate of the two leading producers, the U.S. and Brazil, and it is the variable of interest in the study. In the demand equation, if the rapid expansion of ethanol production affected food prices, then E_{GTH} is expected to have a positive coefficient. This would be due primarily because ethanol production increases the demand for corn. To note, Monteiro et al. (2012) used Brazil's share of total ethanol produced in the U.S. and Brazil as a proxy for ethanol productivity. However, a country's share of ethanol production can change without ethanol production necessarily increasing, and vice versa, hence growth in production is chosen over the share of ethanol. In the supply equation, if the rapid expansion of ethanol production affected the supply of food and hence food prices, then E_{GTH} is expected to have a negative coefficient. This may be due to either 1) food crops being reallocated to fuel production and/or 2) agricultural land being diverted from food crops to energy crops (Monteiro et al. 2012). Table 1 summarizes the model variables and expected signs.

Table 1. *Variable Definitions, Expected Signs, and Sources*

Variable	Definition	Expected Signs		
		D	S	Sources
P_F	World commodity food price index (2010 = 100)	n.a.	+	World Bank Commodity Price data (the Pink Sheet)
Q_F	World gross food production index (2004-2006=100)	–	n.a.	Food and Agriculture Organization Corporate Statistical Database (FAOSTAT)
G	China's real GDP per capita ($2005)	+	n.a.	United Nations Statistics Division
ER	U.S. real effective exchange rate index (2010=100)	–	n.a.	World Bank
P_E	Energy price index (2010 = 100)	+	–	World Bank Commodity Price data (the Pink Sheet)
E_{GTH}	Ethanol production growth rate, US & Brazil (%)	+	–	U.S. Energy Information Administration and Renewable Fuels Association
Y_C	U.S. corn yield (1000 Hg/Ha)	n.a.	+	FAOSTAT
Y_S	Brazil sugarcane yield (1000 Hg/Ha)	n.a.	+	FAOSTAT

n.a. – Not applicable

The system of equations is over identified; thus, equations (1) and (2) are estimated simultaneously using two-stage least squares (2SLS) and three-stage least squares (3SLS) methods. All the exogenous variables serve as instrumental variables.

4.1 Data

Data on all the variables were obtained from various sources from 1980 to 2014. The world commodity food price index and the energy price index were obtained from the World Bank Commodity Price data (the Pink Sheet). The food price index includes crop and livestock prices, and the energy price index is the weighted average of coal, crude oil, and natural gas. The world gross food production index and the U.S. corn and Brazilian sugarcane yields were obtained from the Food and Agriculture Organization Corporate Statistical Database (FAOSTAT). The food production index includes crops and livestock and the 2014 observation was estimated. China's real GDP per capita was obtained from the United Nations Statistics Division. The U.S. real effective exchange rate index, a measure of the value of the dollar against a weighted average of several foreign currencies, was obtained from the World Bank. The ethanol production growth rate is the annual growth rate of the U.S. and Brazilian ethanol production. Table 1 summarizes the data sources and Table 2 shows the descriptive statistics.

Table 2. *Descriptive Statistics*

Variable	Mean	St. Dev.	Min	Max
P_F	68.5	23.3	43.0	124.5
Q_F	84.1	22.3	51.8	123.0
G	1,293.0	1,081.4	220.7	3,862.9
ER	111.4	13.0	95.1	149.0
P_E	53.2	36.8	19.5	129.1
E_{GTH}	9.6	13.3	–9.3	43.7
Y_C	81.0	14.1	50.9	107.3
Y_S	680.5	67.3	551.8	802.6

5. Results and Discussion

The results of the 2SLS and the 3SLS estimations are comparable. The Hausman test results are statistically insignificant, thus indicating no misspecification of the demand and supply equations. Consequently, we fail to reject the null hypothesis that the 2SLS and 3SLS estimators converge to the same probability limit. Under the null, the 3SLS estimator is consistent and more efficient than the 2SLS estimator hence only the estimation results of the 3SLS are presented in Table 3. Overall, the results are significant, and the signs on the estimated coefficients are consistent with expectations. The standard negative relationship between price and quantity demanded holds for the demand equation and the standard positive relationship between price and quantity supplied holds for the supply equation.

The demand equation results indicate that economic growth in China and the subsequent rise in incomes, and the depreciation of the U.S. dollar and the subsequent decline in relative food prices have led to higher demand for food, thus pushing up food prices.

The positive relationship between energy and food prices in the demand equation indicates higher energy prices create an incentive to produce alternative forms of energy, including ethanol. Given ethanol can be produced with corn and sugarcane, the increased demand for these feedstocks increases food prices. In addition, the positive relationship indicates that energy and food may be substitutes. That is, given a consumer's budget, an increase in energy prices leads to a decrease in energy consumption and an increase in food demand, and the increased demand for food leads to an increase in food prices. The cross-price elasticity can be calculated by substituting the estimated demand equation into the estimated supply equation. We find that a 1% increase in energy prices leads to a 0.01% increase in the demand for food, indicating that food and energy are very weak substitutes. That is, higher energy prices lead consumers to reduce

Table 3. *Three Stage Least Squares Results*

Equation	Variable	Est. Coef.
Demand	Q_F	–0.836*** (0.252)
	G	0.025*** (0.007)
	ER	–0.321*** (0.112)
	P_E	0.283*** (0.095)
	E_{GTH}	0.026 (0.112)
	Constant	126.943*** (23.827)
Supply	P_F	0.579** (0.238)
	P_E	–0.142 (0.154)
	Y_C	0.258 (0.136)
	Y_S	0.189*** (0.029)
	E_{GTH}	–0.192 (0.101)
	Constant	–95.881*** (16.971)
n		34
Overall Results		
Demand	Chi-Sq	383.67***
Supply	Chi-Sq	430.73***
Hausman Test		
Demand	Chi-Sq	4.96
Supply	Chi-Sq	4.33

*** and *** denote statistically significant at the 5%, 1%, respectively*

their consumption of energy, but maintain or slightly increase their consumption of food.

Consistent with theory, the supply results indicate that higher food production costs (e.g., energy prices) reduce food production, whereas advances in agricultural technology, captured with corn and sugarcane yields, increase food production. However, only sugarcane yields are statistically significantly related to food production. The results indicate that on average, a 1000 Hg/Ha increase in Brazilian sugarcane yields increases the food production index by 0.19. Consequently, the food price index is estimated to fall by 0.16, suggesting that increases in sugarcane yields could be responsible for dampening the effect of energy prices on food prices. In fact, between 1980 and 2014, sugarcane yield in Brazil increased by 24%.

For the purpose of this study, the most important estimated coefficient is the estimated impact of the growth in ethanol production in the U.S. and Brazil. That is, if ethanol production causes the demand for corn to increase and/or the availability of corn and sugarcane for food to decrease, then we expect food prices to increase. However, the results indicate that, given the demand and supply factors controlled for in our model, there is no statistically significant impact of the growth in ethanol production on world food prices from either the demand or supply side. In regard to the food-versus-fuel debate, these results indicate that the rapid expansion of ethanol production is unlikely to have been related to the high food prices experienced in the late 2000s. Overall, our results are in line with Monteiro et al. (2012) who found that an increase in corn and sugarcane area devoted to ethanol had no effect or a negative effect, respectively, on relative food prices. Moreover, literature reviewed by Zilberman et al. (2013) also suggests the relationship between ethanol and food price is weak. They used a graphical illustration to show that this influence is uncertain as it depends on whether the change is due to demand for ethanol or supply of ethanol.

6. Conclusion and Policy Implications

The world has seen tremendous increase in ethanol production in the last 30 years, primarily due to various government support programs. The initial praise for the increase due to reduced dependence on imported oil, environmental protection, and rural development, was soon replaced with criticism when the height of U.S. ethanol production coincided with high food prices in 2008. Many studies have investigated this criticism but results remain inconclusive. We agree with Wright (2011) about the lack of a widely accepted structural model for the food price and biofuel relationship, and we attribute the conflicting results of previous studies to it. In 2012, Monteiro et al. estimated a structural model to explain how Brazil's ethanol share and corn and sugarcane acreage affect food prices. Building on their model, we estimated a simultaneous equation model of food demand and food supply, with the impact of the growth in ethanol production on food price as our primary focus. Our results show that a weak U.S. dollar and high energy prices are the causes of high food prices rather than ethanol production. Also agricultural productivity has a dampening effect on food prices. Overall, we conclude that data over the period of our study do not provide evidence that the ethanol expansion led to high food prices.

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