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An estimation of a price model of the high fructose corn syrup industry in the Unites States

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Selected Paper prepared for presentation at the Southern Agricultural Economics Association (SAEA) Annual Meeting, Mobile, Alabama, 4-7 February 2017*

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Abstract:
The current research develops a model of pricing in imperfectly competitive markets based on the Stackelberg price leadership behavior model to explain pricing strategies in the high fructose corn syrup (HFCS) and sugar industries in the United States. The model assumes that demanders of HFCS are represented by soft drinks and processed food manufactures that use HFCS as an input. It derives a reaction function for the price of HFCS and a conjectural variations function. The conjectural variations function suggests that the price of sugar is higher than the price of HFCS. The results show that the price of sugar plays an important role in the pricing strategy of the HFCS industry and that a unit increase in the price of sugar increases the price of HFCS by less than the unit increase in the price of sugar.

Key words: High fructose corn syrup, price reaction function, sugar, Unites States

Introduction

High fructose corn syrup (HFCS) has been an important component of the sweetener supply in the United States. The United States is not only the second largest consumer of caloric sweeteners in the world, which includes HFCS, but also number one producer of HFCS and number five producer of sugar (Korves, 2011). Historically, the HFCS price has been lower than the sugar price (Figure 1). The lower price is one of the factors that has made HFCS-42 become a substitute for sugar in the production of baked products, while HFCS-55 has become a substitute for sugar in the production of soft drinks (SD). In 1980, Coca-Cola and Pepsi replaced between 25 and 50 percent of sucrose with HFCS-55 and, in 1984, these SD manufacturers replaced 100 percent of sucrose with HFCS-55 (Pendergrast, 1993). Furthermore, Korves (2011) reports that the USDA estimated that, in 2010, 2.9 million tons of HFCS-42 were used in the production of food and beverages while 4.6 million tons of HFCS-55 were used in the production of SD.

Carman (1982) suggested that the potential use of HFCS in soft drinks and processed food products would be 100 and 75 percent respectively. Barros (1992) found that sugar prices had a positive effect on the growth rate of HFCS consumption in the United States. Evans and Davis (2002) estimated a price reaction function and derived demand, suggesting that the higher sugar price is allowing HFCS producers make profits. However, they did not explain the relation between pricing strategies in the HFCS and sugar industries. Recently, Kennedy and Garcia-Fuentes (2016) estimate a system of demand and supply models for both HFCS and soft drink markets in the United States and find that soft drink production is the main driver of the demand for HFCS. But again, this study does not include the pricing strategies in these two industries. Therefore, it is important to understand the pricing strategies in the HFCS and sugar industries, and how these industries react to their pricing strategies.

The current research develops a model of pricing in imperfectly competitive markets based on the Stackelberg price leadership behavior model (see Nicholson, 2002, chapter 19). The model includes two industries, sugar and HFCS, and the goods are substitutes and have different prices. The model assumes that demanders of HFCS are represented by soft drinks and processed food

manufacturers that use HFCS as an input. The model derives a reaction function for the price of HFCS. Given this reaction function, a conjectural variations function for the HFCS industry is also derived. The conjectural variations function suggests that the price of sugar is higher than the price of HFCS. The development of this model is this research's innovation and contribution to the understanding of the pricing strategies of these two industries.

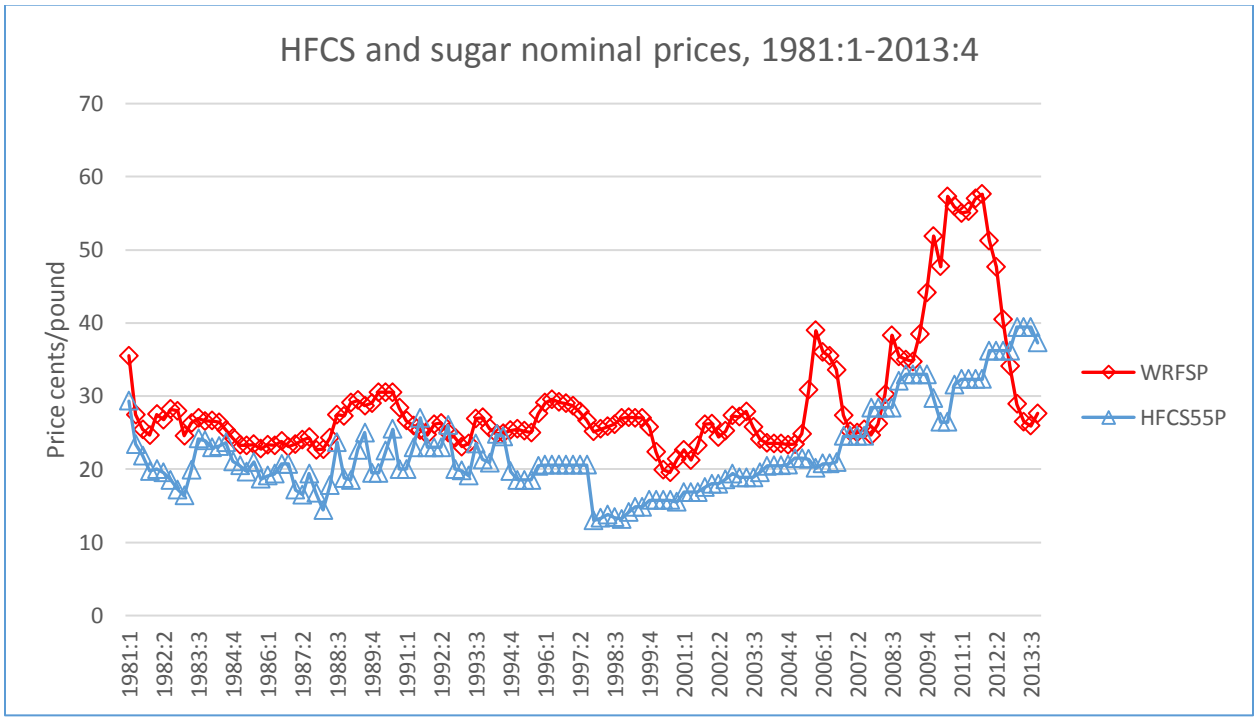

Figure 1. High fructose corn syrup and wholesale refined sugar prices, 1980-2013

The main purpose of this research is to explain the pricing strategy of the HFCS industry as a reaction to the pricing strategy of the sugar industry. The results show that the price of sugar plays an important role in the pricing strategy of the HFCS industry, where a unit increase in the price of sugar increases the price of HFCS by less than the unit increase in the price of sugar, so that the price of HFCS is less than the price of sugar.

The rest of the paper is organized as follows. The second section provides a review of relevant literature, followed by a description of the methodology and data. The next section presents a discussion of the results. The last section presents the conclusions.

Literature Review

Carman (1982) used annual data from 1967 to 1980 to estimate a sweetener demand equation in order to develop a projection of the U.S. HFCS market for the period 1981-1990. Given this projection, population growth would be the main factor affecting the demand for sweeteners as well as the demand for HFCS. The projection also suggested that HFCS per capita consumption would increase from 21.93 pounds in 1981 to 33.15 pounds in 1990, a 51 percent increase. Carman (1982) also suggested that, given a 25-percent market share ceiling use of HFCS, the

beverage product sector use of HFCS would be 100 percent and that the processed food sector use of HFCS would be 75 percent. Further, Carman (1982) suggests that the price differential between sugar and HFCS prices is one of the factors that has an economic impact on consumers and food manufacturers, so lower costs to food manufactures may imply lower food prices to consumers.

Barros (1992) used annual data from 1971 to 1988 and developed a model of demand and supply of HFCS in the United States. He estimated a reduced form of the growth rate of demand for HFCS. He found that sugar prices positively affect the growth rate of U.S. HFCS consumption and argues that permanent changes in sugar price causes a permanent effect on the U.S. HFCS consumption growth rate.

Evans and Davis (2002), given a profit function for the HFCS industry, estimated a price reaction function of HFCS and derived demand for HFCS to analyze the dynamics of the U.S. HFCS market. The price reaction function seeks to explain the pricing strategy of the HFCS industry as a reaction to the pricing strategy of the sugar industry. The assumptions that support the model are that HFCS price is lower than sugar price, HFCS is a substitute for sugar on a given portion of the demand for sugar only, and HFCS demand is relatively inelastic. They argue that the price reaction function can be similar to the Stackelberg model. Given this model, the HFCS industry is considered the one that understand the behavior of the market while the sugar industry is considered naïve. The results of the estimation of the price reaction function show that the price of sugar has a positive and significant effect on the price of HFCS. However, the estimates are not corrected for heteroskedasticity. In addition, the theoretical model does not show the derivation of the reaction function for HFCS price from the profit function even though a description of the process is given. Thus, even though the model assumes that price of HFCS is less than price of sugar, the model does not suggests any relation between the price of HFCS and the price of sugar.

More recently, Kennedy and Garcia-Fuentes (2016) estimate a system of demand and supply models for both HFCS and soft drink markets in the United States that covers the period 1992-2013 and find that soft drink is main driver of the demand for HFCS. But, this study does not consider the pricing strategies in these two industries.

Given the importance of the HFCS market in the United States, it is important to understand the pricing strategies of the HFCS industry due to the pricing strategy of the sugar industry. The current research develops graphical and mathematical models to explain this relationship. The model derives a price reaction function for HFCS that suggests that the price of HFCS is lower than the price of sugar and that an increase in the price of sugar causes an increase in the price of HFCS by less than a unit increase in the price of sugar. This is an innovation relative to Evans and Davis' (2002) study.

Methodology and Data

A graphical model

A model of pricing in imperfectly competitive markets is derived based on the Stackelberg price leadership model (see Nicholson, 2002, chapter 19). There are two industries (sugar and HFCS) that have different pricing strategies and the goods are substitutes. The model assumes that demanders of HFCS are represented by soft drinks and processed food manufacturers that use HFCS as an input.

The model allows for strategic interactions between the two industries. The industries' strategic interactions are related to different pricing strategies. The conjectural variations model shows how the HFCS industry conjectures about the sugar industry pricing strategy. This makes the HFCS industry's profit maximization function to be affected by the sugar industry's pricing strategy. Thus, the HFCS industry is not only concerned with how its pricing strategy affects the HFCS market, but also with how the sugar industry's pricing strategy affects the HFCS market. However, the equilibrium shown in the model may not be unique; it depends upon the assumptions that support the model.

The model is represented by Figure 2 below. The demand curve for sugar is DsDs. The price of sugar P_s is the U.S. sugar support price, which is a policy determined price. The demand curve DsDs and the supply curve PsSs are used to derive the demand curve for HFCS (DhDh). If the price of HFCS is equal to Ps, the sugar industry is willing to supply a quantity of sugar Qh to the soft drinks and processed food market which equals the quantity demanded of sweetener, while the HFCS industry quantity supplied of sweetener to this market is zero. However, for prices of HFCS that are less than Ps, the HFCS industry is willing and able to supply the quantity demanded of sweetener to the soft drinks and processed food market. Note that HFCS demand is relatively more elastic than sugar demand.

At equilibrium point A, the price of HFCS is equal to the price of sugar (Ps), so quantity supplied of sweetener to the soft drinks and processed food market is given by a quantity of sugar that is equal to Qh. The model also assumes that if the price of HFCS Ph equals the price of sugar Ps, soft drinks and food manufacturers are willing to substitute sugar for HFCS. Then, quantity demanded for HFCS is zero and the sugar industry is willing to supply quantity Qh of sugar to the soft drinks and food manufacturing market.

Given the demand curve for HFCS, the HFCS industry can define its marginal revenue curve MRh and then refer to its marginal cost curve MCh to determine output level Qh that maximizes profits. HFCS market price then will be Ph which is less than Ps. This suggests that the HFCS industry pays close attention to the sugar industry's pricing strategies and understand how these strategies affect the HFCS market. This result is a case of the conjectural variations model that explains the pricing strategy of the HFCS industry given the pricing strategy of the sugar industry. This also shows that the positive difference between the price of sugar and the price of HFCS is an important determinant of output in the HFCS industry. That is, as Ph is decreasing relative to Ps, quantity of HFCS is increasing.

The model also assumes that the support price of sugar (Ps) is greater than price of HFCS (Ph) which is determined by the profit maximization principle (MRh=MCh). This also suggests that it is unlikely that the price of sugar will be below the Ps level. Further, if the price of sugar

decreases to the P_h level, profits in the sugar industry will decrease. This may be one factor that makes the sugar industry not willing to supply sugar at a price that is less than Ps. Note that the lower price for HFCS makes the HFCS industry willing to supply quantity Qh to the soft drinks and food manufacturing market. The lower price for HFCS also suggests that the HFCS industry has been more cost efficient than the sugar industry.

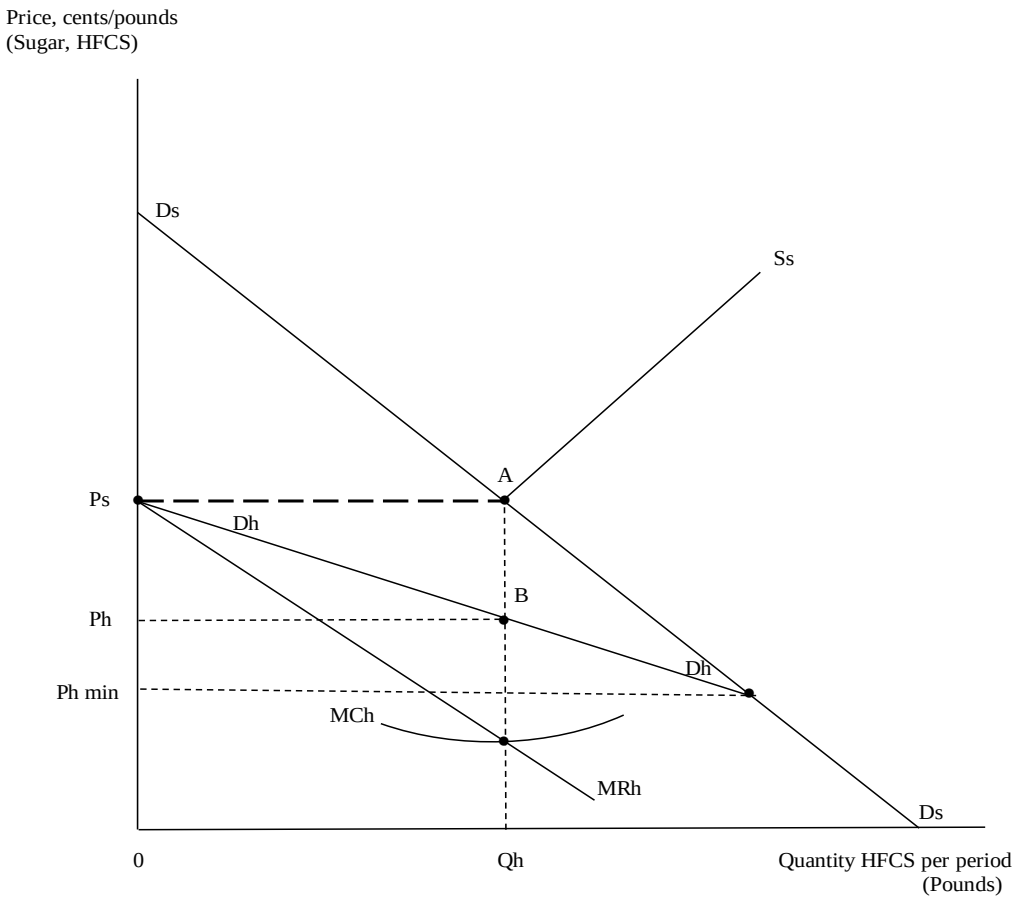

Figure 2 Pricing strategy in the HFCS industry

A mathematical model

The mathematical model associated with Figure 2 derives a reaction function for price of HFCS that also depends on the price of sugar. Given this reaction function, a conjectural variations function for the HFCS industry is also derived. The conjectural variations function suggests that the price of sugar is higher than the price of HFCS.

The model starts with quantity of HFCS being a function of price of sugar P_s and price of HFCS P_h, or $Q_h = f(P_s, P_h)$. So, quantity of HFCS is given by

$$Q_h = aP_s - bP_h \qquad (1)$$

where a, b > 0 and 0 < a/b < 1, so b > a.

Profit maximization for the HFCS industry can be defined as

$$\pi_h = P_h Q_h - TC(Q_h) - \lambda (aP_s - bP_h - Q_h) \qquad (2)$$

Or,

$$\pi_h = aP_h P_s - bP_h^2 - TC(Q_h) - \lambda (aP_s - bP_h - Q_h) \qquad (3)$$

Then, the Lagrangean yields the following marginal conditions:

$$\frac{d\pi_h}{dP_h} = aP_s - 2bP_h + \lambda b = 0 \qquad (3a)$$

$$\frac{d\pi_h}{dP_s} = aP_h - \lambda a = 0 \qquad (3b)$$

$$\frac{d\pi_h}{dQ_h} = -MC_h + \lambda = 0 \qquad (3c)$$

$$\frac{d\pi_h}{d\lambda} = aP_s - bP_h - Q_h = 0 \qquad (3d)$$

Equation (3a) is the reaction function for the HFCS industry. It shows how the pricing strategy of the HFCS industry reacts to the pricing strategy of the sugar industry. It also shows that HFCS price is affected by the price of sugar and marginal cost of HFCS.

Dividing equation (3a) by equation (3b) yields the following

$$\frac{aP_s - 2bP_h}{aP_h} = \frac{\lambda_b}{\lambda_a} \qquad (4)$$

Equation (4) yields the following HFCS price function

$$P_h = \frac{a}{3b} P_s \qquad (5)$$

Given that a, b > 0 and 0 < a/b < 1, equation (5) suggests that $P_h < P_s$. Taking the derivative of equation (5) with respect to price of sugar yields a conjectural variations price function for the HFCS industry as

$$\frac{dP_h}{dP_s} = \frac{a}{3b} \qquad (6)$$

Note that $\frac{a}{3b}$ is less than 1. Thus, Equation (6) shows that for a unit increase in the price of sugar, the price of HFCS increases by $\frac{a}{3b}$ of the unit increase in the price of sugar. As shown in Figure 2 above, this also suggests that the price of HFCS is always less than the price of sugar.

Plugging equation (3c) into equation (3a) yields the following equality

$$bMC_h = 2bP_h - aP_s \qquad (7)$$

Equation (7) yields equation (8) which is the HFCS price reaction function that shows that HFCS price depends on the price of sugar and marginal cost of HFCS (MC_h). It shows how the pricing strategy in the sugar industry affects pricing in the HFCS industry. It also shows how an increase in marginal cost increases HFCS price. The lower price of HFCS relative to the price of sugar has been an important factor for substituting sugar for HFCS in the food and drink manufacturing industries.

$$P_h = \frac{1}{2}MC_h + \frac{a}{2b}P_s \qquad (8)$$

So, $P_h = f(MC_h, P_s)$ (9)

From equation (7) above, and as shown in Figure 2 above, we also get the profit maximizing condition $MC_h = MR_h$, or

$$MC_h = \frac{2bP_h - aP_s}{b} \qquad (10)$$

Econometric model

The reduced form equation (9) above shows that HFCS price is affected by the price of sugar and marginal cost of HFCS. We modify equation (9) to get

$$P_h = f(P_s, P_{cn}, Rir, PIP_{el}) \qquad (11)$$

where P_h is the real price of HFCS in cents per pound, P_s is real U.S. price of wholesale refined beet sugar in cents per pound, P_{cn} is real price of corn, Rir is real interest rate, PIP_{el} producer price index of electricity. The econometric specification of equation (11) is given by

$$lnP_{h,t} = \beta_0 + \beta_1 * lnP_s + \beta_2 * lnP_{cn} + \beta_3 * lnRir + \beta_4 * lnPIP_{el} + e_t \qquad (12)$$

where all the variables are defined as above and e_t is the error term that represents random shocks.

The price of HFCS-55 is the list price in cents per pound of dry weight obtained from USDA/ERS. Price of corn is in dollars per bushel and is obtained from the USDA/ERS. Producer price index of electricity is from the Bureau of Labor Statistics. The real interest rate is computed by subtracting Moody's Seasoned AAA Corporate Bond Yield from the inflation rate. Moody's Seasoned AAA Corporate Bond Yield data is obtained from the Federal Reserve Bank of St. Louis. The GDP deflator is from the Bureau of Economic Analysis (BEA). The wholesale price of refined beet sugar is in cents per pound as obtained from the USDA/ERS. We derived quarterly data for price of HFCS-55, price of corn, producer price index of electricity, wholesale price of refined sugar, and Moody’s seasoned AAA corporate bond yield through interpolation

using Proc Expand in SAS. All monetary figures are in 2005 dollars. Variable definitions, data sources, and descriptive statistics are in Appendices 1 and 2, respectively.

Results

This research uses time series quarterly data that covers the period from 1982:1 to 2013:4. Given this, it is likely that the errors in Equation 12 are serially correlated and heteroscedastic. The Durbin-Watson test indicates that autocorrelation correction is needed. The test for heteroscedasticity based on the Q statistics and Lagrange multiplier (LM) tests suggest that the errors are heteroskedastic. Therefore, Equation 12 is also estimated as an ARCH (1) model and as a GARCH (1, 1) model.

Table 1 below shows the results. The OLS model shows that as the price of inputs and the price of sugar increase, the price of HFCS increases as suggested by Equation (8). Note that all the OLS estimates are significant. The most important finding is that increases in price of sugar by one cent increases the price of HFCS by 0.17 cents as suggested by the theoretical model. This also suggests that the HFCS price is less than the sugar price. However, the OLS estimates are biased due to the errors being correlated and heteroskedastic. Thus, ARCH and GARCH estimations are also conducted.

The discussion of the results is based on the GARCH model given that the GARCH1 coefficient is significant and that the null hypothesis of normality of the residuals is not rejected. The estimate on the price of corn is positive and highly significant which suggests that increases in the price of corn increases the price of HFCS. The coefficient on PPI of electricity is positive and significant at the 10 percent level and suggests that increases in the cost of electricity increases the price of HFCS. The coefficient on the real interest rate is positive and highly significant which suggests that increases in the price of capital increases the price of HFCS. The positive and significant coefficients on these main inputs that are required to produce HFCS suggests that if costs of production of HFCS increase, then the price of HFCS increases. As suggested by Equation (8), increases in marginal cost increases the HFCS price.

The main finding is that the coefficient on the wholesale price of refined sugar is not only less than one, as suggested by the model above, but also positive and significant at the five percent level. As suggested by the HFCS price reaction function (Equation (8)), the increase in the price of HFCS is less than the unit increase in the price of sugar. That is, if the price of sugar increases by 10 cents, the price of HFCS increases by about 1.5 cents. Consequently, the price of HFCS is less than the price of sugar. This result shows that the pricing strategy in the sugar industry affects pricing in the HFCS industry. The lower price of HFCS has been an important factor for substituting HFCS for sugar in the food and soft drinks manufacturing industries.

The finding that the price of HFCS is less than the price of sugar is consistent with Evans and Davis' (2002) results. Evans and Davis (2002) estimate a derived demand for HFCS and a reaction function for HFCS price. The estimation of the price reaction function suggests that the price of sugar has positive and significant effects on the price of HFCS. However, their estimate is not corrected for heteroskedasticity and the economic model does not derive a reaction function for HFCS price, nor does it suggest any relationship between the price of HFCS and the

price of sugar. This is different from the model developed by the current research. In addition, we control for both autocorrelation and heteroskedasticity of the errors in equation (12).

Table 1. Price reaction model for high fructose corn syrup 55, 1982:1-2013:4

	Models		
Variables	**OLS**	**ARCH(1)**	**GARCH(1,1)**
Constant	-1.1916	-0.6251	0.3719
	(-1.24)	(-0.60)	(0.39)
Ln Real wholesale price of refined sugar	0.1656**	0.2250***	0.1545**
	(2.19)	(2.71)	(1.99)
Ln Real price of corn	0.3705***	0.3578***	0.3235***
	(7.43)	(6.77)	(6.19)
Ln Real interest rate	0.4968***	0.4095***	0.3765***
	(4.48)	(3.23)	(3.38)
Ln Electricity PPI	0.5529***	0.4216**	0.2824*
	(3.21)	(2.25)	(1.66)
ARCH0		0.0122***	0.0024
		(6.63)	(1.49)
ARCH1		0.4122	0.2331
		(1.64)	(1.62)
GARCH1			0.6659***
			(5.08)
Obs.	128	128	128
R-squared	0.6190	0.6147	0.5830
AIC		-133.36892	-131.1691
SBC		-113.40471	-108.35286
Normality test		5.3026	3.1156
Normality test p-value		0.0706	0.2106

Note: Asterisks indicate significance at the 10% (*), 5% (**), and 1% (***) level respectively. t-values are in parentheses. Ln is the natural logarithm operator. The null hypothesis of normality of the residuals is not rejected for the GARCH model.

Carman (1982) suggests that the price differential between sugar and HFCS prices is one of the factors that has an economic impact on consumers and food manufacturers; lower costs to food manufactures may imply lower food prices to consumers. Barros (1992) finds that sugar prices positively affect the growth rate of U.S. HFCS consumption and argues that permanent changes in sugar price causes a permanent effect on the U.S. HFCS consumption growth rate. Our findings give support to this earlier research and suggests that the lower price of HFCS represents lower costs to food manufacturers and is one of the main factors that have been promoting the substitution of HFCS for sugar in the food manufacturing industries.

Conclusion

This study uses quarterly data that covers the period 1982:1-2013:4. It develops a model of pricing in imperfectly competitive markets based on the Stackelberg price leadership behavior

model to explain pricing strategies in the high fructose corn syrup (HFCS) and sugar industries in the United States. The model derives a reaction function for price of HFCS and a conjectural variations function that suggests that the price of sugar is higher than the price of HFCS. The results show that the price of sugar plays an important role in the pricing strategy of the HFCS industry and that a unit increase in the price of sugar increases the price of HFCS by less than the unit increase in the price of sugar. Specifically, the coefficient on the wholesale price of refined sugar is not only less than one, as suggested by the model, but also positive and significant at the five percent level. As suggested by the HFCS price reaction function (Equation (8)), the increase in the price of HFCS is less than the unit increase in the price of sugar. That is, if the price of sugar increases by 10 cents, the price of HFCS increases by about 1.5 cents. Therefore, the price of HFCS is less than the price of sugar. This also suggests that the lower price of HFCS has been an important factor for substituting sugar for HFCS in the food and soft drinks manufacturing industries.

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Appendix 1 Variable definitions and data sources

Variable name	Variable definition	Source
Price of HFCS-55	Nominal list price in cents per pound of dry weight	USDA/ERS, Sugar and Sweeteners Yearbook Tables, Table 9. Accessed at http://www.ers.usda.gov/data-products/sugar-and-sweeteners-yearbook-tables.aspx
Price of corn	Nominal price in dollars per bushel	USDA/ERS, Feed Grains Database, Custom Query for No. 2 Yellow Corn Market Prices, Central Illinois. Accessed at http://www.ers.usda.gov/data-products/feed-grains-database/feed-grains-custom-query.aspx
Electricity PPI	Electricity producer price index	Bureau of Labor Statistics
Real interest rate	Real interest rate. It is computed by subtracting Moody's Seasoned AAA Corporate Bond Yield from inflation rate.	Own calculations.
Price of refined beet sugar	Nominal wholesale price of refined beet sugar in cents per pound.	USDA/ERS, Sugar and Sweeteners Yearbook Tables, Table 5. Accessed at http://www.ers.usda.gov/data-products/sugar-and-sweeteners-yearbook-tables.aspx
Moody's Seasoned AAA Corporate Bond Yield	Moody's Seasoned AAA Corporate Bond Yield	Federal Reserve Bank of St. Louis
Inflation	Quarterly percentage change of GDP deflator.	Own calculations.
GDP deflator	Seasonally adjusted quarterly GDP deflator.	Bureau of Economic Analysis

Appendix 2 Summary statistics, quarterly values for the period 1982:1-2013:4

Variable	**N**	**Mean**	**Std. Dev**	**Minimum**	**Maximum**
Real HFCS-55 price	128	26.44	6.11	15.24	41.28
Real wholesale refined beet sugar price	128	34.29	7.68	21.89	51.95
Real interest rate	128	6.96	2.33	2.99	13.60
Electricity producer price index	128	91.52	20.62	62.38	142.25
Real price of corn	128	3.45	1.23	1.72	6.89