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Demand Behavior of U.S. High Fructose Corn Syrup (HFCS) and its Implication for the U.S. Sweetener Market: A Cointegration Analysis*

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Abstract

This paper investigates the relationship between U.S. HFCS demand and refined sugar price. A cointegration analysis is utilized to investigate possible linkages between these markets. The coefficients on the ECM have the expected signs, and they measure adjustments towards long-run equilibrium. The study result also shows that there is cointegration in a relationship including, HFCS price, refined sugar price, and income. the increase in HFCS demand would affect primarily the quantity of sugar imports negatively. However, this study does not necessarily support such a conclusion due to the exclusion of noneconomic factors such as change in consumer preference and health concern.

Keywords: cointegration, HFCS demand, sugar, sweetener.

Introduction

In recent years the U.S. sugar industry has been protected from serious global competition through import restrictions (Koo, Taylor, and Matttson). During the past two decades, inexpensive domestic substitutes, such as high fructose corn syrup (HFCS), have emerged in the food industry. Furthermore, consumer preferences toward low caloric foods affect consumption of sugar and sugar containing products. These developments have important implications for the effectiveness of U.S. sugar policy.

HFCS has rapidly gained commercial acceptance since its introduction in 1967. It is a caloric sweetener made from ordinary corn. It substitutes directly for cane or beet sugar in many sugar containing products. Continued acceptance and market penetration of HFCS has economic implications for various groups, including domestic beet and cane sugar producers and processors, sweetener users, consumers, corn producers, and trading partners (Brooks, Cameron, and Carter). Nevertheless, previous studies have suggested that the refined sugar market did not respond to perturbations in the HFCS-refined sugar long-run equilibrium by investigating the dynamic relationship between refined sugar price and HFCS prices (Rendleman and Hertel; Williams and Bessler; and Moss and Schmitz). Other studies have suggested that the impacts of sugar price on HFCS demand have been minimal analyzing either corn or sugar market (Lopez; Lopez and Sepulveda; and Koo). Carman attempted to project HFCS and sugar demand using a simple logistical trend model. However, since U.S. domestic sugar prices have been maintained at levels substantially above world prices, investigating the dynamic relationship between the refined sugar price and HFCS prices for the U.S. might not be appropriate. In particular, a commodity price that has been protected by the government, such as the U.S. sugar price, does not necessarily behave dynamically. Therefore, analyzing demand behavior for a commodity and its implications on the other commodity might be a more reasonable approach. In addition, Williams and Bessler (1997) and Moss and Schmitz (2002) use cointegration to analyze equilibrium between HFCS and refined sugar prices for certain time periods. However, there were no series cointegrated for their study time periods, which means the prices of HFCS and refined sugar have not been moving together. Learning from those previous studies, this study attempts to examine the relationship between HFCS consumption and refined sugar price estimating the cross price elasticity and investigating the implications on sugar markets.

This paper investigates the relationship between U.S. HFCS demand and the refined sugar price. A cointegration analysis is utilized to investigate possible linkages between these markets. The remainder of the paper is divided into four sections. First, an outline of U.S. HFCS market and demand is provided. The next section presents a brief summary of the cointegration methods applied in the paper. Results from an application of cointegration techniques are then presented. The final section discusses implications for the U.S. sweetener market and offers concluding remarks.

U.S. HFCS Demand

HFCS is a liquid caloric sweetener made from ordinary cornstarch and can be substituted for sugar in most liquid uses. Given its relative low cost, HFCS has been adopted in a wide rage of processed food products including beverages, baked goods, dairy products, jams, jellies etc. (Evans, Ward, and Davis). It may be used as a partial or total replacement for sugar in many products, but it is unsuitable for others. This partial substitutability of HFCS for sugar in industrial uses has resulted in a unique market for sweeteners in the United States (Moss and Schmitz). In addition, corn sweetener manufacturers benefit from the higher long-term prices which have spurred plant and equipment investment, and research and development in corn wet milling products. Stable prices have also facilitated the offering of price discounts, relative to sugar, and acquisition of market share by HFCS manufacturers (Williams and Bessler).

United States' sugar policy sustains returns to domestic producers and processors through support price (loan rate), while restricting imports through tariff-rate-quotas (TRQs). The latter have been set at a level that ensures the policies do not result in budgetary outlays. Since 1985, the support price has been about 18 cents/lb. As a result of these policies, domestic raw cane prices averaged roughly about 22 cents/lb for the past two decades, compared to an average world price of roughly about 9 cents/lb over the same period (El-Obeid and John C. Beghin, 2004).

The 2002 Farm Act continues the essential elements of the previous sugar program, but with some changes which increase support to sugar producers and processor. The non-recourse loan program is reauthorized through fiscal year 2007 at 18 cents/lb for raw cane sugar and 22.9 cents/lb for refined beet sugar. Program changes which benefit the sugar industry include: the termination of the marketing assessment on all sugar processed (between 1.375 and 1.47 percent of the raw sugar loan rate), the termination of the forfeiture penalty on cane ($0.01 per pound) and beet processors ($0.017 per pound), and reduced interest rate on CCC sugar loans by one percent point. The tariff-rate quotas are continued under the 2002 Farm Bill (USDA/ERS).

In the United States, sugar prices are significantly above HFCS prices as mentioned. As a result, HFCS has replaced sugar in many cases. Roughly 10 percent of the U.S. corn production is used for HFCS production. In addition, HFCS comprises the major part of total consumption of caloric sweeteners. In 2003, U.S. per capita consumption of caloric sweeteners was 141.7 pounds, of which HFCS accounted for 60.9 pounds (USDA/ERS). In the meantime, the growth in HFCS is largely a result of U.S. farm policy, which has kept internal sugar prices high and corn prices low, thus providing a favorable price environment for HFCS. Further, there has been an ongoing substitution for sugar in as many applications as is technically possible (Schmitz, Seale, and Schmitz).

Table 1 depicts per capita consumption and market share trends for various sweeteners in the U.S. between 1970 and 2003, the market share of sugar fell from 85.5 percent to 43.1 percent while the market share of HFCS increased from 0.5 percent to 43 percent. Per capita consumption of other sweeteners has remained fairly stable. Furthermore, the combined market share of per capita consumption of sugar and HFCS has not changed at about 86 percent, suggesting that an approximate one-to-one substitution of HFCS for sugar has occurred. It might imply that consumption of HFCS increases as that of sugar decreases. The rapid and considerable increase in the consumption of HFCS in the U.S. and the concomitant displacement of a portion of the U.S. sugar demand has come largely at the expense of sugar imports and by implication, U.S. sugar refiners. The U.S. continues to be both the world's largest producer and consumer of HFCS, producing and consuming about 70% of world HFCS production (USDA/ERS). Given this importance of these changes in both sugar and HFCS consumption, it seems appropriate that an HFCS demand structure be analyzed. In particular, estimating the cross price elasticity seems appropriate to depict the linkages between HFCS and sugar markets.

Theoretic Background and Data

A standard model of HFCS consumption based on utility maximizing theory is rather straightforward to produce. For this study, we use a general demand function in double-log form so that elasticities can be readily observed. The equation for HFCS per capita consumption (Q_t) includes per capita income (Y_t), own price (P_t), price of substitute (refined sugar price, S_t), and other explanatory variables (Z_t), or simply,

(1) $\ln Q_t = \alpha_0 + \alpha_1 \ln Yt + \alpha_2 \ln Pt + \alpha_3 \ln S_t + \alpha_4 \ln Z_t$.

Estimation of the model would seem to be quite simple using the standard ordinary least squares (OLS) method. Previous studies have made implicit assumptions that the data were stationary time series, containing a constant mean, variance, and auto-covariance. Although the coefficient estimates from these models appear to be of theoretically correct sign and magnitude, deeper investigation reveals flaws. Such spurious regressions often include autocorrelation as indicated by a Durbin-Watson d-statistic that is lower than the regression's R^2. The effects of autocorrelation include inefficient estimators and inaccurate hypothesis testing. Similarly, non-stationarity in a time series may result in identifying a significant relationship when none exists. Even though each individual variable may move randomly over time, together they may be moving randomly around a common stochastic trend (Judge, et al.).

Procedures developed by Johansen and Johansen and Juselius provide a means to investigate the cointegrations of the different variables. This cointegrating relationship represents the foundation of a complete dynamic error correction model. The error correction model (ECM) and cointegrating relationship allows us to compare the immediate and overall elasticities of demand, and the model will show how fast adjustments occur. The estimation method of error-correction modeling (ECM) accounts for economic variables that are integrated. The procedure is based on the error correction formulation:

(2) $$\Delta X_t = \beta + \sum_{i=1}^{n} \Gamma_i \Delta X_{t-1} + \Pi X_{t-1} + \psi D_t + \varepsilon_t,$$

which details the long-run and short-run dynamics of integrated variables. X_t is a vector of variables, β is a constant vector, D_t is a set of predetermined variables (seasonal variables or intervention dummy variables), ψ is the associated parameter(s) on these predetermined variables, and ε_t is a vector of white noise residuals. The adjustments to disequilibrium are captured over n lagged periods in the coefficient matrix Γ_i. This portion of the ECM represents a traditional vector autoregression of the differenced variables. The ΠX_{t-i} terms represent long-run equilibrium or cointegrating relationships, and the coefficient matrix can be decomposed into $\Pi = \alpha\beta'$, where β' is a matrix of the cointegrating vectors and α is a matrix of the error correction coefficients. The matrix must have a rank of less than full rank, otherwise it can be shown that X_t is entirely a function of the residuals. The number of cointegrated vectors is then determined by the number of significant eigenvalues of Π. Specifically, letting λ_i be the *i*th eigenvalue of Π, then

(3) $$2 \ln Q\left[H_1(r) \middle| H_1(p)\right] = -T \sum_{i=r+1}^{p} \ln(1 - \lambda_i)$$

can be used to test the hypothesis of *r* cointegrating vectors, $H_1(r)$, against the hypothesis of *p* cointegrating vectors, $H_1(p)$ (Williams and Bessler; and Moss and Schmitz).

The main advantage of Johansen's approach is that it resolves a limitation of the ADF tests, i.e., the simultaneity biases caused by the use of more than on endogenous variable at the same time (Mohanty, Peterson, and Smith).

Before estimating any relationships between HFCS consumption and its explanatory variables, the stationarity of each series needs to be tested. This property is best tested by the augmented Dickey-Fuller ADF test for a unit root.

In addition, each individual series exhibits a random walk type of movement over time. However, there still may exist a stochastic trend that all variables share. This long-run association would show us the elasticities of HFCS demand with respect to its own price, a substitute price, and income. We can approximate an equilibrium relationship by estimating a stationary linear combination(s) using the Johansen cointegration test.

Annual data for the period 1970 through 2003 were used to estimate the U.S. HFCS demand and elasticities. The data was obtained from the *Sugar and Sweetener Situation and Outlook* reports (USDA/ERS various issues) and their *Sweetener Outlook* reports. The refined sugar price is wholesale Midwest market price, and the HFCS price is HFCS-42 wholesale Midwest market price. Income data was obtained from the *International Monetary Fund* (IMF) for the same period. The data are studied in logarithmic units.

Empirical Estimation and Results

Before testing for cointegration, as mentioned, it is necessary to check for unit roots in the individual variable series. The order of integration of each variable series was determined using both the augmented Dickey-Fuller (ADF) and the Phillip Peron (PP) unit root tests. ADF and PP unit root test results for each variable series are presented in table 1. The ADF test statistics were calculated by using equation (2). The number of lags to include in the equations was determined by using the Akaike information criterion (AIC).

The test statistics indicate that the unit root hypothesis cannot be rejected, even at the 1% significance level, for all variable series. Similarly, the PP test statistics failed to reject the hypothesis, confirming the findings of the ADF test.

We now use the Johansen procedure and trace and max-eigenvalue statistic to test for the presence and number of cointegrating vectors. The results are presented in table 2. For the model, we conclude that there are three cointegrating vectors. As a result, we estimate the demand model using least square (LS) method and compared LS statistics with the three conintegrating vector statistics. We compare the log likelihood statistics, coefficient magnitude, estimate signs, and significance.[2] As a result, we conclude that the first cointegrating vector is the reasonable vector to use for the corresponding error correction estimation.

The Johansen model is a form of error correction model (ECM) and its parameters can be interpreted as estimates of the long-run cointegrating relationship between the variables concerned, in our case, HFCS demand. The cointegrating vectors normalized on HFCS demand is

LPCON = 5.919 – 1.249 LHFCSP + 1.444 LGDP + 0.158 LSUGARP

The coefficients on the ECM have the expected signs, and they measure adjustments towards long-run equilibrium. The coefficients represent estimates of long-run elasticities of HFCS demand with respect to own price (LHFCSP), per capita income (LGDP), and substitute price (LSUGARP). In this case, the substitute price is the refined sugar price. The elasticities indicate that a one percent increase in HFCS price decreases approximately 1.25 percent of HFCS demand in the long-run, a one percent increase in per capita income increases 1.444 percent in HFCS demand, and a one percent increase in refined sugar price increases 0.158 percent in HFCS demand in the long-run. However, in terms of short-run effects, the adjustment is not significant. For example, the income adjustment in the short-run is an approximately 0.098% (0.9102-0.8118) increase as income increases by 1%. Further, HFCS demand is not significantly responsive to price and income changes in the short-run, but it is responsive to these changes in the long-run, which implies that consumers eventually adjust their consumption behavior with respect to price and income. In the meantime, the refined sugar price does not affect HFCS demand in the short-run. It has positive sign and the cross elasticity in the long-run is 0.158 implying if the sugar price increase by 1%, in the long-run, HFCS demand increases by 0.158%. In addition, the diagnostic tests of the ECM provide acceptable results for specification, normality, and autocorrelation.

Concluding Comments and Implications on the U.S. Sweetener Market

This paper investigates the relationship between U.S. HFCS demand and refined sugar price and other factors. A cointegration analysis is utilized to investigate possible linkages among the factors.

The cointegration analysis shows that HFCS price, refined sugar price, and income are significant in explaining HFCS demand. The study result also shows that there is cointegration in a relationship including, HFCS price, refined sugar price, and income.

The statistical results in this study have several implications for the economic tradeoff between sugar and HFCS. Undoubtedly, high sugar prices have stimulated the use and development of sugar substitutes, such as HFCS, in industrial uses. Consumers have purchased less sugar and sugar-containing products due to noneconomic factors. If we consider only the economic factors that affect HFCS demand, the HFCS demand seems to increase as the sugar price maintains its price levels significantly higher than that of HFCS. Moreover, the increase in HFCS demand would have a negative impact on the quantity of sugar imports. However, this study does not necessarily support such a conclusion due to the exclusion of noneconomic factors such as change in consumer preference and health concern.

Furthermore, decreased manufacturing costs due to the use of lower-priced HFCS should be passed on to consumers through lower retail prices under competitive market conditions. However, many of the food industries which utilize HFCS are characterized by imperfect competition (Carman; Lopez and Sepulveda). Therefore, the cost savings may not be passed on to consumers.

Footnotes:

1. Johansen and Juselius cointegration tests involve a maximum-likelihood estimation procedure that provides estimates of cointegrating vectors for a given number of variables. It is based on the following error correction representation:

$$\Delta X_t = \sum_{i=1}^{k} \Gamma_i \Delta X_{t-i} + \Pi(r) X_{t-1} + \varepsilon_t,$$

where X_t is a vector of I(1) processes. The rank of $\Pi(r)$ equals the number of cointegrating vectors, which is tested by maximum eigenvalue and trace statistics.

2. The LS estimates are

LPCON = -9.1379 – 0.1075 LHFCSP + 2.0913 LPGDP + 1.3088 LSUGARP.
(-10.46) (-0.19) (10.32) (3.01)
Adjust R2 is 0.88, Log likelihood is 53.2, Durbin Watson statistic is 1.75, and F-statistic is 73.82.

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Table 1. Per Capita Consumption and Market Shares of Caloric Sweeteners in the United Staes.

Year	Sugar	HFCS	Glucose	Dextrose	Others	Total
---Pounds--- (Percentage)						
1970	101.8	0.55	10.7	4.6	1.5	119.1
	(85.5)	(0.5)	(8.9)	(3.9)	(1.3)	(100.0)
1975	89.2	4.9	14.0	4.4	1.4	113.8
	(78.4)	(4.3)	(12.3)	(3.9)	(1.2)	(100.0)
1980	83.6	19.0	12.9	3.5	1.3	120.2
	(69.6)	(15.8)	(10.7)	(2.9)	(1.1)	(100.0)
1985	62.7	45.2	13.5	3.5	1.3	126.2
	(49.7)	(35.8)	(10.7)	(2.8)	(1.0)	(100.0)
1990	64.4	49.6	13.6	3.6	1.2	132.4
	(48.6)	(37.5)	(10.3)	(2.7)	(1.0)	(100.0)
1995	64.9	57.6	16.3	4.0	1.3	144.1
	(45.0)	(40.0)	(11.3)	(2.8)	(1.0)	(100.0)
2000	65.5	62.6	15.8	3.4	1.5	148.8
	(44.0)	(42.1)	(10.6)	(2.3)	(1.0)	(100.0)
2003	61.1	60.9	15.2	3.1	1.4	141.7
	(43.1)	(43.0)	(10.9)	(2.2)	(1.0)	(100.0)

Source: USDA/ERS, www.ers.usda.gov/Data/FoodConsumption, accessed February 2005.

Table 2. Augmented Dickey-Fuller (ADF) and Phillip Peron (PP) Unit Root Test Statistics

Variables	ADF		PP	
	I(0)	I(1)	I(0)	I(1)
HFCS per capita consumption (Q_t)	-3.1745	-7.3613*	-3.1436	-7.0028*
Per capita income (Y_t)	-1.0547	-3.6482**	-0.5936	-4.6571*
Own price (P_t)	-2.8624	-5.7917*	-3.0530	-7.1218*
Refined sugar price (S_t)	-3.0515	-5.0618*	-2.3740	-6.1263*

Note: 1. Prices and income are in real values. 2. The number of lags p is chosen using the Akaike Information Criterion (AIC). 3. The tests were conducted by including both intercept and trend. 4. * and ** represent 1% and 5% significant levels, respectively.

Table 3. Cointegration Results

Null Hypothesis	Max-Eigen Statistic	Trace
$r = 0$*	92.049 (26.81)	163.241 (53.12)
$r \leq 1$*	41.570 (22.00)	71.192 (34.91)
$r \leq 2$*	23.539 (15.67)	29.622 (19.96)
$r \leq 3$	6.082 (9.24)	6.082 (9.24)

Note: the numbers in parenthesis are 5% critical values.

* Denotes rejection of the null hypothesis of no cointegration at the 5% level.

Table 4. The Error Correction Model Estimates for HFCS Demand

Variables	Estimates	
	Short-run	Long-run
Constant	-0.0211 (-1.02)	5.919 (11.262)*
LHFCSP	-	-1.249 (-0.782)
LPGDP	-	1.444 (11.416)*
LSUGARP	-	0.158 (4.978)*
Δ LHFCSP	-0.8512(-2.54)*	-
ΔLPGDP	0.9102 (1.295)	-
Δ LSUGARP	0.0962(3.97)*	-
Δ $LHFCSP_{t-1}$	0.0465 (0.766)	-
Δ $LPGDP_{t-1}$	-0.8118 (-2.971)*	-
Δ $LSUGARP_{t-1}$	-0.0637 (-2.0)*	-
ε_{t-2}	-0.1197(-4.98)*	-
Diagnostic Tests		
R^2	0.83	-
D-W	1.99	-
LM	60.35	78.21
LM- $\chi^2(1)$	161.35	-
LM- $\chi^2(2)$	172.42	-
	177.02	-
LM- $\chi^2(3)$	182.83	-
RESET- $\chi^2(1)$	15.31	-
Jarque-Bera Normality- $\chi^2(2)$	4.73	-

Note: *denotes that the variables are significant at the 5% level.