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Price response of the high fructose corn syrup industry in the United States: a Bertrand model application

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ABSTRACT

This paper uses a Bertrand duopoly model application and derives a high fructose corn syrup (HFCS) price reaction function that shows the response of the price of HFCS to changes in the price of sugar. It conducts cointegration analysis and assesses the performance of the HFCS price reaction model by estimating a Dynamic Ordinary Least-Squares model. It finds that the prices of HFCS-55, sugar, and corn are cointegrated over the period 1981:1 to 2017:12. The estimated long-run relationship shows that a one percent increase in the price of sugar increases the price of HFCS-55 by 0.19 percent. Additionally, the price of corn has a positive effect on the price of HFCS-55. The model and the results offer important insights for antitrust litigation.

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1. Introduction

The development of the high fructose corn syrup (HFCS) industry in the United States has been related to the price of HFCS being below the price of sugar (Ballinger, 1978; Barry, Angelo, Buzzanell, & Gray, 1990). In addition, the relatively low costs of production for HFCS allowed it to be priced at a discount rate of 10–30 percent relative to sugar (Barry et al., 1990). The discounted price of HFCS-55 (55-percent fructose) also influenced the replacement of sugar with HFCS in the soft drink industry (Lord, 1995). However, the price of HFCS was above the price of sugar in 2008 (Haley & Dohlman, 2009), and the price differential between HFCS and refined sugar vanished in the United States in 2016/17 (McConnell, 2018).

The correlation between the prices of HFCS and sugar and market power in the HFCS industry was a relevant issue in the United States v. Archer-Daniels-Midland Co. (1991). In this case, the U.S. government claimed there to be a reduction of competition and trade in the manufacturing and sale of HFCS, which violated section 7 of the Clayton Act and section 1 of the Sherman Act. In an earlier stage of the case (United States v. Archer-Daniels-Midland Co., 1987), a District Court found, based on the corresponding tests, interchangeability between HFCS and sugar on every known use of HFCS, a corresponding cross-price elasticity of demand between HFCS and sugar, a significant price correlation between HFCS and sugar, and suggested that HFCS

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prices followed sugar prices. The Court's decision was based on the application of those tests in two cases about 30 years earlier. For the test of interchangeability and cross-price elasticity of demand the District Court cited *United States v. E.I. Du Pont de Nemours & Co.* (1956), and for the price correlation test, the District Court cited *American Crystal Sugar Co. v. American Crystal Sugar Co. v. Cuban-American Sugar Co.* (1958).¹ Therefore, understanding the long-run relationship between the prices of HFCS and sugar can have implications for anti-trust litigation.

Regarding market power in the HFCS industry, the demand elasticity can be obtained from estimations of residual demands. Froeb and Werden (1992) show that HFCS monopoly mark-ups can be overstated because the estimated residual demand elasticities are small. Brendstrup, Paarsch, and Solow (2006) estimate HFCS residual demand elasticities, control for the effects of both HFCS short-run capacity constraint and of sugar as substitute to avoid underestimating residual demand elasticities and find that the HFCS industry has no market power. They also find that when controlling only for the effect of sugar as substitute in the residual demand and not controlling for HFCS short-run capacity constraint, the HFCS industry has market power, so HFCS producers can charge a higher price given the government policy determined price of sugar.

Cointegration analysis has aimed to explain the long-run relationships between HFCS and sugar prices (Moss & Schmitz, 2002a, 2002b; Williams & Bessler, 1997). Williams and Bessler (1997) suggest that the HFCS industry determines its price based on the price of sugar. 2004) report three different long-run relationships between HFCS and sugar prices over the period 1979–2003 and suggest that there is an HFCS price reaction function that represents the response of the price of HFCS to changes in the price of sugar. Evans and Davis (2002) use maximum likelihood methodology to estimate a reaction function for the HFCS industry. However, neither study develops an economic model to derive an HFCS price reaction function.

Given the importance of the relationship between the prices of HFCS and sugar and to contribute to the economics of HFCS, this paper uses a Bertrand duopoly model to derive an HFCS price reaction function that shows the response of the price of HFCS to changes in the price of sugar. In addition, it updates the analysis of industry pricing through 2017, and it includes the price of corn in the cointegration analysis. It uses a monthly data set that covers the period 1981:1–2017:12, conducts cointegration analysis, and estimates a dynamic ordinary least squares (DOLS) model to assess the performance of the HFCS price reaction model. This makes the current paper different from earlier studies, including cointegration analysis studies, that recognize the existence of an HFCS price reaction function, but these studies do not develop a model to derive it, nor do they estimate it. The results show, based on the estimated long-run relationship, that the price of HFCS increases by less than the increase in the price of sugar as predicted by the HFCS price reaction model. Specifically, a one percent

¹The case *United States v. E.I. Du Pont de Nemours & Co.* (1956) has been cited by 1,031 court cases (Leagle, 2017). Additionally, four 2018 cases refer to the relevant product market given interchangeability and cross-price elasticity of demand (*California Association Of Realtors, Inc. v. Pdfiller, Inc.* 2018; *In Re Solodyn (Minocycline Hydrochloride) (Antitrust Litigation)* 2018; *Packaging Systems, Inc. v. Prc-Desoto International, Inc.* 2018; *Park Irmat Drug Corp. v. Express Scripts Holding Company* 2018). Further, *United States v. Archer-Daniels-Midland Co.* (1991) has also been cited in six cases (*U.S. v. Kinder* 1995; *Federal Trade Com'n v. Cardinal Health, Inc.* 1998; *In Re High Fructose Corn Syrup Antitrust Litig.* 2001; *Chicago Bridge & Iron Co. N.V. v. F.T.C.* 2 July 2008; *Chicago Bridge & Iron Co., N.V. v. F.T.C.* January, 2008; *F.T.C. v. CCC Holdings Inc.* 2009).

increase in the price of sugar leads to 0.19 percent increase in the price of HFCS-55. These results offer important insight for antitrust litigation. Additionally, the price of corn has a positive effect on the price of HFCS-55.

The remainder of this paper is organized as follows. The second section describes the relationship between the HFCS and sugar industries. The third section reviews the relevant literature. The fourth section describes the methodology and data. The next section discusses the results. The final section presents the conclusions.

2. The relationship between the HFCS and sugar industries

The relationship between the HFCS and the sugar industries is mostly related to the prices of these sweeteners. The price of sugar has been determined by U.S. government policy such as import quotas, marketing allotments, loan rates, refined sugar re-export program, nonrecourse loans and tariff rate quotas, which have been defined in the Agricultural Act of 2014 and earlier bills (Beghin & Elobeid, 2017). Thus, the domestic price of sugar has been above its international market price. In addition, it has been argued that the higher prices of sugar in 1974 and 1980 and the government price support program contributed to the development of the HFCS industry and the increase of its share in the U.S. sweetener market (Barry et al., 1990). It is also reported that the high prices of sugar in 1974/75 were an incentive to increasing HFCS processing capacity (U.S. Department of Agriculture, Economic Research Service, 1980).

The higher prices of sugar have been associated with soft drink manufacturer's decisions about increasing their use of HFCS. The price of refined sugar increased from 12.4 cents a pound in 1973 to 56 cents a pound in December 1974 due to lower sugar yields, which is associated with the 1974 decision of the Coca-Cola company about replacing 25 percent of sucrose with HFCS-42 Forrester (1982, as cited in Bode, Empie, & Brenner, 2014). Additionally, lower world sugar yields caused the price of refined sugar to rise again from 21 cents a pound in 1979 to 52 cents a pound in 1980, which is associated with the decisions of Coca-Cola and Pepsi about increasing the use rates of HFCS-55 from 25 to 50 percent in 1980, and finally to 100 percent in 1984 (Pendergrast, 1993).

Since the introduction of HFCS to the market, on average, the HFCS price has been below the price of sugar. It has also been argued that the relatively lower costs of HFCS allowed the HFCS price to be below the refined sugar prices and to follow the sugar price changes at a discount of 10 to 30 percent (Barry et al., 1990). Lord (1995) also argues that the discounted price of HFCS promoted the replacement of sugar with HFCS-55 in the manufacturing of soft drinks. Table 1 shows that HFCS average costs were below those of sugar during the period 1989–2013. Thus, it is likely that HFCS has had cost advantages over sugar, which may have contributed to the price of HFCS staying below the sugar price and increasing the share of HFCS in the U.S. sweetener market. However, HFCS costs increased during the period 2006–2013.

3. Literature review

The relationship between the prices of HFCS and sugar has motivated research on market power in the HFCS industry. Froeb and Werden (1992) base their analysis on a delineated relevant market for HFCS that includes sugar, assume that the price of sugar is exogenous

Table 1. Average costs of production of cane sugar, beet sugar, and HFCS in the United States, Cents/Pound, 1989–2013.

	89/90-94/95	94/95-98/99	97/98-01/02	01/02-03/04	04/05-06/07	07/08-09/10	10/11-12/13
Cane sugar	18.1	17.0	16.7	16.0	20.6	23.6	25.4
Beet sugar	18.1	23.4	26.0	24.1	25.0	29.4	26.0
HFCS	10.1	12.1	10.6	11.9	15.4	20.5	22.9

Notes: Authors' estimations based on the assumption that the cost data is normally distributed and using LMC International data that is published in Sugar and Sweeteners Outlook, May 1998, Sugar and Sweeteners Outlook, September 2001, Sugar and Sweeteners Outlook, September 2004, and Sugar and Sweeteners Outlook, June 2014. For the period 89/90-01/02, cane sugar is U.S. raw cane sugar, beet sugar is U.S. refined beet sugar, and HFCS is U.S. HFCS. For the period 01/02-12/13, cane sugar is U.S. white cane sugar, beet sugar is U.S. beet sugar, and HFCS is U.S. and Mexico HFCS.

because it is determined by the government price support program, assume an HFCS monopolist, and derive an HFCS monopoly mark-up from the first-order conditions for profit maximization as in Froeb and Werden (1991). They estimate residual demand elasticities for the HFCS monopolist and show that delineating a market based on the prevailing demand elasticity overstates the estimated HFCS monopoly mark-up and market power because the estimated residual demand elasticity is small. However, they do not disregard the possibility that the HFCS monopolist can increase price. They also state that is reasonable to assume an HFCS monopolist that would have increased price up to a level just below the price of sugar. The ability of the HFCS industry of fixing the price of HFCS has also been a focus of research. Cotterill (1998) assumes that HFCS producers fixed the price of HFCS and reports that wet corn millers sell HFCS to larger purchasers at a price that is below the list price. In addition, Cotterill (2001), because two producers of HFCS pleaded guilty of fixing the price of citric acid, assumes that HFCS producers fix and increase the price offered to direct buyers of HFCS.

Continuing with the issue of market power in the HFCS industry, Brendstrup et al. (2006) assume that the U.S. HFCS market is a residual-demand market, demand for HFCS changes from period to period, marginal cost of HFCS changes from period to period, sugar is a near-perfect substitute for HFCS, the price of sugar is exogenous because it is determined by the government price support program and changes from period to period, the changes in the price of sugar change the marginal revenue of the HFCS monopolist, plant capacity is fixed in the short-run, and the HFCS monopolist has several identical plants that use the same technology and have the same marginal cost. Their economic model shows that demand for HFCS and the price of sugar increases from period 1 to period 2, and that marginal cost of HFCS decreases from period 1 to period 2. The model suggests that when the price of HFCS is higher than the price of sugar, soft drinks manufacturers replace HFCS with sugar, and the HFCS monopolist sells zero output. Consequently, the effective demand for HFCS is a line that starts going down from the point where the price of HFCS equals the price of sugar. Given this, the HFCS monopolist sets price below the price of sugar to sell a given level of output. The model implies that the HFCS industry pays attention to the behavior of the price of sugar and can adjust the price of HFCS given changes in the price of sugar, which is related to price being a strategic variable for these industries. They estimate a residual demand and a supply of HFCS given a structural econometric model. They find that when controlling for the effect of sugar as substitute in the residual demand only, or for the effect of the HFCS short-run capacity in the supply model only, the HFCS industry has market power, but the HFCS industry has no market power, when controlling for both sugar as substitute and HFCS short-run capacity.

They suggest, given the case that controls for sugar as substitute only, that the HFCS industry can increase price given the government-controlled price of sugar, but that the estimates may be inconsistent without controlling for short-run capacity constraint. However, in the long-run, the HFCS industry can increase its production capacity.

The relationship between the prices of HFCS and sugar has also been the focus of cointegration analysis, which is based on estimating error correction models. Williams and Bessler (1997) find a cointegrating relationship between HFCS and refined sugar prices for the period 1984–1991, that the HFCS price responds to deviations in the long-run equilibrium between HFCS and sugar prices, that the price of sugar is the main determinant of the HFCS price for the period 1984–1991, and that there is no long-run feedback from the price of HFCS to the price of sugar. They suggest that the HFCS industry look adaptively at the refined sugar price, and that when the price of sugar increases in period t , the price of HFCS increases in period $t + 1$. Moss and Schmitz's (2002a) demand models suggest that the price of HFCS is lower than that of sugar, and that these prices move together over a range of prices, in which HFCS and sugar are perfect substitutes. They find a long-run relationship between HFCS and refined sugar prices for the period 1983–1996. They consider that sugar and HFCS competed for the industrial sweetener demand over this period, but that this does not mean that the two industries were perfect competitive. They argue that these industries could have been monopolies, and that the sweetener market could have been modelled as a duopoly. Also, Moss and Schmitz (2002b) assume that HFCS and sugar are perfect substitutes in the soft drink market and find that the prices of HFCS and wholesale refined sugar moved together over the period 1983–1996. Further, (2004) contend that to determine the relevant market for HFCS, a residual demand function for HFCS needs to be derived from the supply and demand for sugar in the production of soft drinks along with a market reaction within this market. However, they do not derive the reaction function. They find, given structural breaks, three different long-run relationships between HFCS and sugar prices over the period 1979–2003. They suggest that this may be related to changes in the HFCS industry's reaction function given changes in sugar prices, which affects the residual demand used to determine the relevant market. They also suggest that there is an HFCS mark-up pricing even under different cointegrating relationships.

The relevance of an HFCS price reaction function is also acknowledged by Evans and Davis (2002). Their economic model considers the HFCS industry as an oligopoly as suggested by LMC (LMC International, Ltd.) (1997) and Polopolus and Alvarez (1991). They suggest deriving an HFCS price reaction function from a profit function and argue that the reaction function represents the best price the HFCS industry charges given the price of sugar and the other factors that affect the profits of the HFCS industry. However, their model does not derive this price reaction function. They argue that HFCS producers set the price of HFCS as an oligopolistic industry, and that when the price of HFCS is above its average costs, HFCS producers earn economic rent and can adjust price within a given price range to maintain or increase market share. They use maximum likelihood methods to estimate an HFCS price equation and a derived demand for HFCS for the period 1977–1998. The results of the estimated price equation show that the price of sugar has a positive and significant effect on the price of HFCS.

The above literature suggests that the relationship between the price of HFCS and the price of sugar is a relevant issue of the economics of HFCS. The capability of the HFCS industry to raise price to a level just below the price of sugar has been associated with

market power in the HFCS industry. Cointegration analysis, by estimating error correction models, has shown that the price of HFCS responds to deviations in the long-run equilibrium between HFCS and sugar prices, and that the prices of HFCS and sugar have moved together over some periods of time. However, the relevant studies have not developed an economic model that represents the response of the HFCS price to changes in the price of sugar nor have they estimated the change in the price of HFCS due to changes in the price of sugar.

It is likely that there is an HFCS price response to changes in the price of sugar, which can be represented by an HFCS price reaction model as suggested by the above literature. However, we did not find any study that developed an economic model and derived an HFCS price reaction function. The current paper contributes to the economics of HFCS by introducing a Bertrand duopoly model application and deriving an HFCS price reaction function that represents the response of the price of HFCS to changes in the price of sugar. In addition, it conducts cointegration analysis and assesses the performance of the HFCS price reaction model by estimating a DOLS model. This makes the current paper different from earlier studies, including cointegration analysis studies, that recognize the existence of an HFCS price reaction function but do not develop a model to derive it, nor do they estimate it.

4. Methodology

4.1. Economic model

There are several firms in the HFCS and sugar industries that use their respective prices to solve their profit maximization problems. However, the price of sugar can affect the profits of the representative HFCS firm. As suggested by Brendstrup et al.'s (2006) economic model, because the soft drink industry is the main buyer of HFCS, if the price of HFCS is above the price of sugar, the soft drink industry replaces HFCS with sugar and HFCS output is zero; however, if the price of HFCS is below the price of sugar, the soft drink industry chooses HFCS as a sweetener and HFCS output is positive. Consequently, the price of HFCS that maximizes profits is defined as $P_h \in (ATC_h, P_s]$, where P_h is the market price of HFCS, ATC_h is average total cost of HFCS, and P_s is the price of sugar. This implies that price is a strategic variable for these industries.

As suggested by LMC (LMC International, Ltd.) (1997) and Polopolus (1991), Evans and Davis (2002) consider the HFCS industry an oligopoly that sets the price of HFCS given the price of sugar. So, the Corn Refiners Association and its members can be considered a single firm that represents the HFCS industry. Then, to maximize profits, the HFCS industry must consider how the price of HFCS affects its output and how variations in the price of sugar affect HFCS output. Similarly, the Sugar Association and its members can be considered a single firm that uses the price of sugar to maximize its profits. Thus, a duopoly model can be used to represent the U.S. sweetener market as suggested by Moss and Schmitz (2002a).

The current paper uses a Bertrand duopoly model that assumes that price is the strategic variable. Brendstrup et al. (2006) assume an HFCS monopolist that has several identical plants that use the same technology and have the same marginal cost. Butler (1981) suggests that the differences in unit costs among HFCS producers would be small and their pricing strategy

very similar. Evans and Davis (2002) consider the HFCS industry an oligopoly that sets the price of HFCS given the price of sugar. Thus, the Bertrand duopoly model assumes that each firm in the HFCS industry is a single plant that belongs to an HFCS oligopolist and that each plant has the same average costs. Similarly, each firm in the sugar industry is considered a single plant that belongs to a sugar oligopolist, and average costs are considered the same across plants. The model also assumes that average total costs and marginal costs of HFCS are lower than average total costs and marginal costs of sugar, respectively. In addition, given that the price of sugar has been determined by the U.S. government price support program at levels above the world price of sugar and above HFCS production costs, HFCS has replaced sugar in those uses for which they are substitutes (Brendstrup et al., 2006). Moreover, HFCS producers set the price of HFCS as an oligopolistic industry and can adjust price within a given price range to maintain or increase market share (Evans & Davis, 2002). Therefore, given that the price of sugar is more than the price of HFCS, the HFCS oligopolist can set price of HFCS equal to the average cost of sugar and above average costs of HFCS to earn economic rent and supply a quantity of sweetener that the soft drink industry demands. This implies that price is a strategic factor for the HFCS and sugar industries and it is what the Bertrand model explains below.

Given the Bertrand duopoly model, one oligopolist produces HFCS and the other produces sugar, and they face a market demand $D(P)$. This market demand represents the soft drink manufacturer's demand for a sweetener. Froeb and Werden (1992) and Brendstrup et al. (2006) assume an HFCS monopolist, and Moss and Schmitz (2002a) argue they these markets could have been monopolies, and that the sweetener market could have been modelled as a duopoly. Cotterill (1998, 2001) suggests that the HFCS industry fixes price; (2004) suggest HFCS mark-up pricing even under different cointegrating relationships between HFCS and sugar prices; and Brendstrup et al. (2006) find that the HFCS industry has market power when controlling for the effect of sugar as substitute in the residual demand for HFCS only or for the effect of HFCS short-run capacity in the supply of HFCS only, but not when controlling for both the effects of sugar as substitute and the HFCS short-run capacity constraint.

Table 1 shows that average costs for HFCS are less than those of sugar, which supports our assumption that average total cost and marginal cost of HFCS are less than average total cost and marginal cost of sugar, respectively. Butler (1981) suggests that the differences in unit costs among HFCS producers would be small and their pricing strategy very similar. This can also be related to HFCS producers using the same technology that can be represented by a Leontief production function (Brendstrup et al., 2006). Additionally, HFCS and sugar are considered homogenous (perfect substitutes), so HFCS is a substitute for sugar in the manufacturing of soft drinks, and vice versa. Moss and Schmitz's (2002a) argue that, given perfect substitution, the HFCS price is lower than the raw and refined sugar prices.

Based on the relevant literature, the demand for HFCS can be specified as a residual demand. The residual demand can include demand shifters such as income (Froeb & Werden, 1992), or it can be specified as a quantity that depends on its own price only (Genesove & Mullin, 1998), or it can be specified as a quantity that depends on its own price and the price of a substitute only (Brendstrup et al., 2006). Following Brendstrup et al. (2006), we define a residual demand for an HFCS oligopolist as a function of the prices of HFCS and sugar only. The residual demand for HFCS can be specified as

$$d_h(P_h, P_s) = \begin{cases} D(P_h) & \text{if } P_h < P_s \\ D(P_h)/2 & \text{if } P_h = P_s \\ 0 & \text{if } P_h > P_s \end{cases} \quad (1)$$

where $d_h(P_h, P_s)$ is the residual demand for HFCS, P_h is the price of HFCS, and P_s is the price of sugar.

Equation (1) shows that the HFCS oligopolist can capture the entire market by setting a price of HFCS below the price of sugar. Similarly, the sugar oligopolist can capture the entire market by setting the price of sugar below the price of HFCS. However, the U.S. sugar program is based on price supports, domestic market allotments, and tariff-rate quotas that support the U.S. sugar price above the world sugar price (U.S. Department of Agriculture, Economic Research Service, 2020), and the Agricultural Act of 2014 guarantees minimum domestic sugar prices (Beghin & Elobeid, 2017). 2004 suggest that the U.S. sugar price support program allows for pricing HFCS with limited competition from sugar. Further, the HFCS price has been lower than the refined sugar price and has followed sugar price changes at a discount of 10 to 30 percent (Barry et al., 1990).

Given equation (1), a Nash equilibrium results where the HFCS firm sets the price of HFCS equal to the average cost of sugar ($P_h = AC_s$), while the price of sugar is greater than the price of HFCS ($P_h < P_s$). If this HFCS price yields positive profits for the HFCS firm, there is a Bertrand equilibrium (Varian (1992, 291–295) describes a similar case).

Next, we derive a price reaction function for the profit maximizing HFCS oligopolist. We define the residual demand for HFCS as $Q_h = f(P_s, P_h)$, where P_s is the price of sugar and P_h is the price of HFCS. It can also be written as

$$Q_h = aP_s - bP_h \quad (2)$$

where Q_h is quantity of HFCS, $a > 0$, and $b > 0$. Then, $\partial Q_h / \partial P_s > 0$ and $\partial Q_h / \partial P_h < 0$, so HFCS and sugar are substitutes. If $a = b$ and $P_s = P_h$, then $Q_h = 0$. If $a > b$ and $P_s > P_h$, then $Q_h > 0$. If $a < b$ and $P_s < P_h$, then $Q_h < 0$.

Given equation (2) and the prices of HFCS and sugar, the HFCS oligopolist's profits are defined as

$$\pi_h = P_h Q_h - TC[Q_h(P_s, P_h)] \quad (3)$$

where TC is total cost of HFCS.

The first-order conditions associated with maximizing equation (3) become

$$\frac{\partial \pi_h}{\partial P_h} = Q_h + P_h \left[\frac{\partial Q_h}{\partial P_h} + \frac{\partial Q_h}{\partial P_h} \times \frac{\partial P_h}{\partial P_s} \right] - \frac{\partial TC[Q_h(P_s, P_h)]}{\partial P_h} \times \frac{\partial Q_h}{\partial P_h} = 0 \quad (4)$$

Equation (4) is a conjectural variation model that shows how the HFCS price reacts to the sugar price. The part in brackets in the second term shows that the HFCS oligopolist is concerned with how its price affects its output and with how the price of sugar affects HFCS output through the price of HFCS. The derivative $\partial P_h / \partial P_s$ represents the price decisions (conjectures) of the HFCS oligopolist when the price of sugar changes. Thus, an increase in the price of sugar increases the price of HFCS. The derivative $\partial Q_h / \partial P_h$ implies that an increase (decrease) in the price of the HFCS decreases (increases) the quantity of HFCS. Then, the HFCS price range is defined as $P_h \in (ATC_h, P_s]$.

As in Froeb and Werden (1992) and Brendstrup et al. (2006), the price of sugar is considered exogenous because it has been mostly determined by the U.S. sugar program. Froeb and Werden (1992) argue that it is unlikely that the HFCS price affects the price of sugar, and based on Granger causality test, they do not find any HFCS price feedback into the sugar price. Additionally, Williams and Bessler (1997) fail to reject the null of weak exogeneity for the price of sugar and find that the price of HFCS does not have a long-run feedback on the price of sugar.

Equation (4) can be rewritten as

$$\frac{\partial \pi_h}{\partial P_h} = aP_s - (2b + a)P_h + bMC(Q_h) = 0 \quad (5)$$

Equation (5) yields equation (6) which is the HFCS oligopolist's price reaction function of the Bertrand Model. It shows that the HFCS price depends on the price of sugar and marginal cost of HFCS. It is the price that maximizes the HFCS oligopolist's profits given the price of sugar. That is

$$P_h = \frac{a}{(2b + a)} P_s + \frac{b}{(2b + a)} MC(Q_h) \quad (6)$$

Equation (6) suggests that when the market price of sugar increases, the price of HFCS increases by less than the increase in the price of sugar. Equation (6) is similar to Genesove and Mullin's (1998) price model for refined sugar, in which the price of refined sugar depends on variable costs and the price of raw sugar.

The derivative of equation (6) with respect to the price of sugar yields the conjectural variation of the HFCS oligopolist. That is,

$$\frac{dP_h}{dP_s} = \frac{a}{(2b + a)} \quad (7)$$

Equation (7) shows that the HFCS oligopolist increases its price by less than the increase in the price of sugar. Thus, the price of HFCS that maximizes profits is less than the price of sugar.

Based on equation (6), the price of HFCS depends on the price of sugar and its marginal costs. That is,

$$P_h = f(P_s, MC_h) \quad (8)$$

We modify the reduced form equation (8) to obtain

$$P_h = f(P_s, P_c) \quad (9)$$

where P_h is the price of HFCS, P_s is the price of wholesale refined beet sugar, and P_c is the price of corn (a proxy for costs of producing HFCS).

The econometric specification of equation (9) is given as

$$\ln P_{h,t} = \beta_0 + \beta_1 \ln P_{s,t} + \beta_2 \ln P_{c,t} + e_t \quad (10)$$

where the variables are defined above and e_t represents random shocks. Equation (10) is similar to the refined sugar price model estimated by Genesove and Mullin (1998), in which the price of refined sugar depends on variable costs and the price of raw sugar.

The current paper aims at assessing the long-run relationship between the prices of HFCS and sugar by using time-series data for the prices of HFCS, sugar, and corn. This requires considering the time-series properties of the price series to obtain reliable estimates of β_1 and β_2 , which we explain in the following sections. This is different from estimating a system of HFCS residual demand and supply models as in Brendstrup et al. (2006). Therefore, since we are interested in the relationship between the prices of HFCS and sugar, and not deriving the shape of the demand or supply curve, we do not include demand shifters in equation (10).

4.2. Data and econometric methodology

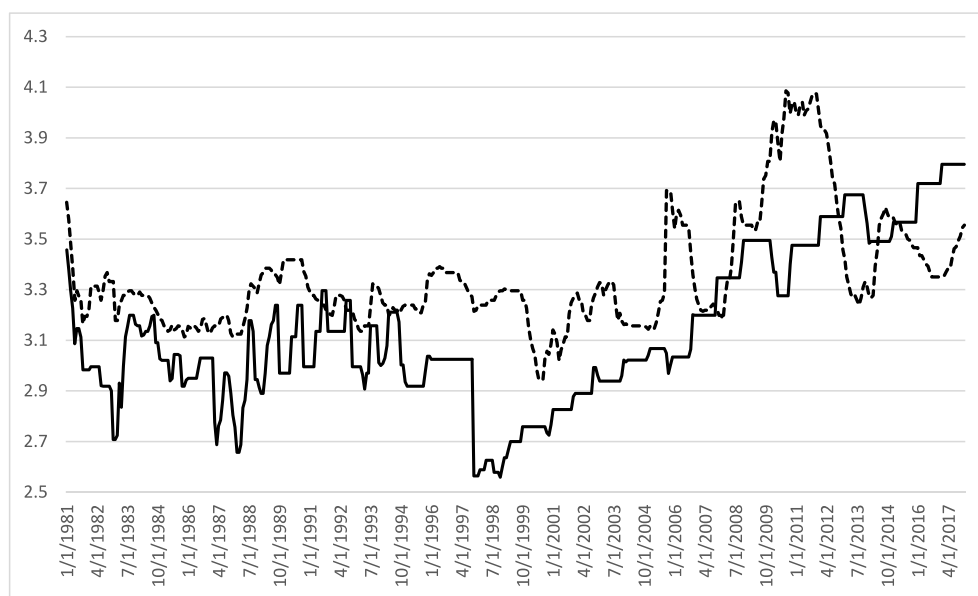
This paper uses monthly price data for HFCS-55, refined sugar, and corn for the period from 1981:1 to 2017:12. It uses the list price of HFCS-55 in cents per pound (dry weight), the wholesale price of refined beet sugar in cents per pound, and the price of corn in dollars per bushel. The data is obtained from the USDA/ERS. Data sources and variable definitions are in appendix A, and descriptive statistics are in appendix B.

We use the logarithms of the nominal price series as in Williams and Bessler (1997) and Moss and Schmitz's (2002a, 2002b, 202004) because deflating the price series changes the time-series properties of the original series. The deflated price series show a downward trend that does not exist in the original series.² Peterson and Tomek (2000) explain the implications of deflating and its effects on time-series analysis and suggest that forecasts of real prices that are negative are not rational.

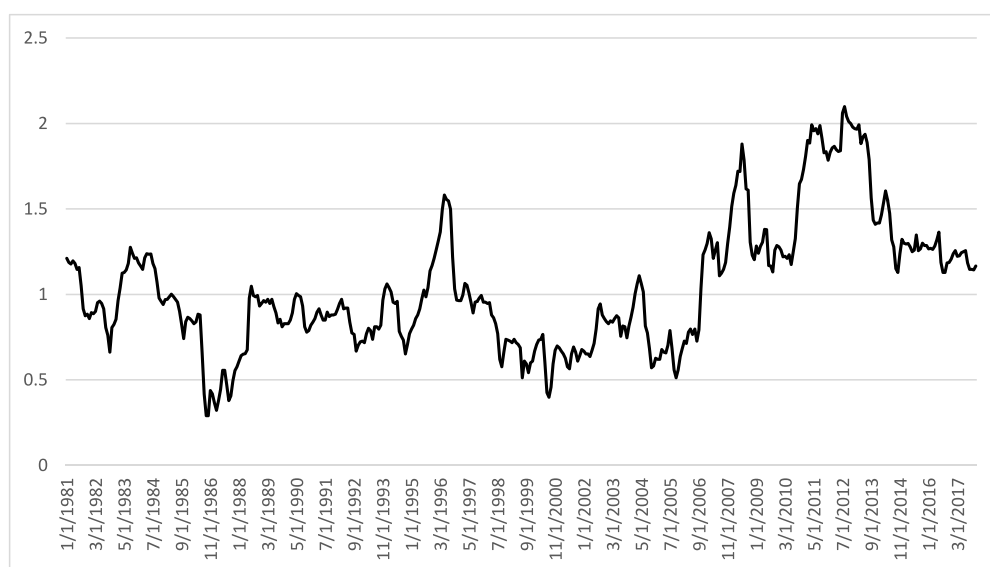
Figure 1 plots the logs of the prices of HFCS-55, refined sugar, and corn for the period 1981:01–2017:12. The log of the price of HFCS-55 decreased from August 1994 to November 1998. This is associated with a significant increase in HFCS production capacity between 1995 and 1997 and a U.S. HFCS consumption growth rate that was less than the growth rate of production capacity (Haley, Suarez, & Jerardo, 2004; Lord, Suarez, Salsgiver, & Napper, 1997). Figure 2 shows that the annual growth rate of total HFCS production (HFCS-42 plus HFCS-55) rises from 3.91 percent in 1995 to 6.37 percent in 1997. However, the growth rate of HFCS production decreases from 1998 onwards and it is negative for most of the years. This coincides with the increase in the price of HFCS-55 from November 1998 onwards and with increases in the price of corn, as shown in Figure 1. The increase in the price of HFCS-55 is also associated with rising costs of production of HFCS from 10.6 cents a pound in the period 1997/98–2001/02 to 22.9 cents a pound in the period 2010/11–2012/13, as shown in Table 1. Higher HFCS prices have been associated with higher corn prices (Haley & Dohlman, 2009; McConnell, 2016).

Figure 1 suggests that the series are nonstationary. The series may be integrated of an order higher than zero and differencing may be needed. To determine the order of integration of the series, we conduct the Augmented Dickey–Fuller (ADF), the Phillips–Perron (PP), and the Kwiatkowski, Phillips, Schmidt, and Shin (KPSS) unit root tests. The null hypotheses of the ADF and the PP tests are that the series has unit roots, while that of the KPSS test is that the series is stationary.

²Figure not included in the paper.



Log of the price of HFCS-55 (—) and log of the price of sugar (-----), 1981:01–2017:12



Log of the price of corn, 1981:01–2017:12

Figure 1. Plot of the time series ($\ln P_h$, $\ln P_s$, $\ln P_c$), 1981:01–2017:12.

The unit root tests suggest that the series are integrated of order one, or $I(1)$. Given this, OLS estimation of equation (10) would not be appropriate because of the spurious regression problem (Granger & Newbold, 1974). However, if P_h , P_s and P_c are cointegrated, then e_t in equation (10) is $I(0)$ (Lutkepohl, 2007, 301). Consequently, the OLS estimates of equation

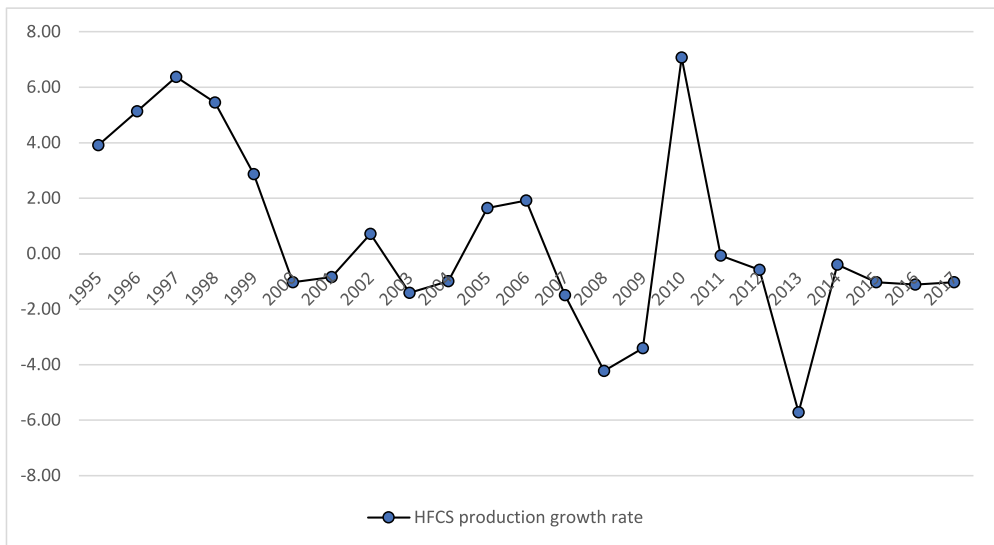


Figure 2. HFCS production annual growth rate, 1994–2017. Source: Authors' computations. Total HFCS is HFCS-42 plus HFCS-55. Growth rates for the period 1994–2003 are computed based on data from Table 6: U.S. high fructose corn syrup supply and use, calendar year of the Sugar and Sweeteners Outlook, May 2004. Growth rates for the period 1994–2003 are computed based on data from Table 29: U.S. high fructose corn syrup production, quarterly, by fiscal and calendar year of the Sugar and Sweeteners Yearbook Tables, USDA, ERS.

(10) are not only consistent, but they are superconsistent, because they converge to their true values at rate T , or the convergence rate in terms of order in probability is $(\hat{\beta} - \beta) = O_p(T^{-1})$ (Stock, 1987). This convergence rate is faster than $O_p(T^{-1/2})$, which is the convergence rate of most estimators for stationary time series (Hamilton, 1994, 460). The problem is that the OLS estimators have nonnormal limiting distributions (Stock, 1987). This issue is addressed by using the DOLS model developed by Stock and Watson (1993). This requires adding leads and lags of the first differences of the $I(1)$ variables to equation (10), so the OLS estimators become asymptotically normally distributed (Stock & Watson, 1993).

The next step is to test for the existence of a long-run relationship among P_h , P_s and P_c . The Johansen cointegration method (Johansen, 1995) identifies one cointegrated relationship among P_h , P_s and P_c . Based on this, the DOLS proposed by Stock and Watson (1993) is used to estimate equation (10). This allows for estimating long-run relationships between P_h and P_s and P_c .

5. Empirical analysis

5.1. Unit root tests

To results of the unit root tests are shown in Table 2. The ADF) the PP) and the Kwiatkowski, Phillips, Schmidt, and Shin (KPSS) tests suggest that the levels of the price series have unit root. However, the first differences of the series are stationary.³ The next section describes the cointegrating relationship among P_h , P_s , and P_c .

³The unit root tests do not include a deterministic trend, but inclusion of a deterministic yielded the same results.

5.2. Cointegration test

We apply the Johansen cointegration method (Johansen, 1995) to the price system to identify the cointegrated relationship among P_h , P_s and P_c . The method starts with an unrestricted vector autoregressive (VAR) process such as

$$y_t = c + \sum_{i=1}^{p-1} \Gamma_i \Delta y_{t-i} + \varepsilon_t \quad (11)$$

where $y_t = (y_{1t}, \dots, y_{nt})'$ is a $(k \times 1)$ vector that contains the $I(1)$ variables,⁴ c is a $(k \times 1)$ constant vector, Γ_i is a $(k \times k)$ coefficient matrix, and $\varepsilon_t = (\varepsilon_{1t}, \dots, \varepsilon_{nt})'$ is a $(k \times 1)$ white noise or innovation process such that $E(\varepsilon_t) = 0$ and $E(\varepsilon_t \varepsilon_t') = \Sigma$.

The vector error correction form of equation (10) is given as

$$\Delta y_t = c^* + \Pi y_{t-1} + \sum_{i=1}^{p-1} \Gamma_i^* \Delta y_{t-i} + \varepsilon_t \quad (12)$$

where the matrix $\Pi = \alpha\beta'$, α and β are $(k \times r)$ matrices, and Γ_i^* is a $(k \times k)$ coefficient matrix. The number of cointegrating relationships is given by the rank (r) of Π , which defines one of three different scenarios. Firstly, the variables in the vector y_t are $I(0)$ when Π is full rank, or $r = k$. Secondly, the first difference of the variables in the vector y_t are $I(0)$ when $r = 0$. Lastly, the number of cointegrating relations are given by $0 < r < k$, so that r represents the cointegrating relationships. Given the existence of at least one cointegrating relationship ($r = 1$) and the error correction term $\Pi y_{t-1} = \alpha\beta' y_{t-1}$, where β' is the cointegrating vector, $\beta' y_t$ gives the cointegrating relationship, and α represents the adjustment matrix that contains the adjustment coefficients that restore equilibrium. The cointegrating vector is stationary despite that the vector y_t is nonstationary.

To determine the number of cointegrating vectors in the price system, we use the trace statistic. The null hypothesis is that the number of cointegrating vectors (r) is equal to any number i such that $i = 0, \dots, k$, in which k is the number of series in the price system, while the alternative hypothesis is that $r > i$. To conduct the test, we determine the lag order of the VAR process based on the Akaike information, Hannan-Quinn, and Schwarz Bayesian criteria, so we include two lags. Table 3 shows the results of the

Table 2. Unit root tests: $LnPh$, $LnPs$, $LnPc$, 1981:1–2017:12.

Variable	ADF(τ)	PP(τ)	KPSS(η)	Result
<i>Levels</i>				
LnP_h	−1.50	−1.50	1.37***	$I(1)$
LnP_s	−1.99	−1.99	0.91***	$I(1)$
LnP_c	−1.98	−1.98	0.97***	$I(1)$
<i>First differences</i>				
ΔLnP_h	−18.56***	−18.56***	0.28	$I(0)$
ΔLnP_s	−14.78***	−14.78***	0.08	$I(0)$
ΔLnP_c	−14.44***	−14.44***	0.05	$I(0)$

Notes: ADF is the Augmented Dickey-Fuller test, PP is the Phillips-Perron test, and KPSS is the Kwiatkowski, Phillips, Schmidt, and Shin test. The null hypotheses for the ADF and PP tests are that the series are not stationary. The null hypothesis for the KPSS test is that the series is stationary. *** means significant at the 1 percent. The tests do not include a deterministic trend.

⁴In our case, $y_t = (P_{ht}, P_{st}, P_{ct})'$.

Table 3. Johansen trace test for cointegration: LnP_h, LnP_s, LnP_c .

Null hypothesis	Alternative hypothesis	Trace statistic	5 % critical value
$r = 0$	$r > 0$	44.80	34.80
$r = 1$	$r > 1$	16.33	19.99

cointegration test. The null hypothesis that there is one cointegrating relation in the price system cannot be rejected at the 5 percent level. Thus, LnP_h, LnP_s, LnP_c are cointegrated and there is a long-run relationship in this price system. The next section presents the estimation of the long-run relationships between P_h, P_s , and P_c .

5.3. Estimation of a price reaction model of the HFCS oligopolist

The model in [section 4.1](#) implies that the price of HFCS responds to changes in the price of sugar. Therefore, to estimate a price reaction of the HFCS oligopolist, we transform equation (10) into equation (13). This is a DOLS specification (Saikkonen, 1991; Stock & Watson, 1993). That is,

$$\begin{aligned}
 \ln Ph_t = & \beta_0 + \beta_1 \ln Ps_t + \beta_2 \ln Pc_t + \delta_1 D84 + \delta_2 DIc + \delta_3 DPi + \delta_4 D08 + \sum_{i=2}^{i=-2} \Phi_1 \Delta \ln Ps_{t+i} \\
 & + \sum_{i=2}^{i=-2} \Phi_2 \Delta \ln Pc_{t+i} + \varepsilon_t
 \end{aligned}
 \tag{13}$$

where Ph is the price of HFCS-55, Ps is the price of sugar, Pc is the price of corn, $D84$ is a dummy variable that takes the value of 1 from January 1984 onwards and zero otherwise, DIc is a dummy variable that captures the effect of HFCS increasing capacity on price and takes the value of 1 from August 1994 to November 1998 and zero otherwise, DPi is a dummy variable that captures the effect of HFCS-55 price increase after November 1998 and takes the value of 1 from November 1998 to December 2017 and zero otherwise, and $D08$ is dummy variable that captures the effect of the 2008–09 recession and takes the value of 1 from December 2007 to June 2009 and zero otherwise. The dummy $D84$ is included to control for the fact that soft drink manufacturers completely replaced sucrose with HFCS-55 in 1984 (Pendergrast, 1993). We also add monthly dummies to equation (13). β_1 and β_2 represent the responsiveness of the HFCS price to changes in the prices of sugar and corn. Φ_1 and Φ_2 are the parameters of the lead and lag differences of the prices of sugar and corn and are considered nuisance parameters. The nuisance parameters represent the short-run dynamics of the process (Stock & Watson, 1993). These parameters adjust for potential endogeneity, autocorrelation, and nonnormality of the residuals, so the estimates are consistent. The lag order used is the same as that of the cointegration test. Further, given this methodology, the estimates are valid even if some of the regressors in equation (13) are endogenous (see Saikkonen (1991) about the relationship between the DOLS estimator and instrumental variable estimators). Additionally, the DOLS estimator is asymptotically equivalent to the Johansen's (1995) maximum likelihood estimator (Herzer & Nowak-Lehmann, 2006).

To manage potential problems of autocorrelation, we estimate equation (12) as Dynamic Estimated Generalized Least Squares (DEGLS) (Griffiths, Hill, & Judge, 1993). The results of the DEGLS estimation are presented in Table 4. The p-values for the Portmanteau tests (Q) and Lagrange multiplier (LM) tests do not indicate heteroskedasticity and ARCH problems. The Durbin–Watson (DW) statistic for model 2 suggests that the residuals are positively correlated. However, for the other models the DW statistic is in between the DW 1 percent or 5 percent lower and upper bounds obtained from Savin and White (1977), so the test is inconclusive, and we do not reject the null of zero autocorrelation of the residuals.

Model 1 shows that the prices of sugar and corn have a highly significant effect on the price of HFCS-55. However, because Coca-Cola and Pepsi completely switched to a 100 percent use of HFCS-55 in soft drink manufacturing in 1984 (Pendergrast, 1993), model 2 controls for this effect by adding the dummy *D84*, but it is not significant. To control for HFCS increasing capacity, Model 3 adds the dummy *D1c*. This model shows that increasing capacity decreases the price of HFCS-55. To control for the effect of increases in price and costs of production of HFCS-55 from November 1998 to December 2017, model 4 adds the dummy *DPI*, which is positive and significant.⁵ Model 5 adds the dummy *D08* to control for the effect of the 2007–09 recession, but it is nonsignificant. Lastly, model 6 adds monthly dummies to control for seasonality. The main results are robust to the inclusion of important factors that can affect the relationship between the price of HFCS-55 and the prices of sugar and corn. In all cases, the price of sugar and corn have positive and significant effects on the price of HFCS-55.

The main discussion of the results is based on model 6. The estimate on the price of sugar represents the responsiveness of the HFCS price to changes in the price of sugar, so a - one percent increase in the price of sugar results in an average increase of 0.19 percent in the price of HFCS-55. Specifically, one standard deviation increase (7.92 cents) in the price of sugar relative to its average (29.30 cents) represents a 27 percent increase in the price of sugar, and it causes a 1.24 cent increase in the price of HFCS-55 ($0.27 \times 0.19 \times 24.14 = 1.24$ cents). Additionally, given that the period average price of HFCS-55 (24.14 cents) is less than the average price of sugar (29.30 cents), a 0.19 percent increase in the price of HFCS-55 in response to one percent increase in the price of sugar keeps the price of HFCS-55 below the price of sugar. Therefore, as suggested by the model in section 4.1, the results show that the HFCS oligopolist's response to changes in the price of sugar is to increase the price of HFCS-55 by less than the increase in the price of sugar.

The current paper's results are different from those of earlier cointegration analyses. Cointegration analysis, by estimating error correction models, has shown that the price of HFCS responds to deviations in the long-run equilibrium between HFCS and sugar prices, and that the prices of HFCS and sugar have moved together over some periods of time. However, it does not estimate the response of the price of HFCS to changes in the price of sugar. The current paper derives an HFCS price reaction model, conducts cointegration analysis, assesses the performance of the HFCS price reaction model by estimating a DOLS model, and estimates the response of the price of HFCS to changes in the price of sugar.

⁵Table 1 shows that average costs of production for HFCS increased from 1997/98 to 2012/13. This might have also been due to increases in the prices of other inputs different from corn.

Table 4. DEGLS estimation of the long-run relationships between LnP_h and LnP_s and LnP_c , 1981:1–2017:12.

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Constant	2.2240*** (8.44)	2.1880*** (8.26)	2.1017*** (8.28)	2.1744*** (8.57)	2.1541*** (8.53)	2.2060*** (8.53)
LnP_s	0.2191*** (2.79)	0.2238*** (2.87)	0.2356*** (3.11)	0.2066*** (2.71)	0.2088*** (2.75)	0.1870*** (2.40)
LnP_c	0.1882*** (3.97)	0.1813*** (3.86)	0.2210*** (4.81)	0.2089*** (4.55)	0.2196*** (4.75)	0.2361*** (4.94)
D84		0.0295 (0.59)	0.0415 (0.84)	0.0283 (0.57)	0.0315 (0.64)	0.0188 (0.38)
Dlc			−0.0687* (1.84)	−0.0572 (1.53)	−0.0565 (1.53)	−0.0527 (1.43)
DPI				0.0933** (2.19)	0.0916** (2.19)	0.0880** (2.09)
D08					−0.0182 (0.47)	−0.0037 (0.10)
Dm2-12						yes
R-Sq.	0.9675	0.9668	0.9654	0.9659	0.9666	0.9690
Obs.	439	439	439	439	439	439
DW	1.6626	1.5205	1.5878	1.6203	1.6303	1.6560
Q(1)	0.0097 (0.9215)	0.4106 (0.5217)	0.0706 (0.7905)	0.0488 (0.8252)	0.0179 (0.8935)	0.0048 (0.9446)
Q(2)		0.6064 (0.7385)				
Q(6)	0.4592 (0.9983)	1.0553 (0.9834)			0.4757 (0.9981)	0.4774 (0.9981)
Q(7)	0.6954 (0.9984)	1.2950 (0.9886)			0.6582 (0.9986)	0.8235 (0.9972)
Q(11)	1.5001 (0.9996)	2.1355 (0.9980)	1.3760 (0.9998)	1.6119 (0.9995)	1.4842 (0.9996)	1.6364 (0.9994)
LM(1)	0.0101 (0.9199)	0.4089 (0.5225)	0.0711 (0.7897)	0.0488 (0.8251)	0.0181 (0.8931)	0.0050 (0.9438)
LM(2)		0.6268 (0.7309)				
LM(6)	0.4440 (0.9985)	1.0904 (0.9820)			0.4611 (0.9983)	0.4730 (0.9982)
LM(7)	0.6769 (0.9985)	1.3410 (0.9873)			0.6411 (0.9987)	0.8177 (0.9973)
LM(11)	1.3970 (0.9997)	2.0778 (0.9982)	1.2970 (0.9998)	1.5024 (0.9996)	1.3774 (0.9997)	1.5653 (0.9995)
AR	(1, 6, 7, 11, 14)	(1, 2, 6, 7, 11, 14)	(1, 11, 14)	(1, 11, 14)	(1, 6, 7, 11, 14)	(1, 6, 7, 11, 14)
DW(dl, du) 1%	1.571; 1.779	1.561; 1.791	1.550; 1.801	1.539; 1.813	1.528; 1.824	1.462; 1.896
DW(dl, du) 5%	1.665; 1.874	1.654; 1.885	1.643; 1.896	1.632; 1.908	1.621; 1.919	1.554; 1.991

Notes: The dependent variable Ph is the price of HFCS-55. Ps is the wholesale price of beet refined sugar. Pc is the price of corn. Ln is the natural logarithm operator. Values in parentheses for the explanatory variables are t-values. Dm 2–12 represent monthly dummy variables. DW is the Durbin-Watson statistics. $Q(.)$ is Portmanteau statistic with p-values in parentheses. $LM(.)$ is the Lagrange statistic with p-values in parentheses. AR is the autoregressive order. $DW(dl, du)$ is the Durbin-Watson lower and upper bounds.

The results are related to Brendstrup et al.'s (2006) results on the assessment of market power in the HFCS industry while controlling for the effect of sugar as substitute without controlling for HFCS short-run capacity constraint. Their estimate on the price of sugar in the demand equation is positive and significant, and it affects the price of HFCS through the positive and significant estimate on the HFCS quantity in the supply equation. These results suggest that the HFCS industry has market power and that the government policy determined price of sugar allows for a higher price of HFCS. Also, the price of liquid corn starch, a proxy for marginal cost of HFCS, has a positive and significant effect on the

price of HFCS. The authors also claim that the estimates may be inconsistent due to lack of controlling for HFCS short-run capacity constraint. However, in the long-run, capacity constraint has no effect, while the price of sugar affects the price of HFCS. Brendstrup, Paarsch, and Solow's analysis that considers only the effect of sugar as substitute can be considered as a long-run case for the period 1980:1–2000:4. Given the results of the current paper and because the HFCS industry faces no constraint capacity in the long-run, note that the dummy *Dic* that proxies for increases in HFCS capacity is negative in all models and significant only in model 3, the HFCS industry can set a price of HFCS that is below the price of sugar and follows the behavior of the price of sugar. Thus, the current paper's results combined with Brendstrup et al.'s (2006) results offer important insights for anti-trust litigation.

The results also support the argument that the relatively lower costs of HFCS allowed the HFCS price to be below refined sugar prices and to follow sugar price changes at a discount of 10 to 30 percent (Barry et al., 1990). It also supports earlier research that finds that the price of HFCS responds to deviations in the long-run equilibrium price of sugar (Williams & Bessler, 1997), and that the price of sugar has a positive and significant effect on the price of HFCS (Evans & Davis, 2002).⁶ The results also support Moss and Schmitz's (2002a) contention that, given perfect substitution, the HFCS price is lower than the raw and refined sugar prices.

Regarding the relationship between the prices of HFCS and sugar, sugar deliveries in the United States have been greater than HFCS deliveries when the price of HFCS is higher than the price of sugar (Haley & Dohman, 2009). Also, HFCS deliveries have decreased when the competitiveness of the HFCS price relative to the price of sugar has decreased (McConnell, 2016). However, Lord (1995) argues that the price of HFCS-55 was set below the price of sugar to promote the replacement of sugar with HFCS-55 in soft drink manufacturing. Therefore, given our results, it may be beneficial for the HFCS industry to increase the price of HFCS-55 by less than the increase in the price of sugar, which may contribute to increasing HFCS-55 deliveries in the U.S. sweetener market.

The price of corn represents costs of production of HFCS. The estimate on the price of corn suggests that a one percent increase in the price of corn increases the price of HFCS-55 by 0.24 percent. This supports Froeb and Werden's (1992) results, who find that the HFCS price is highly responsive to changes in the price of corn. The dummy *DPI* is positive and significant and suggests that the price of HFCS-55 increased during the period from November 1998 to December 2017.

5.4. Estimation of an HFCS Price reaction model: robustness checks

To check for the robustness of the results, Table 5 presents DGLS estimations of the HFCS price reaction model for the period 1984:1 to 2017:12. This is because the soft drink manufacturers switched to 100 percent use of HFCS-55 in 1984 (Pendergrast, 1993). The sample size decreases to 403 observations. The results are qualitatively the same as those in Table 4 and the estimates on the prices of sugar and corn are positive and significant.

⁶However, the methodologies used in these studies are different from the one used in the current paper.

Table 5. DEGLS estimation of the long-run relationships between LnP_h and LnP_s and LnP_c , 1984:01–2017:12.

	Model 1	Model 2	Model 3	Model 4	Model 5
Constant	2.4673*** (9.18)	2.2769*** (8.91)	2.3387*** (9.18)	2.3301*** (9.15)	2.3787*** (9.15)
LnP_s	0.1561* (1.96)	0.2008*** (2.61)	0.1701** (2.20)	0.1716** (2.22)	0.1453* (1.84)
LnP_c	0.1699*** (3.52)	0.2087*** (4.50)	0.1956*** (4.22)	0.1995*** (4.27)	0.2258*** (4.70)
Dlc		−0.0678* (1.86)	−0.0561 (1.53)	−0.0564 (1.54)	−0.0499 (1.39)
DPI			0.0957** (2.26)	0.0960** (2.27)	0.0896** (2.15)
$D08$				−0.0173 (0.45)	−0.0027 (0.07)
$Dm1-11$					yes
R-Sq.	0.9713	0.9689	0.9694	0.9694	0.9726
Obs.	403	403	403	403	403
DW	1.6593	1.5449	1.5784	1.5765	1.5875
$Q(1)$	0.0001 (0.9929)	0.0223 (0.8813)	0.0087 (0.9256)	0.0099 (0.9207)	0.0085 (0.9263)
$Q(6)$	0.3879 (0.9989)				0.6870 (0.9948)
$Q(7)$	0.5002 (0.9994)				0.8474 (0.9969)
$Q(11)$	1.0040 (0.9999)	0.9908 (1.0000)	1.1512 (0.9999)	1.1322 (0.9999)	1.3951 (0.9997)
$LM(1)$	0.0001 (0.9914)	0.0227 (0.8802)	0.0091 (0.9238)	0.0104 (0.9189)	0.0079 (0.9292)
$LM(2)$					
$LM(6)$	0.3687 (0.9991)				0.6543 (0.9954)
$LM(7)$	0.4769 (0.9995)				0.8185 (0.9973)
$LM(11)$	0.9298 (1.0000)	0.9253 (1.0000)	1.0635 (0.9999)	1.0466 (0.9999)	1.3049 (0.9998)
AR	(1, 6, 7, 11, 14, 15)	(1, 11, 14)	(1, 11, 14)	(1, 11, 14)	(1, 6, 7, 11, 14)
$DW\ 1\%(dl, du)$	1.571; 1.779	1.561; 1.791	1.550; 1.801	1.539; 1.813	1.462; 1.896
$DW\ 5\%(dl, du)$	1.665; 1.874	1.654; 1.885	1.643; 1.896	1.632; 1.908	1.554; 1.991

Notes: The dependent variable Ph is the price of HFCS-55. Ps is the wholesale price of beet refined sugar. Pc is the price of corn. Ln is the natural logarithm operator. Values in parentheses for the explanatory variables are t-values. $Dm\ 2-12$ represent monthly dummy variables. DW is the Durbin-Watson statistics. $Q(.)$ is Portmanteau statistic with p-values in parentheses. $LM(.)$ is the Lagrange statistic with p-values in parentheses. AR is the autoregressive order. $DW(dl, du)$ is the Durbin-Watson lower and upper bounds.

6. Conclusion

This paper uses a Bertrand duopoly model application and derives an HFCS price reaction function that shows the response of the price of HFCS to changes in the price of sugar. It conducts cointegration analysis and assesses the performance of the HFCS price reaction model by estimating a DOLS model. It finds that the prices of HFCS-55, sugar, and corn are cointegrated over the period 1981:1 to 2017:12. The main results, based on the estimated long-run relationship between the prices of HFCS-55 and sugar, show that a one percent increase in the price of sugar increases the price of HFCS-55 by 0.19 percent. Given that the period average price of HFCS-55 (24.14 cents) is less than the average price of sugar (29.30 cents), a 0.19 percent increase in the price of HFCS-55 in response to one percent increase in the price of

sugar keeps the price of HFCS-55 below the price of sugar. The finding that the HFCS oligopolist increases the price of HFCS-55 by less than the increase in the price of sugar can be combined with Brendstrup et al.'s (2006) results on market power in the HFCS industry to offer important insights for anti-trust litigation. The results also support earlier findings that show that the price of sugar is an important determinant of the HFCS price (Evans & Davis, 2002; Williams & Bessler, 1997), and the argument that the relatively lower costs of HFCS allowed the HFCS price to be below refined sugar prices and to follow sugar price changes at a discount of 10 to 30 percent (Barry et al., 1990). Additionally, the costs of production, proxied by the price of corn, positively affect the price of HFCS-55.

Based on the results of this paper and the average prices of HFCS-55 and sugar, the HFCS industry may benefit from increasing the price of HFCS-55 by less than the increase in the price of sugar, which may contribute to increasing HFCS-55 deliveries in the United States. These findings also indicate that the price of HFCS is positively impacted by the U.S. government support of sugar and have political economic implications for the U.S. sugar program. Additionally, the results of this paper can contribute to future studies that focus on price relationships between HFCS and sugar, as well as other interdependent industries. Given that this analysis uses the list price of HFCS-55, which is greater than its corresponding spot price, it would be interesting to replicate the analysis once the spot price data become available.

Disclaimer

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Appendix A. 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: U.S. prices for high fructose corn syrup (HFCS), Midwest markets, monthly, quarterly, and by calendar and fiscal year. 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
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: U.S. wholesale refined beet sugar price, Midwest markets, monthly, quarterly, and by calendar and fiscal year. Accessed at http://www.ers.usda.gov/data-products/sugar-and-sweeteners-yearbook-tables.aspx

Appendix B. Descriptive statistics, 1981:1-2017:12

Variable			Std Dev	Std Dev	Maximum
HFCS price (cents/pound)	444	24.14	7.76	12.92	44.48
Sugar price (cents/pound)	444	29.30	7.92	19.00	59.50
Corn price (dollars/bushel)	444	3.04	1.35	1.34	8.15