Testing for Speculative Behavior in US Corn Ethanol Investments

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1. Introduction

US corn ethanol industry saw remarkable growth during 2000s. The installed capacity increased from 1.7 billion gallons in 1999 to 13 billion gallons in 2009 (figure 1).[1] The installed capacity increased steadily due to growing (mandated) demand, initially due to low corn prices, and subsequently due to rising crude oil prices which resulted in higher ethanol profitability. Not withstanding these factors, the idled capacity jumped up in 2008-09 reaching as high as 3.2 billion gallons or 26% of the installed capacity due to rapid expansion in the installed capacity coupled with a sudden contraction of crude oil prices. The widespread expansion of installed capacity during 2004-08 followed by a large scale idling in 2008-09 raise two important questions about ethanol industry: whether the speculative pricing of crude oil contributed to speculative capacity addition in US corn ethanol industry? If so, how much of that installed capacity was actually warranted by the market factors and how much could be attributed to speculative investment?

To answer these questions, the presence of speculative bubbles in corn ethanol investments must be checked. If a speculative bubble were present at industry level, the installed capacity may be divided into two components: (i) installed capacity that can be supported by *market fundamentals*, i.e. based on factors such as expected crude oil prices, corn input prices, processing costs and government support; and (ii) installed capacity that may be unwarranted by the market factors showing a systematic explosive pattern termed as *speculative bubble* (Flood and Garber, 1980).

The speculative bubble considered here with respect to corn ethanol investment differs from speculation in crude oil prices. This study assumes speculation in crude oil prices pre-existed over the past decade (Eckaus, 2008; Hamilton, 2009). Moreover, relative differences in the size of crude oil and ethanol markets is such that ethanol prices did not have the ability to influence crude oil prices. Even if a speculative pricing bubble in crude oil prices did not exist, it would already be reflected in the market prices of ethanol because they are linked to crude oil prices based on energy content. Therefore, crude oil price speculation is not the focus of this study. It is speculative behavior with regard to added capacity of ethanol industry – that is affected by crude oil prices and of interest in this study.[2] The main objectives of this paper are to test for and quantify speculative activity in corn ethanol investment.

This paper uses a rational expectations model (with perfect foresight) to study a system of supply, demand, inventory and price expectations for ethanol (Muth, 1961). Rational prices predicted using this system help determine the capacity of corn ethanol plants supported solely by market fundamental factors. Alternatively, the price expectation can be modified to include new variables which can potentially capture any speculative activity that underlay ethanol industry investments. These new variables are

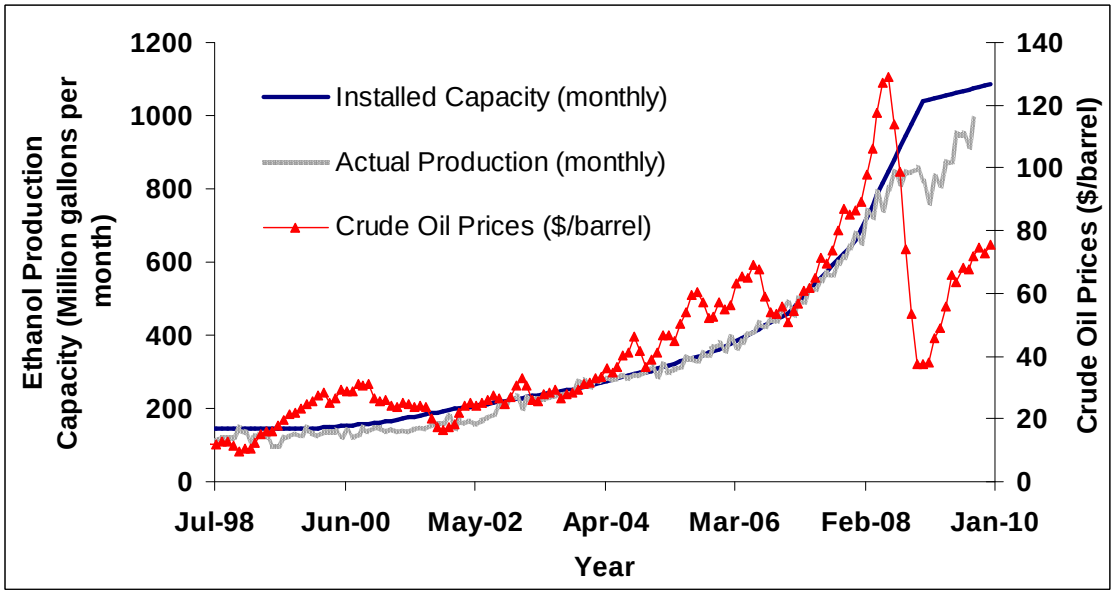
[1] with an average capacity utilization (defined as the ratio of actual production to installed capacity) of 84%. The average capacity utilization reached a high of 93% in 2004, but has been declining steadily. In 2008, it reached an all time low of 74%

[2] The ethanol industry may have expanded on the expectation (or speculation) that favorable market conditions – high crude oil prices, low corn (input) prices or both – would last very long in the future.

computed based on the demand and supply parameters through cross equation restrictions as suggested in Flood and Garber (1980) and Sargent (1987).

The speculative component, if any, is specified as the difference between capacity warranted by the market fundamentals and actual installed capacity. Testing for this residual speculative portion is an essential step to estimate speculative investment in corn ethanol industry. Flood and Garber suggested that there could be evidence for speculative behavior when either of the following two conditions are possible: 1) either the estimated coefficient associated with the new variable is statistically significant or 2) the new installed capacity attributed to speculative investment depicts a nonstationary (actually, explosive time series) pattern. Section 2 contains literature review on speculative bubbles, ways to apply it to ethanol investments and econometric estimation issues. Section 3 proposes three alternative approaches to test for speculation which also provide a means to compare results from different procedures.[3]

Figure 1: Growth in US corn ethanol industry



Source: Ethanol RFA, EIA

2. Literature Review:

A substantial rise and fall in prices (or unusually high volumes of trading by speculators) usually raises the suspicion of speculative behavior. Such speculative bubbles are often linked with booms and busts in stocks prices, financial asset prices, and exchange rates (Hong, et al., 2006; Wu, 1997). Among commodities, speculative bubbles are frequently associated with crude oil prices. The US Senate staff report (2006) found evidence for speculation in energy commodities in mid-2000s; other studies have also argued that the dramatic rise and fall in crude oil prices during 2008-09 might have speculative components (Eckaus, 2008; Hamilton, 2009). These studies, among others, present evidence for speculative activity in crude oil pricing, but their impact on corn ethanol investment is unknown.

[3] Detailed empirical results are available from authors.

There is evidence that volatility and price movements spilled over from crude oil to agricultural commodities markets. Recently, Du, et al. (2009) found that crude oil price volatility spilled over into corn price volatility due to 'tighter interconnection' between energy and feedgrains markets with the large scale use of corn for ethanol production in the US. They also showed that there was a speculative component in crude oil pricing behavior. (Harri, et al., 2009) found weak evidence for long run cointegrating price relationships between crude oil prices, exchange rates and corn prices. Although these are pieces of evidence for crude oil price volatility spilling over to agricultural markets, Irwin et al (2009) argued that there was no speculation in agricultural commodities independent of crude oil markets. They suggested that price movements in agricultural commodities were simply a response to crude oil price movements and not a speculative behavior themselves. The implication of their results is that agricultural commodity prices were affected by crude oil prices, possibly including corn ethanol prices, but not vice-versa. Hence, crude oil prices will be one of the main factors to differentiate the investment arising out of speculative behavior from that supported by the market fundamentals. To incorporate the impacts of crude oil prices, a supply-demand model of corn ethanol is required.

Irrespective of the asset type (financial or physical assets), reliable models are necessary to explain the pricing patterns (Brooks and Katsaris, 2003; Hassan and Suk-Yu, 2007). The methods used to test for speculative bubbles in financial assets are not directly applicable to test for speculative investment in the physical assets such as ethanol plants, because the installed capacity did not rise and fall as it happened in financial asset or crude oil prices. In the context of physical assets such as corn ethanol plants, a supply-demand model that can explain ethanol price expectations and tie those expectations with the installed capacity can prove useful. Consequently Muth's rational expectations model on explaining price movements in commodities can serve as the required useful model in this analysis.

Rational expectations theory is frequently associated with the identification of speculative behavior (Blanchard, 1979). Muth's (1961) seminal paper on rational expectations and price movements deals with such a system for commodities. It also discusses how commodity markets can result in speculative behavior when storage is possible. To study possible speculative investment in ethanol industry, his model has to be used in conjunction with other procedures. These procedures include econometric testing for speculation using tests such as bubble premium tests, and cointegration tests (Brooks and Katsaris, 2003; Hassan and Suk-Yu, 2007). The bubble premium tests can be reinterpreted as the study of idled capacity in ethanol industry; the cointegration tests can be reinterpreted as the study of long run relationship between idled ethanol capacity and crude oil prices. Irrespective of the method, Muth's model remains fundamental to all types of testing conducted in this study.

Muth's model presents a system of equations for commodity supply, demand, inventory changes and price movements predicted using rational expectations. The rational prices for the commodity is proved to be a second order difference equation (see equation (10) below). Sargent showed that solving such a second order difference equation introduced two new variables. (Flood and Garber, 1980) proposed that such variables and associated parameter estimates can provide information about the speculative behavior in pricing pattern; their illustration was based on testing for speculative behavior in money

supply and inflation. Flood and Garber employed cross equation restrictions to estimate these new variables. This study employs similar restrictions in the context of Muth's commodity pricing model applied to ethanol supply and demand systems. These restrictions are explained in detail in Sargent (1987).

The methodological novelty of this study is that it combines the tests proposed by (Flood and Garber, 1980) with Muth's model for commodity pricing pattern and test for speculation in corn ethanol investments. If the estimated coefficients associated with these variables are significant, then it may serve as an evidence for speculative investments in corn ethanol industry. This study uses multivariate GARCH estimation technique to estimate the system of ethanol supply-demand-inventory, to account for the heteroskedastic volatility in crude oil prices and ethanol prices. The econometric implementation of this procedure can be difficult because one of the new variables is explosive (i.e. its value approaches infinity over time) as a regressor. This problem is described below along with two alternative methods that can overcome the problem.

The basic method adopted in this study uses a combination of approaches advanced in Muth (mathematical derivations in Sargent), and Flood and Garber. Starting with the system of demand-supply-inventory equations this study derives price expectations for ethanol based on rationality (or quasi-rationality). Sargent shows that such an equation introduces two new variables in the price expectations equation for ethanol. These two variables are λ_1^t and λ_2^t, where λ_1 and λ_2 are roots of the characteristic equation associated with the second order difference equation; t indicates time period. As Muth states, one of the roots will be less than unity in value (p 326). Sargent shows that these roots will be real and inverse of each other (i.e. $\lambda_1 = 1/\lambda_2$). Without loss of generality, assume that $|\lambda_1| < 1$ and $|\lambda_2| > 1$ with the associated parameters c_1 and c_2. As $t \rightarrow \infty$, one root vanishes ($c_1\lambda_1^t \rightarrow 0$ as $t \rightarrow \infty$, since $|\lambda_1| < 1$) and the other root ($c_2\lambda_2^t \rightarrow \infty$ as $t \rightarrow \infty$, since $|\lambda_2| > 1$) approaches infinity. Muth restricts both c_1 and c_2 to zeroes to avoid any explosive behavior in price expectations. But, the Flood and Garber approach suggests that c_2 may be estimated and tested for significance. Their method is implemented by including the two new variables $[c_1 \lambda_1^t]$ and $[c_2 \lambda_2^t]$ as part of the estimation procedure. As shown below, λ_1 and λ_2 are dependent on supply-demand system parameters and implemented as cross equation restrictions. If the estimated coefficient for c_2 is statistically significant, then it is a probable evidence for speculative price expectation within ethanol industry which could have affected ethanol investments. The difficulty with this procedure is in estimating c_2 reliably because λ_2^t explodes over time.

Alternative Methods:

An alternative technique to overcome estimating c_2 is to test the idled capacity of ethanol plants. Modeling the installed or idled capacity in conjunction with ethanol prices under rational expectations can provide a basis to test for speculative investment in corn ethanol plants. This is similar to testing for cointegration between idled capacity and ethanol (crude oil) prices. Another method that overcomes estimation problems is a slight variant of the basic method. First, the coefficients of new variables (c_1 and c_2) are suppressed to zero as done by Muth. Next, price expectations are estimated based purely on market fundamentals; omitting the possible speculation on ethanol prices. Finally, this price equation is used to predict the capacity that would have been supported by market fundamentals. Subtracting the predicted ethanol capacity from actual installed capacity

defines the speculative component. The resultant series can then be tested for stationarity. If it is nonstationary or if there is a pattern that persists over time, it can be taken as an evidence for speculative behavior in corn ethanol industry.

3. Model A

The Muth's model which is considered as basic is described below. The exposition closely follows Sargent (1987).

Ethanol Demand:
Let the demand for ethanol be
(1) $C_t = -\beta P_t + D_t$

C_t = monthly demand for corn ethanol at time t (million gallons)
P_t = actual market price of ethanol ($/gallon)
D_t = other factors that affect demand (growth in energy use, GDP, etc)
$\beta > 0$

There is an extra term D_t which is the only variation in this model compared to Sargent.

Ethanol Supply:
Let the supply for ethanol be

(2) $Y_t = \gamma \mathbf{P}_t + X_t$

Y_t = monthly supply of corn ethanol at time t (million gallons)
$\mathbf{P}_t$ = price expectation of ethanol
X_t = factors that affect supply (installed capacity, inputs, processing technology)

Inventory:
Let the inventory maintained for ethanol be

(3) $I_t = \alpha (\mathbf{P}_{t+1} - P_t)$

I_t = Demand from inventory
$\alpha > 0$, depends on the variance of ethanol prices

Market Clearing Condition:
(4) $Y_t = C_t + (I_t - I_{t-1})$

Substituting (1), (2) and (3) in (4) gives
(5) $\gamma \mathbf{P}_t + X_t = -\beta P_t + D_t + \alpha (\mathbf{P}_{t+1} - P_t) - \alpha (\mathbf{P}_t - P_{t-1})$

Muth assumed perfect foresight rational expectations, which yielded $\mathbf{P}_t = P_t$ (an alternate assumption could be to use quasi-rational expectations and replace $\mathbf{P}_t$ with a functional representation that includes P_t).

Substituting $\mathbf{P}_t = P_t$ in (5)

(6) $X_t - D_t = -\beta P_t + \alpha (P_{t+1} - P_t) - \alpha (P_t - P_{t-1}) - \gamma P_t$

Or

(7) $\alpha P_{t+1} - [(2\alpha + \beta + \gamma)] P_t + \alpha P_{t-1} = X_t - D_t$

Or

(8) $P_{t+1} - \phi P_t + P_{t-1} = (X_t - D_t) / \alpha$, where $\phi = (2\alpha + \beta + \gamma)/ \alpha = (\beta + \gamma)/ \alpha + 2$

Stepping back by one period,

(9) $P_t - \phi P_{t-1} + \alpha P_{t-2} = (X_{t-1} - D_{t-1}) / \alpha$

This is the second order difference equation:

(10) $(1 - \phi L + L^2) P_t = (X_{t-1} - D_{t-1}) / \alpha$ where L = lag operator

Factoring the polynomial in lags in LHS:

(11) $(1 - \phi L + L^2) = (1 - \lambda_1 L) (1 - \lambda_2 L) = 1 - (\lambda_1 + \lambda_2) L + \lambda_1 \lambda_2 L^2$

Equating coefficients of (11) with (10), we get

(12) $(\lambda_1 + \lambda_2) = \phi = (\beta + \gamma)/ \alpha + 2$

(13) $\lambda_1 \lambda_2 = 1 \rightarrow \lambda_1 = 1/\lambda_2$

(note that if one root is less than unity, the other will be greater than unity)

Substituting (13) in (10):

(14) $(1 - \lambda_1 L) (1 - \lambda_2 L) P_t = (X_{t-1} - D_{t-1}) / \alpha$

Or

(15) $P_t = [1/(\alpha \ (1 - \lambda_1 L) (1 - \lambda_2 L))] (X_{t-1} - D_{t-1}) + c_1 \lambda_1^t + c_2 \lambda_2^t$

(16) $P_t = \alpha^{-1} [(1 - \lambda_1 L) (1 - \lambda_2 L)]^{-1} (X_{t-1} - D_{t-1}) + c_1 \lambda_1^t + c_2 \lambda_2^t$

where c_1 and c_2 are two arbitrary constants. Without loss of generality, assume $|\lambda_1| < 1$ and $|\lambda_2| > 1$.If the coefficient c_2 (corresponding to λ_2) is statistically significant, then we may conclude that there was speculative behavior in ethanol industry. The lag terms in (15) are substituted with their standard expressions as following (See Sargent, page 199):

Since $\lambda_1 \neq \lambda_2$, the term $[(1 - \lambda_1 L) (1 - \lambda_2 L)]^{-1}$ in (16) can be replaced by the following term (Sargent, page 184)

$$(17)\ [(1 - \lambda_1 L) (1 - \lambda_2 L)]^{-1} = \frac{1}{(\lambda_1 - \lambda_2)} \left[\frac{\lambda_1}{(1 - \lambda_1 L)} - \frac{\lambda_2}{(1 - \lambda_2 L)} \right]$$

Substituting (17) in (16):

(18) $P_t = \alpha^{-1} [1/(\lambda_1 - \lambda_2)] [\lambda_1/(1- \lambda_1 L) - \lambda_2/(1- \lambda_2 L)] (X_{t-1} - D_{t-1}) + c_1 \lambda_1^t + c_2 \lambda_2^t$

$= A + B + c_1 \lambda_1^t + c_2 \lambda_2^t$

Where $A = [\alpha^{-1} \lambda_1/(\lambda_1 - \lambda_2)] [1/(1- \lambda_1 L)] (X_{t-1} - D_{t-1})$

$= [\alpha^{-1} /(\lambda_1 - \lambda_2)] \sum_{i=1}^{\infty} \lambda_1^i (X_{t-i} - D_{t-i})$

and

$B = [\alpha^{-1} \lambda_2/(\lambda_1 - \lambda_2)] [1/(1- \lambda_2 L)] (X_{t-1} - D_{t-1})$

$= [\alpha^{-1} \lambda_2/(\lambda_1 - \lambda_2)] (- 1) [(\lambda_2 L)^{-1}/(1- \lambda_2^{-1} L^{-1})] (X_{t-1} - D_{t-1})$

$= - [\alpha^{-1} \lambda_1^{-1}/(\lambda_1 - \lambda_2)] [\lambda_1 L^{-1}/1- \lambda_1 L^{-1}] (X_{t-1} - D_{t-1})$

$= - [\alpha^{-1} /(\lambda_1 - \lambda_2)] [L^{-1}/1- \lambda_1 L^{-1}] (X_{t-1} - D_{t-1})$

$= - [\alpha^{-1} /(\lambda_1 - \lambda_2)] [1/1- \lambda_1 L^{-1}] (X_t - D_t)$

$= - [\alpha^{-1} /(\lambda_1 - \lambda_2)] \sum_{i=0}^{\infty} \lambda_1^i (X_{t+i} - D_{t+i})$

Substituting the expressions for A and B in (18)

$P_t = [\alpha^{-1} /(\lambda_1 - \lambda_2)] \sum_{i=1}^{\infty} \lambda_1^i (X_{t-i} - D_{t-i}) - (-1) [\alpha^{-1} /(\lambda_1 - \lambda_2)] \sum_{i=0}^{\infty} \lambda_1^i (X_{t+i} - D_{t+i}) + c_1 \lambda_1^t + c_2 \lambda_2^t$

$= [\alpha^{-1} /(\lambda_1 - \lambda_2)] \sum_{i=1}^{\infty} \lambda_1^i (X_{t-i} - D_{t-i}) + [\alpha^{-1} /(\lambda_1 - \lambda_2)] \sum_{i=0}^{\infty} \lambda_1^i (X_{t+i} - D_{t+i}) + c_1 \lambda_1^t + c_2 \lambda_2^t$

$= [\alpha^{-1} /(\lambda_1 - \lambda_2)] \sum_{i=-\infty}^{\infty} \lambda_1^{|i|} (X_{t-i} - D_{t-i}) + c_1 \lambda_1^t + c_2 \lambda_2^t$

Flood and Garber (1981) suggested autoregressive processes (of X_t and D_t) to approximate the infinite summation in the above expression. This method could capture the economic 'process' that connects supply and demand parameters with the price expectation. The order of the autoregressive process is chosen based on the time series properties of X_t and D_t. Upon finalizing a functional form for the first term in the above expression, c_2 (associated with $|\lambda_2| > 1$) can be estimated and if it is statistically significant, then we may conclude there was speculative production. The systems estimation procedure available with Eviews software can be used to estimate supply-demand-inventory-price expectations equations. Since volatility clustering (a form of heteroskedasticity) prevalent in crude oil prices spills over to ethanol prices as well, the proposed systems estimation could be done using (multi-variate) GARCH estimation procedure. More importantly, the restrictions (13) and (19) are imposed as part of the estimation procedure.

$\lambda_1 + \lambda_2 = \lambda + 1/\lambda = \phi$
i.e.
$\lambda^2 - \phi\,\lambda + 1 = 0 \rightarrow$

$\lambda = [\phi - (\sqrt{\phi^2}-4)]/2$
OR
$\lambda = [\phi + (\sqrt{\phi^2}-4)]/2$

where
(19) $\phi = (\beta + \gamma)/\ \alpha + 2$

Note that the roots λ_1 and λ_2 are dependent on parameters that affect supply and demand elasticities (α, β, γ). This model helps analyze whether ethanol markets (demand and supply) can be fully explained using market fundamentals such as the prices of ethanol, crude oil and government mandates or is there some unexplained speculative behavior captured by c_2. After estimation, *prices* can be forecast based on the estimated equation by suppressing c_1 and c_2 (i.e. price estimated after removing the speculative demand arising from inventory). Plugging the forecast price in the supply equation (2), we can predict what the supply (not the installed capacity) would have been in the absence of speculation. The impact of speculation on ethanol industry's installed capacity can be included with the above system by including another equation that connects price expectation with the installed capacity (model B).

Model B:

Assume that Q_t is the cumulative demand for corn ethanol plants (say, number of plants or name-plate capacity) at time t. Let it depend on the existing capacity (Q_{t-1}) and future anticipated demand (denoted by the function $F(\mathbf{P}_{t+1}; X_t)$ where $\mathbf{P}_{t+1}$ is the expected price of ethanol in period t+1) with the weights being θ, $0 \leq \theta \leq 1$.

i.e.
(B1) $Q_t = \theta\, Q_{t-1} + (1- \theta)\, F(\mathbf{P}_{t+1}; X_t)$;

Rearranging using the lag operator:
(B2) $(1- \theta L)\, Q_t = (1- \theta)\, F(\mathbf{P}_{t+1}; X_t)$
Or
(B3) $Q_t = (1- \theta L)^{-1}\, (1- \theta)\, F(\mathbf{P}_{t+1}; X_t)$

Let the supply of ethanol be
(B4) $S_t = \Omega\, Q_t + G(\mathbf{P}_t)$ where Ω = average capacity utilization of corn ethanol plants and G(.) is the ethanol price expectation for period t. Ω varied from 0.73 to 0.93; if $\Omega > 1$, then the ethanol plants are operated above the name-plate capacity.

Substitute (B3) in (B4):
(B5) $S_t = \Omega\, (1- \theta L)^{-1}\, (1- \theta)\, F(\mathbf{P}_{t+1}; X_t) + G(\mathbf{P}_t)$

Since, (1- θ) is constant in (85), it can be written as:
(86) $S_t = \Omega (1- \theta) (1- \theta L)^{-1} F(P_{t+1}; X_t) + G(P_t)$

Under rational expectations model under perfect foresight to predict ethanol prices (similar to above model), this becomes
(87) $S_t = \Omega (1- \theta) (1- \theta L)^{-1} F(P_{t+1}; X_t) + G(P_t)$

Multiplying and dividing the first term in (87) by $[- (\theta L)^{-1}]$:

$S_t = \Omega (1- \theta) [- (\theta L)^{-1}/- (\theta L)^{-1}] (1- \theta L)^{-1} F(P_{t+1}; X_t) + G(P_t)$

$= \Omega ((\theta-1)/ \theta) [1/(1- \theta^{-1}L^{-1})] [L^{-1}] F(P_{t+1}; X_t) + G(P_t)$

$= \Omega ((\theta-1)/ \theta) [1/(1- \theta^{-1}L^{-1})] F(P_{t+2}; X_t) + G(P_t)$

Since $\theta < 1$, $\theta^{-1} > 1$,

$= \Omega ((\theta-1)/ \theta) (-1) \sum_{i=1}^{\infty} \theta^{-i} L^{-i} F(P_{t+2}; X_t) + G(P_t) + c_3 \theta^{-t}$

where c_3 is an arbitrary constant; if c_3 were statistically significant, then it would correspond to speculative production S_t; also note that θ^{-t} explodes as $t \rightarrow \infty$, if $0 < \theta < 1$

$= \Omega ((1-\theta)/ \theta) \sum_{i=1}^{\infty} \theta^{-i} L^{-i} F(P_{t+2}; X_t) + G(P_t) + c_3 \theta^{-t}$

$= \Omega ((1-\theta)/ \theta) \sum_{i=1}^{\infty} \theta^{-i} F(P_{t+2-i}; X_{t-i}) + G(P_t) + c_3 \theta^{-t}$

Although this is a forward-looking solution, it can be approximated using an auto-regressive process of the function F(.) and factors that affect supply G(.), as suggested by Flood and Garber.

Summary:
Crude oil price speculation could have increased installed capacity in corn ethanol plants beyond what was warranted by the market factors. The above discussion proposed using Muth's commodity pricing model and Flood and Garber's tests to test for speculative investment in US corn ethanol industry. The ethanol prices predicted using rational expectations (perfect foresight) are used to differentiate the installed capacity into two: capacity supported by the market fundamentals and the capacity that is installed based on speculation. The econometric estimation procedures and functional form approximations discussed above will be implemented using monthly data from 1999-2009 to test for possible speculative behavior in ethanol industry. The empirical results are available with the authors.

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