Flex-Fuel Vehicle Adoption and Dynamics of Ethanol Price: Lessons from Brazil and Implications for the United States

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Motivation

THE FEDERAL GOVERNMENT has set ambitious targets in the Renewable Fuel Standard for increasing consumption of renewable fuels. However, large displacements of gasoline by ethanol will critically depend on the development and adoption of a higher-percentage ethanol-gasoline blend (85% ethanol or E85), which can only be used in flex-fuel vehicles (FFVs) (Corts 2010). Brazil has successfully overcome the initial challenges of ethanol development. Since 2003, FFVs have been replacing single fuel cars in Brazil, and they have started to dominate the new vehicle market there (Fgure 1). A clearer picture of the dynamics of the Brazilian ethanol market will aid in better understanding consumer behavior concerning the substitute fuels, as affected by the fleet composition. Insights from the Brazilian market can be used to infer the likely price dynamics in the U.S. market and, as a first step, to infer the costs of increasing mandated volumes of ethanol.

Research Hypotheses: FFVs make it possible for Brazilian drivers to arbitrage across the prices of ethanol and gasoline at the pump and to increase ethanol demand. Figure 2 presents a schematic representation of aggregate domestic ethanol demand with the presence of FFVs in the vehicle fleet. The demand curve of the relative prices of ethanol and gasoline per mile traveled and Q_e is given by *CABD*. The kink *A(B)* corresponds to the quantity Q_A (Q_B) at the price P_0, where the price of ethanol is equal to that of gasoline on the basis of per unit of distance traveled. P_0 is roughly equal to 0.7, the equilibrium price if drivers can arbitrage between fuels. The quantity demanded of ethanol is thus determined by the number of FFVs in the fleet and is in the range of [Q_A, Q_B]. With the increases of the FFV shares (Figure 1), the domestic ethanol demand is now represented by the curve $C'A'B'D'$.

Hypothesis 1: *The relative prices of ethanol and gasoline, $P_{e/g}$, exhibit strong mean-reversion.*

Hypothesis 2: *Given exogenous gasoline prices, domestic ethanol prices are affected positively by market supply shocks such as sugar prices and demand factors such as export demand and vehicle fleet composition. The increase of FFV shares in the vehicle fleet strengthens these effects of the demand factors.*

Modeling, Data and Empirical Strategy

WE EMPLOY A partial-adjustment model (Li, Timmins, and von Haffen 2009) to quantify the dynamics of relative prices of ethanol and gasoline, i.e., P_e/P_g, which is the dependent variable denoted by y_t. The rationale is that in equilibrium the relative fuel prices reach the appropriate level of θ, which is largely determined by the relative energy content of the fuels. Price adjusts to the equilibrium level by the mean-reverting rate of λ. The PA model is specified as

$$(1)\quad \ln(y_t) = \alpha + \ln(y_{t-1}) + \lambda(\theta - \ln(y_{t-1})) + \boldsymbol{\beta}\mathbf{X}_t + \varepsilon_t,\ \lambda \in [0,1],\ t = 1,\ldots,T,$$

where represents a set of determining factors of relative fuel prices The data consist of monthly average ethanol, gasoline, and sugar prices, as well as monthly ethanol exports and FFV shares, from January 2005 to October 2010. We can rewrite the expression (1) as

$$(2)\quad \ln(y_t) = \alpha^* + \delta\ln(y_{t-1}) + \boldsymbol{\beta}\mathbf{X}_t + \varepsilon_t,\ \lambda \in [0,1],\quad t = 1,\ldots,T,\ \text{and}\ \varepsilon_t = \gamma\varepsilon_{t-1} + \zeta_t$$

where $\alpha^* = \alpha + \lambda\theta$, $\delta = 1-\lambda$, and γ denotes the first-order correlation coefficient of the error term, which is used to account for the fact that the lagged dependent variable is one of the explanatory variables. Since FFV shares may be endogenous or correlated with unobserved determinants of relative fuel prices, we use monthly Brazilian real GDP as an instrumental variable (IV). In the literature, the sugar price is found to be exogenous to the ethanol market (Balcombe and Rapsomanikis 2008), which is how sugar prices are treated in the study.

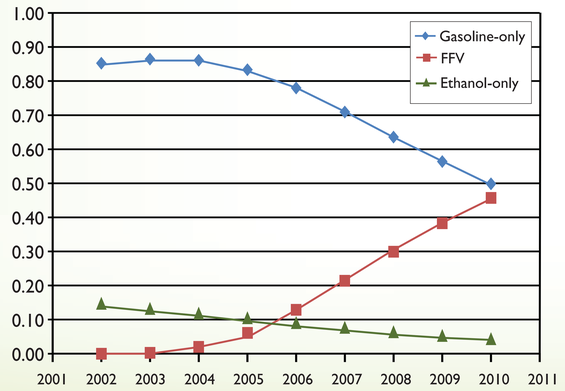

Figure 1. The fleet composition in Brazil (2002-2010)

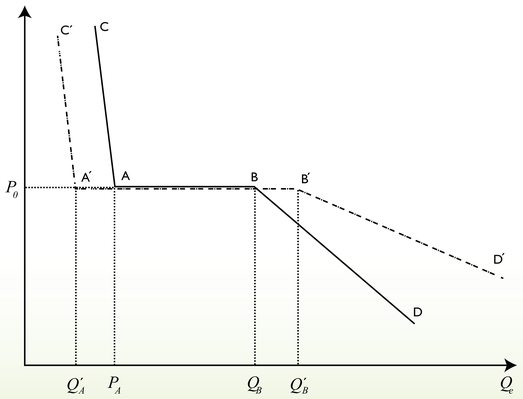

Figure 2. Domestic market demand curve of ethanol in the presence of flexible fuel vehicles

Some Results and Remarks

A THRESHOLD TEST (Hansen 2000) is applied to test for a sample split using the FFV share as the threshold variable. The null hypothesis of no threshold is rejected with LM-test statistics of 24.2 with a bootstrapped p-value <0.001. The threshold level of FFV shares is estimated as 30%. The sample is then split into two subsamples (regimes), one below (regime I) and one above (regime II) the estimated threshold. Equation 2 is then estimated for each of the two subsamples, with results presented in Table 1. Column I details the results when treating FFV shares as an exogenous variable while column II gives the results for IV regression. Both sets of results provide clear evidence supporting our first research hypothesis, that relative fuel prices exhibit strong mean reversion. The mean-reverting parameter ($\lambda = 1-\delta$) is about 0.60, indicating that on average the price, $P_{e/g}$, converges to the equilibrium level in about two months. As expected, the sugar price has a significant positive impact on the ethanol price. Furthermore, a significant pattern of autocorrelation in the error terms emerges.

The estimates for regime I and II are reported in the upper and lower panels of table 1, respectively. Under regime I, when FFVs comprise less than 30% of the vehicle fleet, estimated coefficients of FFV shares and ethanol exports for both regular and IV regressions are not significantly different from 0. However, both estimates are positive and statistically significant under regime 2. The estimates indicate that the domestic price of ethanol increases by about $0.0048 per gallon per additional million gallons of ethanol exports under regime 2.

This study has important implications for the development of the U.S. ethanol market, and for estimating the expected costs of consumption mandates. In order to increase ethanol consumption to mandated levels, a significant proportion of FFVs in the fleet are needed. Our results indicate that the retail price of ethanol needs to be at parity (in energy terms) with gasoline in order for the required quantities to be used by consumers. Additionally, we find that given the expanding demand for ethanol by the Brazilian fleet, imports from that country to meet the advanced renewable fuel mandates may lead to a nontrivial increase in the price of the fuel.

Table 1. Partial Adjustment Model Estimation Results on the Splitted Samples

Regime I (FFV share<30%)	I	II (IV Regression)
Lagged effect (δ)	0.33** (0.14)	0.35** (0.17)
FFV share	0.03 (0.02)	0.33 (0.92)
Sugar price	0.25*** (0.06)	0.21** (0.08)
Ethanol exports	-0.000041 (0.000052)	-0.0000052 (0.000061)
Autocorrelation (γ)	0.58*** (0.14)	0.61*** (0.17)
Constant	-1.14*** (0.25)	-0.33 (2.21)
Regime II (FFV share >30%)		
Lagged effect (y)	0.38 (0.23)	0.40*** (0.15)
FFV share	0.23* (0.14)	7.55** (3.23)
Sugar price	0.27*** (0.08)	0.14** (0.06)
Ethanol exports	0.00015** (0.000063)	0.00015** (0.000072)
Autocorrelation (y)	0.51** (0.21)	0.90*** (0.12)
Constant	-1.12*** (0.37)	6.63* (3.27)

Notes: (1) Standard errors are in parentheses.
(2) Single (*), double (**), and triple (***) asterisks denote significance at the 0.10, 0.05, and 0.01 levels, respectively.

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