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Flex-fuel vehicle adoption and dynamics of ethanol prices: lessons from Brazil

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HIGHLIGHTS

- The relative prices of ethanol and gasoline in Brazil exhibit strong mean-reversion.
- The fuel price dynamics are mainly influenced by supply and demand factors.
- The impacts of demand factors are strengthened by the increasing proportion of FFVs.

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ABSTRACT

Focusing on dynamics of the relative prices of substitute fuels, namely ethanol and gasoline, this study quantifies the impact of the increase in shares of flex-fuel vehicles (FFVs) in the vehicle fleet on the domestic ethanol prices in Brazil. A modified partial adjustment model is employed. Estimation results provide strong support for our research hypotheses: (i) when consumers can choose between the fuels the relative ethanol and gasoline prices converge to a long-run equilibrium level, which is determined by the fuel economy, and (ii) price dynamics are largely determined by market supply and demand factors including the price of sugar, ethanol exports, and composition of vehicle fleet. Furthermore, the impacts of demand factors such as ethanol exports are strengthened by the increasing proportion of FFVs in the vehicle fleet.

1. Introduction

Brazil is the world's largest ethanol exporter and the second largest producer after the United States. In 2009, Brazil produced 6.57 billion gallons, which is about 37.7% of the world's total fuel ethanol, and exported 873 million gallons accounting for about 50% of the global exports. The United States and the so-called Caribbean Basin Initiative (CBI) countries have been the main destination countries.[2]

As a pioneer in the production of sugarcane ethanol, Brazil has successfully overcome the initial challenges of ethanol development.[3] Using efficient agricultural production technology for sugarcane cultivation, modern agricultural management practices, and cane bagasse to generate heat and power for the ethanol plant, Brazil's sugarcane-based ethanol has the lowest cost among major producing countries. Valdes (2011) indicates that the average ethanol production cost in Brazil was estimated at \$0.48/liter, about 58% lower than that of US corn ethanol.[4] The relatively low production cost largely attributes to productivity gains in feedstock and ethanol production as well as lower labor and input costs (Balat and Balat 2009). In addition, the use of sugarcane bagasse for energy in ethanol production provides good energy balance for sugarcane ethanol (Goldemberg 2006). However, the growth in domestic fuel ethanol demand has outpaced that of supplies, and the export quantities were sharply reduced in 2011 (FAS/USDA 2011) and prices increased.

Since 2003 flexible fuel vehicles (FFVs) are replacing single fuel (ethanol-only or gasoline-only) cars and started to dominate Brazil's new vehicle market. By 2010 FFVs account for over 40% of Brazil's active vehicle fleet and thus allow for increasing demand on domestic ethanol and choice between fuels. The introduction of FFVs makes it possible for Brazilian drivers to arbitrage across the prices of ethanol and gasoline at the pump. Given the lower energy content of ethanol relative to gasoline,

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[2] Most of the imports by the countries in the Caribbean Basin are reprocessed and then re-exported to the United States. The 2.5% duty and the \$0.54 per gallon import tariff, which expired at the end of 2011, are waived as granted in the "Caribbean Basin Economic Recovery Expansion Act" of 1990. This process is limited by 7% of US ethanol consumption.

[3] For reviews of the history of Brazilian ethanol industry, readers are referred to, e.g, Martines-Filho, Burnquist, and Vian (2006), Tokgoz and Elobeid (2006).

[4] It should be noted that the relative cost advantages of the countries fluctuate with relative prices of feedstocks and energy.

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price parity occurs when the price of ethanol approximately equals 70% of that of gasoline.[5] This economic efficiency is largely determined by the technical efficiencies of different fuels, i.e., the distances a car can travel with each fuel (Ferreira et al., 2009). In a relatively short period of time (five-year sample period in our study), it is reasonable to assume that there is no change in the energy efficiency of ethanol and thus the corresponding relative fuel price is constant. We focus on national average prices in the current study. At the regional level, prices may fluctuate to reflect local supply and demand conditions as well as the policy environment. In Brazil, prices of oil products are classified as regulated prices even after the domestic deregulation in 2002 as the prices are established by the government-owned company Petrobras, who is the monopolistic player in the Brazilian refinery production and distribution markets (Banco Central do Brasil (BCB), 2008). It means that wholesale (unblended) gasoline prices are not responsive to supply and demand conditions.[6] Hence, the mean-reverting behavior is expected in the dynamics of relative fuel prices.

In addition, the strong increase in domestic and export demand will impose upward pressure on ethanol price given the government-controlled gasoline market. In summary, the introduction of a fleet able to consume larger quantities of ethanol, also provides individual consumers with the tools to arbitrage between fuels. A major objective of this study is to analyze the dynamics of relative ethanol and gasoline prices in Brazil after the introduction of the flex-fuel technology. More specifically, we investigate the potential driving factors of the evolution of fuel prices including sugar price, ethanol exports, and the increase in FFV shares.

Several studies in the recent literature investigate the dynamic behavior of relative fuel prices and relevant facts of Brazilian automobile and fuel markets. By examining price and demand data, Pacini and Silveira (2011) compare the evolution of prices and consumption of ethanol and gasoline in Brazil and Sweden, especially during the period of speedy adoption of flex-fuel technology. Ferreira et al., (2009) develop a theoretical model seeking to understand the interaction between fuel price dynamics and changing composition in the fleet. In the empirical analysis the authors find that the relative price of ethanol and gasoline is well approximated by a stationary process, i.e., ethanol and gasoline prices are cointegrated, and Granger causality runs stronger from gasoline to ethanol price. The most relevant to our work is Salvo and Huse (2011). They provide a stylized model of the domestic ethanol demand and sugar/ethanol industry, through which they investigate how the introduction of FFVs impacts the demand for ethanol. Their study provides strong evidence that in equilibrium the price of ethanol should increasingly co-vary with the price of gasoline as the market adoption of FFV grows.

Building on previous work (e.g., Salvo and Huse, 2011; Ferreira et al., 2009), this study provides a more complete understanding of fuel price dynamics in Brazil. An extended partial adjustment model is employed to capture the mean-reverting behavior and the effects of supply and demand factors on fuel price determination. Sugar price and export demand are found to have significant positive effects on ethanol price. Interestingly, the impact of ethanol demand increases significantly with FFV shares in the vehicle fleet. These findings not only help in explaining the evolution of the interaction between Brazil's ethanol and automobile markets, but may have implications for inferring the development of similar markets in other countries in which consumers have a choice between fuels.

The remainder of the paper is organized as follows. Section 2 provides a theoretical foundation for the empirical tests in the study. Section 3 lays out the empirical model, describes the data and identification strategies. Section 4 discusses the main results, and Section 5 concludes with a summary of the major findings.

2. Flex-fuel vehicle adoption and dynamics of ethanol price

Building on the conceptual framework developed in Salvo and Huse (2011), this section addresses a number of research hypotheses. We discuss the theoretical foundations of the estimation in a heuristic way, since this article is primarily empirical in its focus. The market demand of ethanol consists of demand from international and domestic markets, where the latter is largely determined by (i) domestic prices of substitute fuels, (ii) vehicle fuel economy or efficiency represented by the average mileage per unit of fuel, and (iii) the number of cars by fuel type, including ethanol-only, gasoline-only, and flex fuel vehicles in the vehicle fleet, as well as macroeconomic condition and personal disposable income. Fig. 1 presents a schematic representation of aggregate domestic ethanol demand with the presence of FFVs in the vehicle fleet. The vertical axis is the relative prices of ethanol and gasoline per mile traveled, denoted by $P_{e/g}$. The horizontal axis, Q_e, denotes market level demand for ethanol, which is derived and aggregated from the total miles traveled of individual consumers.[7] We assume that gasoline prices are exogenous to the ethanol market as it is strongly controlled by the Brazilian government. Thus the dynamics of the relative prices largely reflect that of the price of ethanol.

The demand curve of $P_{e/g}$ and Q_e is given by $CABD$ in Fig. 1. The demand curve has two kinks: A and B. 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 gasoline on the basis of per unit of distance traveled. P_0 is roughly equal to 0.7 as on average one gallon of ethanol is considered to deliver 70% of the mileage of one gallon of gasoline (Goldemberg, 2007). When the relative fuel price $P_{e/g}$ is around the price of P_0, gasoline and ethanol have equal economic costs to car drivers. Given sufficient flex-fuel vehicles in the fleet, this price should be the long-run equilibrium as drivers can arbitrage across ethanol and gasoline at the pump. The quantity demanded of ethanol is thus determined by the number of FFVs in the fleet and is in the range of $[Q_A, Q_B]$, represented by AB in the demand curve. In this case, storage, transportation and distribution infrastructure for ethanol and ethanol-gasoline blends will significantly affect fuel availability and thus their price relation. When $P_{e/g} > P_0$, i.e., fueling with ethanol is not advantageous to gasoline, the demand of ethanol then only comes from ethanol-only and gasoline cars and the demand curve is relatively inelastic.[8] When $P_{e/g} < P_0$, relative lower ethanol prices provide consumers strong incentives to substitute gasoline in the tank. Changes in the fleet composition affect the demand structure for fuels. Fig. 2 shows the evolution of fleet composition over the period 2002–2010 in Brazil. Notice that the share of FFVs in the fleet increased from 0% to 46%, while the share of ethanol-only cars decreased from 15% to 4% by the end of 2010. With the increase of the FFV shares, the domestic ethanol demand is now represented by the curve $C'A'B'D'$. The contraction

[5] The 70% threshold is a well-established ratio for the relative value of ethanol to gasoline in Brazilian consumer minds. For a detailed and convincing discussion of this threshold see Salvo and Huse (2011).

[6] The wholesale price of gasoline A in the southeast (unblended gasoline) ranged between 1.53 reals/liter and 1.57 reals/liter for most of the period between January 2006 and December 2010. It declined to 1.50 reals/liter for the period of February–April 2010. For comparison, the Brent crude oil price ranged between $40 and $133 per barrel for the same period.

[7] For a theoretical derivation of the demand curve readers are referred to pp. 125–127 in Salvo and Huse (2011).

[8] Gasoline sold at the pump to consumers in Brazil (namely gasoline C) is mandated to include between 20% and 25% anhydrous ethanol. The range results from changes in the minimum mandates set by the government over time.

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