



Complement or substitute: Ethanol's uncertain relationship with gasoline under alternative petroleum price and policy scenarios



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HIGHLIGHTS

- Ethanol's demand relationship with gasoline can vary with market situations.
- There is much uncertainty regarding medium-term, future crude oil prices.
- These uncertainties call for forward-looking, applied policy analysis.
- A structural economic model of the global biofuel market is expanded and simulated.
- High crude oil prices could lead to expanding ethanol exports and non-binding RFS.

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ABSTRACT

Ethanol demand depends on the crude oil price and domestic biofuel mandate, but the aggregate effect on consumer fuel choices and export demand is uncertain. The relationship between crude oil and ethanol price is complex, and the presence of policy driven domestic biofuel use (mandate) make the modeling of the world ethanol market challenging. A structural economic multi-market multi-region partial equilibrium model considering the complementary and substituting effects between gasoline and ethanol demand is developed. In this study, a kinked ethanol demand curve that reflects those relationships is used to depict ethanol demand. We further simulate two forward-looking alternative crude oil price scenarios to identify how the crude oil price interacts with ethanol use mandates and trace the consequences on the U.S. Renewable Identification Number (RIN) market. The study finds that, under high crude oil prices, the substitution effect might trigger a large increase in ethanol demand by the rest of the world and the U.S. and Brazil will be the key ethanol exporting countries. In the U.S., the overall biofuel mandate might become non-binding.

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1. Introduction

Ethanol accounts for a larger share of global liquid fuels markets than ever before, but interactions between ethanol and fossil fuel sources are complicated by varying consumer uses and policy interventions. Since 2000, total energy consumption in the global transportation sector has been increasing 2% annually, and global ethanol production has risen from 28.5 billion liters in 2004 to 98 billion liters in 2015 [1]. In 2015, renewable energy use in the road transportation sector is estimated to be 4% of the total trans-

portation fuel use and liquid biofuels, including ethanol, dominate among all other renewable fuels in this sector [1]. Ethanol is the most widely used biofuel that is blended with and displaces petroleum-based fossil fuel, leading to greenhouse gas emission (GHG) reductions [2]. While the recent increase has attracted attention, Brazil has been using ethanol as a fuel since 1925 [3]. In the U.S. and E.U., as in Brazil, government policies intervene in biofuel markets by setting minimum quantities or shares of domestic use, but these policies tend to be complex. For example, the U.S. Renewable Fuel Standard (RFS) sets a hierarchy of volume targets by biofuel type while allowing for waivers based, in part, on market conditions [4]. Ethanol use has grown in importance, but the interaction of demand and policy drivers is difficult to assess

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because this market has evolved so quickly and so recently in most countries.

The effect of petroleum price changes on ethanol markets and policies is uncertain yet important. The uncertainty relates to the sudden increase in this market and the nature of demand. As global ethanol use has more than doubled in just a decade, historical data might not represent current market conditions. Moreover, as shown later, demand is likely to be non-linear, ranging from a complementary relationship with gasoline at very low volumes where it is used as a fuel additive to influence its physical properties, to a strong substituting relationship as fuels with high ethanol inclusion rate displace petroleum products. In addition, these relationships can be influenced by policies that set minimum use targets, particularly if a fixed blend is required. Estimates drawn from decades of U.S. data, for example, might span periods when the marginal use of ethanol was as an additive and periods when the marginal use was as a competing fuel source. Future interactions are uncertain.

The importance of these interactions is without doubt. Scientific assessment of supply chains and environmental impacts demonstrates the broad relevance of ethanol (e.g. [5–7]). Debates in the U.S. Congress, during the Presidential campaigns, and in the industry press about the details and very existence of the RFS show that the policy should be a subject of applied energy economics. The U.S. mandates affect markets and can cause billions of dollars in compliance costs for obligated parties, as discussed below. Looking ahead towards the legislated increases in the mandate and taking into account an uncertain petroleum price and its implications for ethanol demand, applied research has a role in outlining the potential market and policy cost impacts.

2. Background

Estimates over past data might not relate to market conditions in the future and, moreover, time series methods focusing on price series tend not to address the mandate compliance costs. The linkage between food and fuel markets has been discussed in the applied economic literature for many years. Serra and Zilberman [8] review time series studies of prices and find that, in general, energy prices tend to drive agricultural commodity prices historically. Serra et al. [9], Serra et al. [10], Whistance et al. [11], Whistance and Thompson [12], and Zhang et al. [13] use time series analysis for both U.S. and Brazilian biofuel markets to estimate links between ethanol, petroleum-based fuels, and crop prices. They found that an increase in the petroleum prices results in an increase in the ethanol price and, consequently, an increase in the prices of corn in the U.S. and sugar in Brazil. However, very few of these studies rely primarily on recent data and also exploit information about U.S. mandate compliance [11,12]. These studies argue that the linkage between food and fuel prices depends on the relationship between biofuels and gasoline markets. If biofuels complement petroleum products, as might be true in the case of fuels with a 10% ethanol inclusion rate (E10) in the U.S. (Fig. 1), then a high gasoline price will cause a decrease in biofuel use and can lower feedstock prices. Conversely, if biofuels and petroleum products are substitutes, as in the case of hydrous ethanol in Brazil (Fig. 2), then rising petroleum-based fuel prices increase biofuel demand and increase the prices of crops that are used as feedstocks. Demirbas [14] and Szklo et al. [15] point out that there are both complementary and substitute relationships between ethanol and gasoline. However, this line of work tends to be backward-looking, whereas future market conditions might differ if there are changes in petroleum price levels, mandated volumes or shares, or the relationship between ethanol and petroleum products at the margin. Moreover, studies that represent ethanol

as either a complement to gasoline (Fig. 1) or a substitute (Fig. 2) could be completely incorrect about price relationships if the switch from one segment of demand to the other is not taken into account.

Structural modeling represents an alternative tool to time series that allows researchers to focus on current or anticipated market conditions. Many authors, including de Gorter and Just [16–18], Keeney and Hertel [19] and Tyner et al. [20], use structural models to study some of the consequences of policy on energy and agricultural markets. For example, Elobeid and Tokgoz [21] trace out the impact of removing the U.S. tax credit on ethanol markets using a multimarket international ethanol model that consists of U.S., Brazil, and ROW (Rest of the World). Christensen and Siddiqui [22] pointed out the consequences of RFS implementation in the U.S. and world ethanol markets. However, RFS sub-mandates are not considered in many past studies. Many studies also represent aggregate demand for ethanol, without regard to the specific fuel choices that consumers make. Meyer and Thompson [23] and Whistance et al. [24,25] examine several alternative mandate scenarios concerning the RFS sub-mandates and take into account relative prices of E10 and E85. These studies estimate that certain waiver scenarios that limit U.S. RFS expansion would result in a significant increase in the import of sugarcane-based ethanol, for example. To the best of our knowledge, studies do not consider the consequences for world ethanol markets of various options to waive the overall mandate and its components, identify sensitivity with respect to the petroleum price, and take into account the complexities of demand and mandate compliance.

We focus on (i) modeling the alternating complementary or substituting relationship between ethanol and gasoline simultaneously, (ii) waiver options for various RFS components that are currently under debate, and (iii) alternative future petroleum price levels. We use a structural economic model to consider the use of ethanol as a complement to gasoline in E10 and substitute at higher blends. Ethanol use in the U.S. and other key ethanol producing and consuming countries or regions, including Brazil is represented as elastic at a higher gasoline price relative to ethanol price to represent the dominance of the substitute effect and inelastic at a lower gasoline price relative to ethanol price to allow for a greater role of the complementary effect. The consequence is a non-linear, kinked ethanol demand curve with the petroleum price determining the location of the kink (Fig. 3). This representation of ethanol demand is part of a larger global partial equilibrium model of ethanol, ethanol feedstock, and related markets, including agricultural commodity markets to represent additional complications such as slow adjustments to area allocation or livestock numbers that can also influence responses. This model builds on similar research using structural models by applying the ideas about ethanol demand drawn from the time series literature to the global ethanol market. This approach allows an examination of how petroleum price levels interact with the U.S. biofuel mandates and estimation of biofuel price and RFS compliance implications related to this key indicator of global energy markets.

The objectives of this study are to estimate the consequences of a lower and higher petroleum price on (a) the U.S. and global ethanol markets and (b) the U.S. biofuel mandate compliance costs. Our study expands on an economic partial equilibrium model for the world ethanol market, and related markets, breaking out the U.S., Brazil, and other key countries or regions. We introduced a kinked ethanol demand curve to represent the possibility of either a complementary or substituting relationship between ethanol and gasoline market. We find that these demand-side effects are suppressed in certain key markets, including Brazil, because of existing policies. We also find that a combination of factors, including U.S. domestic and export demands as well as mandate implementation, cause a higher petroleum price to have strong ethanol price

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