An Assessment of Simultaneous Ethanol Policy Changes on U.S. Ethanol and Related Markets

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In the late 2000s, corn prices rose rapidly and were closely followed by prices of other major agricultural commodities. A widespread explanation for these market changes is an increased demand for corn in the production of ethanol, prompted by the introduction of programs intended to encourage biofuels production in the United States. Empirical evidence of these market effects has been shown in numerous studies (for example, see McNew and Griffith, 2005; Baker and Zahnister, 2007; Park and Zilberman, 2007; DeGorter and Just, 2008; Low and Isserman, 2009) and Naylors and Falcon (2011) suggest that U.S. agriculture has entered a new era in which commodity prices are increasingly determined by U.S. biofuel policies. In 2011, concerns about continued corn price rises, increased global food price volatility, and reallocation of corn away from traditional uses led domestic and global leaders to urge U.S. policymakers to modify existing biofuel legislation.[1]

In response to political pressures, the U.S. Congress considered amending three ethanol policies. The first of these policies is a tax exemption originally introduced in the Energy Tax Act of 1978, which allowed ethanol producers to forego paying the federal fuel excise tax. In 2004, however, the tax exemption was changed to a $0.45 tax credit to fuel blenders for each gallon of ethanol used in producing blended gasoline. The Omnibus Reconciliation Act of 1980 introduced a specific import tariff on foreign ethanol producers to offset rents captured by taking advantage of the fuel excise tax exemption. Until 2001, the specific tariff amount was equal to

[1] Reallocation of corn from its traditional uses has been non-trivial. For example, in the 2004-2005 marketing year, 53.4% of the U.S. corn crop was used in livestock and poultry feed, and only 12.5% was used in the production of corn-based ethanol. In the 2011-2012 marketing year, 38% of the corn was used for feed while 40% was for biofuel production.

the value of the fuel excise tax exemption; however, in the early 2000s the blender's credit was lowered to $0.45 per gallon while the specific import tariff remained at $0.54 per gallon and the ethanol ad valorem tariff remained at 2.5%. These combined tariffs created a $0.14 per gallon net import tariff, altering the market structure in favor of domestic ethanol production.[2]

The third legislation is the Renewable Fuel Standards (RFS) program, first introduced in the Energy Policy Act of 2005 and later amended in the Energy Independence and Security Act of 2007. The latest RFS program is a federal mandate requiring 36 billion gallons of renewable fuels to be blended into gasoline by 2022. By 2015, a maximum of 15 billion gallons can be from corn-based ethanol and the remaining amount must be a combination of advanced, cellulosic, and biodiesel fuels.[3] Currently, excessive production costs and technological constraints limit the quantity of non-corn based biofuels, implying that a greater burden is placed on the use of corn to fulfill the mandated ethanol production requirement. Consequently, increased production and continued reallocation of corn to ethanol production will likely continue, contributing to increased commodity and land prices (and volatility) and unanticipated market-distorting spillover effects into other agricultural and non-agricultural sectors.[4]

Although each ethanol program can individually contribute to distorting a particular market, it is likely that the interaction among the three policies can exacerbate these distortions. Consequently, changes in one or more of these programs can have direct and indirect economic

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[2]Between 2008 and 2010, the average ad valorem tariff rate was $0.05 per gallon. When added to the $0.54 per gallon specific rate tariff this resulted in an average net tariff from 2008 – 2010 of $0.59 per gallon.

[3] In January 2011, the Environmental Protection Agency (EPA) approved the use of blended gasoline that included as much as 15% ethanol for most vehicles manufactured in 2001 or later. This approval implies that the production of 15 billion gallons of biofuels will not create excess ethanol supply due to an inability to use blended gasoline in most vehicles.

[4] The EPA has the ability to waive the mandate for one of two reasons. First, the mandate can be waived if there is an inadequate domestic supply of corn to meet the program requirements. Second, a waiver can occur if enforcing the mandate would severely harm the economy or environment of a state, region, or country. This provision was first implemented in February 2010, when the EPA reduced the cellulosic biofuel requirement from 100 million to 6.5 million gallons, because of insufficient cellulosic biofuel production capacity.

impacts on multiple linked energy and agricultural markets. Existing literature, however, has mainly focused on evaluating the effects of altering a specific policy within a particular market (primarily, the corn market). For example, De Gorter and Just (2008) and Thompson et al. (2009) investigate the effects of imposing or removing ethanol import tariffs while mandating domestic ethanol production. De Gorter and Just (2008, 2009), Yano et al. (2010) and Kim et al. (2010) examine the effects of changing the value of the blenders tax credit on the prices and quantities of fuels.

This study seeks to model the effects of simultaneous policy changes on multiple sectors of the blended gasoline marketing channel. We first model the marketing channel and demonstrate the effects of policy changes on economically linked sectors within the channel. Next, we use an equilibrium displacement model (EDM) to simulate various policy modifications, including a simulation of simultaneously removing the blender's tax credit and specific import tariff without changing the mandated ethanol blending quantity requirement – a change that occurred in January 2012.[5] We calibrate the EDM using elasticity measures found in the literature and we account for large discrepancies in elasticity values by estimating the equilibrium displacement model over a range of possible values, which are simulated using known elasticity measures as *priors*. Generally, the EDM estimation results indicate that U.S. corn and ethanol producers are affected primarily by changes in the mandate blending requirement. Domestic consumers and foreign ethanol producers, however, are impacted by changes in any of the three policies. Furthermore, we show that the removal of all ethanol industry support programs would result in a less than 20% reduction in supplied ethanol quantities, implying that in the short to medium-run.

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[5] The 2.5 percent ethanol Ad Valorem tariff doesn't expire until December 31, 2050 (United States International Trade Commission, 2011).

Modeling the Blended Fuel Marketing Channel

Policy-induced market distortions can have non-trivial unanticipated impacts on linked sectors within a marketing channel. Figure 1 shows a representation of the blended fuel marketing channel segment and the role of agricultural markets. We assume that this segment can be characterized by seven markets, which are economically linked vertically and horizontally. That is, changes in higher-level markets (e.g., the retail level) affect related lower-level markets (in which intermediate goods are produced and processed), and conversely, changing conditions in lower-level markets are passed upward through the marketing channel. When markets are linked horizontally within a marketing channel – goods in these markets are close substitutes or complements – changes in one market would trigger shifts in related sectors. In figure 1, we use dashed supply and demand curves to indicate endogenous linkages among markets, and supply and demand curves assumed to be exogenous to the marketing channel are depicted as solid lines.

In figure 1, the top-most, retail level is characterized by the market for gasoline equivalent blended fuel.[6] The demand for retail-level blended fuel is assumed to be exogenously determined and the fuel is supplied by blenders who use inputs from the horizontally-related gasoline and total ethanol markets. In both the gasoline and total ethanol markets, demand is derived from the retail-level; however, the supply in the ethanol market is jointly determined by the horizontally-related domestic ethanol production and imported ethanol. All ethanol consumers and producers are assumed to be price takers, because ethanol contributes a small

[6] To be consistent with consumer behavior, we model gasoline equivalent blended fuel rather than actual blended fuel. That is, because consumers evaluate energy products based on their energy content, we rescale all fuel sources used in producing retail-level gasoline to supply an equivalent unit of energy content per unit of the fuel source. For example, if one gallon of gasoline is assumed to provide one unit of energy content, then a one gallon of ethanol would provide 0.677 units of equivalent energy content (Oak Ridge National Laboratory 2010).

share to the total production of gasoline equivalent blended fuel.[7] Consequently, the demand curve is likely to be nearly perfectly elastic, and for expositional convenience we model the curve to as perfectly elastic. Furthermore, in the absence of policy-induced market distortions, the price of ethanol is assumed to be the product of the equilibrium per-unit price of gasoline, P_G^0, and the gasoline energy ratio, m, which represents the proportion of gasoline-equivalent energy content supplied by a unit of ethanol.

Finally, demand in the domestic ethanol market is derived and the supply is a function of corn and non-corn inputs. Importers' demand function is also derived, but the supply is assumed to be exogenous. Demands in the farm-level corn and the non-corn input markets are endogenously determined and the supply functions are exogenous.

Market Impacts of Subsidies and Tariffs

Until 2012, four policy-induced market distortions affected the blended gasoline marketing channel. Today, only the 2.5 percent ad valorem ethanol tariff remains. We first illustrate the impacts of the two price-based distortions that were removed January 1, 2012: a subsidy to fuel blenders for each gallon of ethanol used to produce gasoline equivalent blended fuel, and a specific tariff assessed on ethanol importers. In figure 2, we show a characterization of these distortions on the gasoline, total ethanol, domestically produced ethanol, and imported ethanol markets. In the base-case, when no market distortions exist, equilibrium quantities and prices are marked by the points Q_G^0 and P_G^0 in the gasoline market, Q_{TE}^0 and $P_{TE}^0 = m \cdot P_G^0$ in the total ethanol market, Q_D^0 and P_D^0 in the domestically produced ethanol market, and Q_I^0 and P_I^0 in the imported ethanol market.

[7] In 2010, ethanol contributed an 8% share to the total quantity of gasoline equivalent blended fuel.

A per-unit ethanol subsidy to gasoline blenders lowers their marginal cost of production and increases their demand for total ethanol. In figure 2, this is characterized as an upward shift of the total ethanol demand curve and a resulting increase in the price and total ethanol quantity supplied, marked by points P_{TE}^1 and Q_{TE}^1. Note that even though blenders use a higher quantity of total ethanol, the subsidy is passed down the marketing channel. The impacts in the total ethanol market are passed down the marketing channel to the domestic ethanol production market (shown by points P_D^1 and Q_D^1) and to the importers, and then to the corn and non-corn input markets. The effects on the gasoline and gasoline equivalent blended fuel markets are ambiguous. If a higher percentage of ethanol is blended with the gasoline to produce the same quantity of blended fuel (no change in the gasoline equivalent blended fuel market), then the demand curve in the gasoline market would shift downward, resulting in lower equilibrium prices and quantities (as shown in figure 2 and marked by points Q_G^1 and P_G^1). Alternatively, if the same quantity of gasoline (no changes to the gasoline market) is blended with a higher quantity of ethanol, then the supply curve in the blended fuel market will shift outward, leading to higher equilibrium retail-level quantities and lower prices. The most likely outcome is some combination of these two effects.

The impact of subsidies on the import market is conditional on the net tariff faced by importers. The net tariff is defined as the difference between the ethanol import tariff and the subsidy, $NT = (T - S)$. When $NT = 0$, the subsidy to U.S. blenders is expected to have no impacts on the import market because the subsidy will be exactly offset by the tariff, preserving the initial price faced by importers ($P_I = P_{TE} - NT$). When the net tariff is positive or negative, importers adjust their quantities of ethanol supplied accordingly. Figure 2 shows the scenario when $NT < 0$, which is representative of the policy and market conditions in the United States, both before 2012 when the specific ethanol tariff, ad valorem tariff and subsidy were in place and also today when only the ad valorem tariff is in place. The lower equilibrium quantities and prices are marked by points Q_I^1 and P_I^1.[8]

Market Impacts of Mandates

Price-based ethanol policies are conditional on existing market prices. The implementation of the quantity-based mandate, however, depends on the actual amount of blended ethanol relative to a required quantity. Absent price-based policies, when the mandate is non-binding – the market-determined quantity of ethanol being blended exceeds the mandated quantity – the market is characterized by the conditions shown in figure 1. However, if the mandate becomes binding, the blenders' ethanol demand curve has a discontinuity at the mandated quantity. This demand curve is shown in figure 3, where the discontinuity in the "Total Ethanol Market" occurs at the points marked by Q_{TE}^2 and P_{TE}^2.

Figure 3 shows that when the mandated quantity exceeds the quantity when no market distortions exist, $Q_{TE}^2 > Q_{TE}^0$, ethanol is valued more than the gasoline equivalent value, $m \cdot P_G^0$. When this is the case, blenders respond by reducing their consumption of gasoline, resulting in a downward shift of the demand curve in the gasoline market and lower equilibrium prices and quantities marked by points Q_G^2 and P_G^2 in figure 3. Furthermore, because ethanol has a lower gasoline equivalent energy content than gasoline, the mandated higher quantity of blended ethanol could sufficiently increase consumer prices to a level that reduces the total quantity of gasoline equivalent blended fuel consumed.

[8] There are both short- and long-run effects of policy-induced changes in the import market. For example, in the long-run, eliminating the net tariff such that $T = S$ would result in increased quantities of imported ethanol, but would have no impact on the price received by domestic producers because they face a nearly perfectly elastic demand curve.. However, market, technological, and capacity short-run rigidities may result in temporary market departures from long-run equilibrium conditions.

A binding mandate can also have important implications on the imported ethanol and corn markets. If domestic production capacity of corn inputs nears its maximum as a result of the mandate (the corn supply curve is likely highly inelastic at very high values of demanded quantities), then corn prices would continue rising with only small incremental increases in the quantities supplied. These price increases can be further exacerbated by unexpected adverse production shocks. Moreover, these effects would likely be distributed across other markets that are economically linked with the corn market. The production capacity constraint could also increase the importance of ethanol imports, which may be necessary to meet mandated ethanol quantity demands if domestic production is insufficient.

An Equilibrium Displacement Model of Ethanol Markets

An equilibrium displacement model (EDM) can be used to simulate and quantify the welfare effects of altering price- and/or quantity-based policies. The EDM is one of the most extensively used approaches for simulating effects of hypothetical shocks and changes within agricultural marketing channels (for example, see Muth 1964; Gardner 1975; Gardner 1987; Brester and Wohlgenant 1997; and Atwood and Helmers 1998). It is a useful modeling tool, because it is relatively easy to implement, data required for solving the model are usually readily available, and resulting inferences are intuitive. However, equilibrium displacement models have rarely been used to understand ethanol policy impacts.[9]

We use the EDM framework to investigate market distortion effects of price-based and quantity-based ethanol policies. Specifically, we simulate four policy prescriptions and quantify their effects on each of the seven markets shown in figure 1. The four policy prescriptions are as

[9] To our knowledge, only Bhattacharya, Azzam, and Mark (2009) have used the EDM approach to investigate proposed ethanol policy effects on U.S. meat markets.

follows. First, we simulate the elimination of the blenders' subsidy and specific import tariff while requiring that the ethanol blending quantity be at least equal to the average blending quantity in 2008-2010 (11,223 million gallons). This simulation most closely resembles the policy prescription that became effective on January 1, 2012. Second, we investigate market effects of eliminating the subsidy and specific tariff and increasing the mandated ethanol blending requirement to 15 billion gallons, making the mandated quantity binding relative to recent consumption. If the subsidy and specific tariff that expired at the end of 2011 are not re-instituted and the 2007 Renewable Fuel Standards program is not amended, this prescription is likely to become effective in 2015. The third simulation is an increase in the mandated ethanol blending quantity to 15 billion gallons while preserving both price-based distortions. Lastly, we simulate the elimination of all market-distorting policies. Table 1 shows a summary of the simulated policy prescriptions and the associated changes in prices and quantities relative to recently observed values.

To model the U.S. blended fuel marketing channel, we specify behavioral, equilibrium, and zero-profit equations representing the market conditions and participants within the marketing channel. Behavioral equations specify the exogenously and endogenously determined supply and demand curves, equilibrium equations represent conditions that must be satisfied to clear the markets, and profit equations are used to derive zero-profit conditions for fuel blenders and ethanol producers. We compute logarithmic differential approximations to the behavioral and equilibrium equations following Gardner (1987). The approximations allow us to express the marketing channel as a function of elasticities and market factor shares in the seven markets shown in figure 1. The 17 equations used in specifying the equilibrium displacement model are presented in the Appendix.

Calibrating the Model

To simulate and quantify proportional changes in quantities and prices due to the implementation of particular policy prescriptions, we must first specify the initial prices and quantities, factor shares, and supply and demand elasticities in each of the markets. We assume average observed market outcomes in 2008-2010 as the initial values to ensure that abnormal market conditions do not bias estimation results. Data for quantities of domestically produced ethanol are from the U.S. Energy Information Administration, consumption quantities of domestically produced and imported ethanol are from the Renewable Fuels Association, quantities of corn used in ethanol production and corn prices received by farmers are from the USDA Economic Research Service, and gasoline and ethanol prices are from the Nebraska Energy Office. Values for the remaining variables are computed by the authors. The computed variables include the quantity of non-corn inputs used in ethanol production, price of non-corn inputs, quantity of consumed gasoline, gasoline equivalent blended fuel price, quantity of consumed gasoline equivalent blended fuel, ethanol demand price, imported ethanol price, total import tariff, gallons of ethanol produced per bushel of corn, and fuel blenders' and ethanol producers' profits. Table 2 presents the variables used in the EDM estimation, formulas used for calculating the computed variables, factor shares, and the initial values.

Elasticity measures are drawn from the existing literature. The equilibrium displacement model in this study requires estimates of six elasticities: (a) the demand elasticity of gasoline equivalent blended fuel; (b) the supply elasticity of gasoline; (c) the supply elasticity of corn; (d) the supply elasticity of non-corn inputs used in ethanol production; (e) the supply elasticity of imported ethanol; and, (f) the elasticity of substitution between corn and non-corn inputs in ethanol production.[10] Table 3 presents elasticity estimates found in the literature and the values chosen for modeling the blended fuel marketing channel. The table indicates that for gasoline equivalent blended fuel demand and supply of corn, elasticity estimates are consistent across numerous studies and, therefore, we use the most recently estimated value. For the elasticity of gasoline equivalent blended fuel demand, we use a value of -0.38, and for the elasticity of corn supply is assumed to be 0.61.

Estimated elasticities of the supply of non-corn inputs, imported ethanol, and gasoline are vastly different across known studies. These ranges imply that we can treat these estimates as stochastic and use them as *priors* for specifying a distribution from which we can simulate sets of probable elasticity values. The simulation procedure follows Brester et al. (2004), but we assume that the distributions of non-corn inputs, imported ethanol, and gasoline supplies are jointly independent. Non-corn inputs primarily consist of labor, natural gas and capital, but the share of total natural gas, labor and capital used in U.S. ethanol production is small. Therefore, even if one of the components of non-corn inputs are correlated with the supply elasticity for gasoline or the supply of ethanol imports, a change in the quantity of domestically produced ethanol will have little effect on the total supply of labor, natural gas, and capital. Furthermore, the supply of ethanol imports is primarily influenced by the world sugar price and ethanol demand rather than the U.S. gasoline or non-corn input supplies.

We further assume that each of the three supply elasticities is characterized by a Beta distribution, which can be calibrated using the mean and standard deviation of elasticity estimates in the literature. However, because we only have enough elasticity measurements from the literature to calibrate a Beta distribution for the U.S. gasoline supply, we use the Beta distribution of gasoline supply as an approximation for all three elasticities. The resulting

[10] The equilibrium displacement model assumes a homogeneous of degree one production function.

distribution is a Beta (2.52, 3.71). One-thousand elasticity estimates were randomly drawn from this distribution for each of the three elasticity measures and these 1,000 sets of generated elasticity estimates were then used in the equilibrium displacement model approximation. As shown in table 3, the resulting elasticity range for non-corn input supply is 2 to 10, and for ethanol import and gasoline supplies, the ranges were [0.16, 2.76] and [2.8, 12.1].

Finally, there has been no empirical research estimating the elasticity of substitution between corn and non-corn inputs in ethanol production. Consequently, we assume that this elasticity is 0.5, because there are relatively few opportunities to directly substitute corn for non-corn inputs, and vice versa.

Equilibrium Displacement Model Results

The equilibrium displacement model was used to approximate responses of markets within the blended fuel marketing channel under one of the four policy prescriptions. For each prescription, we performed 1,000 simulations corresponding to the simulated sets of elasticity values. Table 4 presents the EDM estimation results, showing the initial values of prices and quantities (average of observed values in 2008-2010) in each of the markets within the blended fuel marketing channel and the mean absolute and proportional changes in those values after an implementation of a particular policy prescription. Table 4 also provides the standard deviations of approximated price and quantity changes, demonstrating that the estimation results are robust across the range of simulated elasticities.

Equilibrium displacement model approximation results indicate that ending price distorting policies, with the exception of the ad valorem tariff and maintaining the 2008-2010 average ethanol blending quantity using a mandate – the scenario most closely resembling the

2011 expiration of the ethanol blenders' subsidy and import tariff – primarily affects only the ethanol import market and the price in the total ethanol market. The tariff rate reduction increases importers' incentives to increase the quantity of ethanol supplied, resulting in a 119 million gallons (47%) per year increase in ethanol imports and $0.57 per gallon increase in the price received by importers. The increase in imported ethanol is due to tariff reductions, however, substitutes for only 0.01% of domestic ethanol production.

Interestingly, the model also predicts that removing the price-based policies while imposing an 11,223 million gallon ethanol quantity mandate raises the price that U.S. blenders pay for ethanol. This outcome suggests that when the price supports are removed, the demand for ethanol would decrease below the mandated blending quantity, causing the quantity requirement to become binding. Consequently, as shown in figure 3, blenders consume the minimum required ethanol amount, 11,233 million gallons, and must pay a price higher than the gasoline equivalent market price. The EDM results indicate that the price paid for ethanol by fuel blenders would be 28% higher, approximately the proportion by which price would decrease as a result of ending the subsidy. This implies that the consumers bear the full cost of the policy prescription. That is, although the subsidy is removed, the binding quantity mandate requires that the same quantity of ethanol is supplied, helping maintain U.S. production and import quantities that are similar to those observed on average between 2008 and 2010. Therefore, because there are only trivial changes to the overall demand for ethanol, there are similarly small quantity and price variations in the corn and non-corn input markets.

Increasing the mandated ethanol blending requirement to 15 billion gallons has similar market impacts regardless of whether price-based distortions also exist. In both cases (removing price-based policies except for the ad valorem tariff and maintaining them) the mandated ethanol blending quantity is binding, causing total ethanol prices to be greater than the gasoline energy equivalent price and domestic ethanol production to be over 30% higher than the average production in 2008-2010. The primary effect of coexisting price- and quantity-based programs is on the level of prices paid by ethanol blenders. When blenders' production costs are subsidized, they would be expected to pay $2.40/gallon of ethanol, 51% higher than the initial price. However, when subsidies are removed, blenders incur the full price of $2.84/gallon, with the difference being approximately equal to the average subsidy from 2008 – 2010 of $0.47/gallon.

In the import market, the effect of a binding ethanol production mandate would generally increase imported quantities and prices. However, price-based programs contribute to the magnitude of these increases. When price based distortions are maintained and ethanol quantity mandate is increased to 15 billion gallons per year, ethanol imports increase by 170 million gallons and the price received by importers rises to $2.28/gallon. Removing the specific tariff and subsidy is expected to lead to an additional 119 million imported gallons with importers receiving an additional $0.57/gallon. As expected, the price difference is approximately equal to the specific tariff rate.

The higher mandated ethanol blending requirement also has large effects on U.S. ethanol production. To meet the increased demands for ethanol, U.S. producers are predicted to supply an additional 14,458 to 14,577 million gallons, a 31.8%-32.9% increase relative to the average production in 2008-2010. Consequently, U.S. corn production is expected to increase by approximately 28% regardless of price-based policies, raising corn prices above $6.00/bu. – over a 45% increase relative to the initial value. Related non-corn input quantities demanded rise by an average of 46%, but prices of non-corn inputs increase by only $0.04 per gallon of produced ethanol. The seemingly disproportionate change in non-corn input prices is primarily due to our assumption of an elastic non-corn input supply curve, implying that non-corn inputs can be acquired with relative ease from other agricultural and non-agricultural sectors.

Finally, the last two columns in table 4 present the EDM estimates when all policies are removed. The simulation results show that, similarly to the three policy prescriptions described above, changes in the gasoline and retail-level gasoline equivalent blended fuel markets are negligible. A 1.12% increase in gasoline quantities and a 0.07% reduction in gasoline equivalent blended fuel are expected as a result of decreases in ethanol use, but these quantity changes are insufficient to significantly impact prices in those markets. Markets directly associated with ethanol blending and production do experience non-trivial adjustments. For example, although prices paid by blenders for ethanol do not change (recall that even when the subsidy was in place, its value was passed down the marketing channel), the decrease in mandated blending requirements leads to a reduction in the total quantity of ethanol used by blenders. Specifically, the quantity consumed is 2,066 million gallons (18.4%) less than the 2008-2010 average.

With the elimination of both the price- and quantity-based policies, domestic ethanol producers are also expected to experience reductions in overall demand and prices. The EDM results predict that quantities of ethanol supplied would fall by 19.1% and domestic ethanol producers would receive $1.60/gallon – a 22.3% reduction relative to the initial value. In the import market, the elimination of the specific tariffs would contribute to a price increase, but this effect would be dampened by the overall reduction in demand by U.S. ethanol blenders. The aggregate effects are expected to be an 8.8% increase in the price received by ethanol importers and a 10.7% increase in the quantity of imported ethanol. As expected, terminating all of the policies leads to equalization among the price paid by ethanol blenders and prices received by domestic and ethanol importers.

Finally, the reduction in overall demand for ethanol is passed down the marketing channel to the corn and non-corn ethanol input markets. In the corn market, the EDM results predict a 16.7% (717 million bushel) decrease in the quantity of corn used in ethanol production and a 27.4% reduction in the price of corn. The subsequent price of corn, $2.99/bushel, is representative of the long-run average prices in the corn market. Similarly, the demand for non-corn ethanol production inputs decreases to 7,949 million units, constituting a 27.5% reduction in the non-corn input quantity supplied. However, due to the assumption of a highly elastic supply curve in the non-corn input market, the price of these inputs is only $0.03 less than the 2008-2010 average.

Implications and Conclusions

An extensive literature has researched the impacts of specific ethanol policies on particular agricultural markets. This study contributes to this literature by investigating the effects of simultaneous changes in ethanol policies on multiple markets within the blended fuel marketing channel. We provide a stylized representation of a seven sector marketing channel, calibrate an equilibrium displacement model characterizing the linked markets associated with the production of blended fuel, and simulate four policy prescriptions that were either recently carried out by the U.S. Congress or that have been otherwise proposed. Specifically, we first simulate the termination of a $0.45/gallon subsidy to U.S. ethanol blenders and a $0.54/gallon specific import tariff while enforcing the current level of ethanol production through a mandate – a prescription that most closely resembles the U.S. policy at the beginning of 2012. Furthermore, we simulate an increase in the mandated ethanol blending quantity to the levels required to be in place in

2015 by the Renewable Fuel Standards program, both with and without additional price distortions, and the removal of all ethanol programs, except the ad valorem ethanol tariff.

In contrast to popular opinion, ethanol policies only trivially affect the retail-level blended fuel market. Simulation results of all four policy prescriptions predict that prices and quantities in both the gasoline and gasoline equivalent blended fuel markets never change by more than 5.5%. This is likely due to ethanol's small, 8% share of the total gasoline equivalent blended fuel quantity. Furthermore, changes in price-based policies – the blender's subsidy and import tariff – minimally affect the ethanol blending and production markets. The largest impacts are associated with changes in the ethanol blending mandate. For example, increasing the mandated quantity to 15 billion gallons (the proposed requirement in 2015) would increase the quantity of corn and non-corn inputs into ethanol production, raising the price of corn to over $6.00/bushel. The increased use of U.S. produced corn in ethanol could have numerous unanticipated impacts on other agricultural and food markets. For example, the program effects can contribute to a substitution of land away from the production of other crops, reallocation of corn inputs away from other industries (e.g., the livestock industry), and rises in the level and volatility of commodity and agricultural land prices. These impacts could lead to potential food insecurity concerns and domestic and global political distress.

Alternatively, eliminating all ethanol government support programs would not decimate the U.S. ethanol industry. The resulting domestic production of ethanol would decrease by only 19%, indicating that the blended fuel industry would likely be self-sustaining in the long-run. This estimate is consistent with results in McPhail and Babcock (2008), who find that removing all price- and quantity-based ethanol programs would reduce domestic ethanol production by 11.5% in the short-run. The larger long-run reduction estimated in this study appropriately indicates that additional market adjustments would occur, but that the ethanol industry is likely stable enough not to perish.

It is also likely that ethanol production facilities with highest marginal costs (such as those with older production technology) would exit the domestic ethanol industry. Moreover, assuming that non-corn inputs into ethanol production are used in fixed proportions, changes in the use of these inputs may approximately indicate the capital investment in the U.S. ethanol industry. The 27.5% reduction in the use of non-corn inputs as a result of the termination of all government ethanol programs implies that this percentage of capital would be written down, with the losses taken on by plant owners and financers. These potential adverse effects, however, must be evaluated relative to the benefits of reduced market-distortions and savings to tax payers who currently subsidize the ethanol support programs.

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TABLE 1. SUMMARY OF SIMULATED POLICY PRESCRIPTIONS AND ASSOCIATED CHANGES IN THE VALUES OF EXISTING OR RECENT POLICY STATUTES

Policy Prescription	Absolute Changes	Percentage Changes[a]
1) Keep mandate below the current level of consumption and eliminate the specific tariff and subsidy	*Subsidy*: -$0.47 / gal *Tariff*: -$0.54 / gal *Mandate*: --	*Subsidy*: -22.8% *Tariff*: -26.2% *Mandate*: 0%
2) Eliminate the specific tariff and subsidy and increase mandate to 15 billion gallons[b]	*Subsidy*: -$0.47 / gal *Tariff*: -$0.54 / gal *Mandate*: +3.78 bil. gal.	*Subsidy*: -22.8% *Tariff*: -26.2% *Mandate*: +33.7%
3) Increase mandate to 15 billion gallons and maintain tariffs and subsidy	*Subsidy*: -- *Tariff*: -- *Mandate*: +3.78 bil. gal.	*Subsidy*: -- *Tariff*: -- *Mandate*: +33.7%
4) Eliminate all federal ethanol policies except for the ad valorem tariff.	*Subsidy*: -$0.47 / gal *Tariff*: -$0.54 / gal *Mandate*: -10.5 bil. gal.	*Subsidy*: -22.8% *Tariff*: -26.2% *Mandate*: Non-binding

Notes:

[a] Percentage change are calculated as a proportion of the average prices and quantities in 2008-2010. Specifically:

Subsidy: $\frac{S}{P_D} = \frac{0.47}{2.06} = 22.8\%$

Tariff: $\frac{T}{P_D} = \frac{.54}{2.06} = 26.2\%$

Mandate: $\frac{(E_R - E_o)}{E_o} = \frac{(15{,}000 - 11{,}223)}{11{,}223} = 33.7\%$

[b] Ethanol consumption (11,223 million gallons) was calculated as an average of observed consumption in 2008-2010. The current non-binding quantity mandate is 10.5 billion gallons.

TABLE 2: VARIABLES AND FACTOR SHARES USED IN MODELING THE BLENDED FUEL MARKETING CHAIN AND THEIR ASSUMED INITIAL VALUES

Description	Notation	Formula (if applicable)	Initial value
Gasoline equivalent blended fuel price	P_F	$\frac{(P_G \cdot Q_G) + (P_G \cdot Q_{TE})}{Q_G + (P_{TE}/P_G) \cdot Q_E}$	$2.17/gal.
Gasoline equivalent blended fuel quantity	Q_F	$Q_G + (P_{TE}/P_G) \cdot Q_E$	135,016 mil. gal.
Gasoline price	P_G	--	$2.17/gal.
Gasoline quantity	Q_G	--	126,763 mil. gal.
Total ethanol price paid by blenders	P_{TE}	$P_D - S$	$1.59/gal.
Total ethanol consumed	Q_{TE}	--	11,223 mil. gal.
Domestic ethanol price received by producers	P_D	--	$2.06/gal.
Domestic ethanol produced	Q_D	--	10,969 mil. gal.
Imported ethanol price	P_I	$P_D - T$	$1.47/gal.
Imported ethanol quantity	Q_I	--	253 mil. gal.
Domestic corn price	P_C	--	$4.12/bu.
Domestic quantity of corn used in ethanol production	Q_C	--	4,292 mil. bu.
Non-corn input price	P_{NC}	$P_{TE} - (P_C \cdot Q_C/Q_D)$	$0.46/gal.
Non-corn input quantity per gallon of produced ethanol	Q_{NC}	$\frac{(P_D \cdot Q_D - P_C \cdot Q_C)}{P_{NC}}$	10,969 mil. units
Ethanol subsidy	S	--	$0.47/gal.
Ethanol tariff	T	$\$0.54 + 0.025 \cdot P_D$	$0.59/gal.

Corn's share of U.S. ethanol production costs: $K_{CD} = 0.78$	Import share in total ethanol production: $J_{I,TE} = 0.02$
Non-corn share of U.S. ethanol production costs: $K_{ND} = 0.22$	Gasoline's share of blender's revenue: $K_{GF} = 0.92$
Ethanol's share of blended fuel: $B_{TE,F} = 0.06$	Ethanol's share of blender's revenue: $K_{TE.F} = 0.08$
Gasoline's share of blended fuel: $B_{GF} = 0.94$	Gas price share of blended fuel price: $R_{GF} = 1$
Ethanol's share of gasoline equivalent fuel: $J_{TE,F} = 0.08$	Ethanol price share of blended fuel price: $R_{TE,F} = 0.74$
Gasoline's share of gasoline equivalent fuel: $J_{GF} = 0.92$	U.S. ethanol price share of ethanol price: $R_{TE,D} = 0.77$
U.S. share in total ethanol production: $J_{D,TE} = 0.98$	Import price share of ethanol price: $R_{TE,I} = 0.71$

TABLE 3: ESTIMATED ELASTICITIES IN THE EXISTING RESEARCH AND VALUES USED IN THE EQUILIBRIUM DISPLACEMENT MODEL

Source	Estimate
U.S. gasoline demand	
U.S. Energy Information Administration, 1995	-0.38
Small, K. & Van Dender K. (2007).	-0.38
Cui et al., (2010)[11]	-0.5
Parry and Small (2005)	-0.55
Gallagher et al., 2003	-0.8
Elasticity used in modeling: $\boldsymbol{\eta_F = -0.38}$	
U.S. corn supply	
Gardner, 2007	0.5
Gallagher et al., 2003	0.6
FAPRI U.S Crops Model, Scott Gerlt, 2011	0.61
Elasticity used in modeling: $\boldsymbol{\varepsilon_C = 0.61}$	
Supply of non-corn inputs used in domestic ethanol production	
Gardner, 2007	2 to 10
Elasticity range used in modeling: $\boldsymbol{\varepsilon_{NC} = [2, 10]}$	
Imported ethanol supply	
de Gorter and Just, 2008a	2.69
Tokgoz and Elobeid, 2007	2.76
Martinez-Gonzalez et al., 2007	0.16
Elasticity range used in modeling: $\boldsymbol{\varepsilon_I = [0.16, 2.69]}$	
U.S. gasoline supply	
Koshal et al. (1991)	4.2
Crago and Khanna, 2011	2.8 to 12.1
Elasticity range used in modeling: $\boldsymbol{\varepsilon_G = [2.8, 12.1]}$	

[11] Assumed value, therefore elasticity estimated by Small, K. & Van Dender K..(2007) is used.

TABLE 4. EDM SIMULATION RESULTS: ABSOLUTE AND PROPORTIONAL CHANGES IN BLENDED FUEL MARKETING CHANNEL

		Eliminate price distortions only		*Eliminate price distortions; increase mandate to 15 bil. gal.*		*Maintain price distortions; increase mandate to 15 bil. gal.*		*Eliminate all programs*	
Variable	**Initial value**	**Avg. ending value**	**Percent change**	**Avg. ending value**	**Percent change**	**Avg. ending value**	**Percent change**	**Avg. ending value**	**Percent change**
Gasoline equivalent blended fuel price ($/gal.)	$2.17	$2.20 (0.00)	1.38%	$2.29 (0.01)	5.53%	$2.25 (0.00)	3.69%	$2.17 (0.00)	0.00%
Gasoline equivalent blended fuel quantity (mil. gal.)	135,016	134,189 (22)	-0.61%	132,005 (120)	-2.23%	133,148 (95)	-1.38%	134,922 (25)	-0.07%
Gasoline price ($/gal.)	$2.17	$2.16 (0.00)	-0.46%	$2.15 (0.00)	-0.92%	$2.15 (0.00)	-0.92%	$2.17 (0.00)	0.00%
Gasoline quantity (mil. gal.)	126,763	125,936 (22)	-0.65%	120,974 (120)	-4.57%	122,117 (95)	-3.67%	128,188 (46)	1.12%
Total ethanol price paid by blenders ($/gal.)	$1.59	$2.04 (0.01)	28.30%	$2.84 (0.03)	78.62%	$2.40 (0.02)	50.94%	$1.60 (0.00)	0.63%
Total ethanol consumed (mil. gal.)	11,223	11,223 (0)	0.00%	15,000 (0)	33.65%	15,000 (0)	33.65%	9,157 (52)	-18.41%
Domestic ethanol price received by producers ($/gal.)	$2.06	$2.04 (0.01)	-0.97%	$2.84 (0.03)	37.86%	$2.87 (0.02)	39.32%	$1.60 (0.00)	-22.33%
Domestic ethanol produced (mil. gal.)	10,969	10,850 (43)	-1.08%	14,458 (105)	31.81%	14,577 (62)	32.89%	8,877 (52)	-19.07%
Imported ethanol price ($/gal.)	$1.47	$2.04 (0.01)	38.78%	$2.84 (0.03)	93.20%	$2.28 (0.02)	55.10%	$1.60 (0.00)	8.84%
Imported ethanol quantity (mil. gal.)	253	372 (43)	47.04%	542 (105)	114.23%	423 (62)	67.19%	280 (10)	10.67%
Domestic corn price ($/bu)	$4.12	$4.05 (0.02)	-1.70%	$6.00 (0.06)	45.63%	$6.06 (0.04)	47.09%	$2.99 (0.02)	-27.43%
Domestic quantity of corn used in ethanol production (mil. bushels)	4,292	4,252 (15)	-0.93%	5,488 (37)	27.87%	5,508 (24)	28.33%	3,575 (11)	-16.71%
Non-corn input price ($/gal. of produced ethanol)	$0.46	$0.45 (0.00)	-2.17%	$0.50 (0.01)	8.70%	$0.50 (0.01)	8.70%	$0.43 (0.01)	-6.52%
Non-corn input quantity	10,969	10,798 (63)	-1.56%	16,003 (185)	45.89%	16,175 (142)	47.46%	7,949 (134)	-27.53%

Notes:
Ending values are the means from performing an equilibrium displacement scenario using 1,000 sets of simulated elasticity values. Values in parentheses are the standard deviations.

FIGURE 1: THE U.S. BLENDED FUEL MARKETING CHANNEL

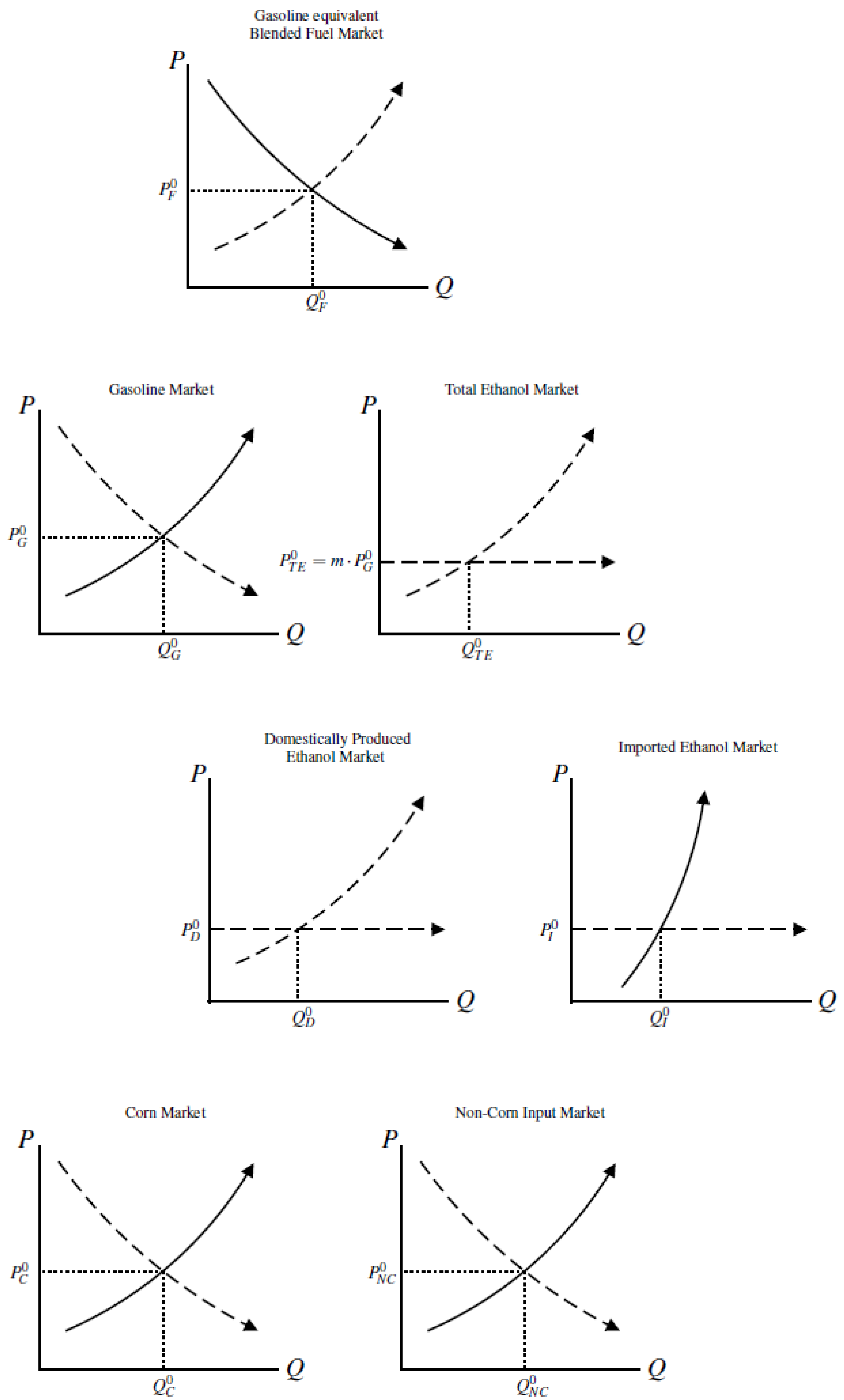


FIGURE 2: EFFECTS OF A SUBSIDY TO FUEL BLENDERS AND EQUIVALENT IMPORT TARIFF

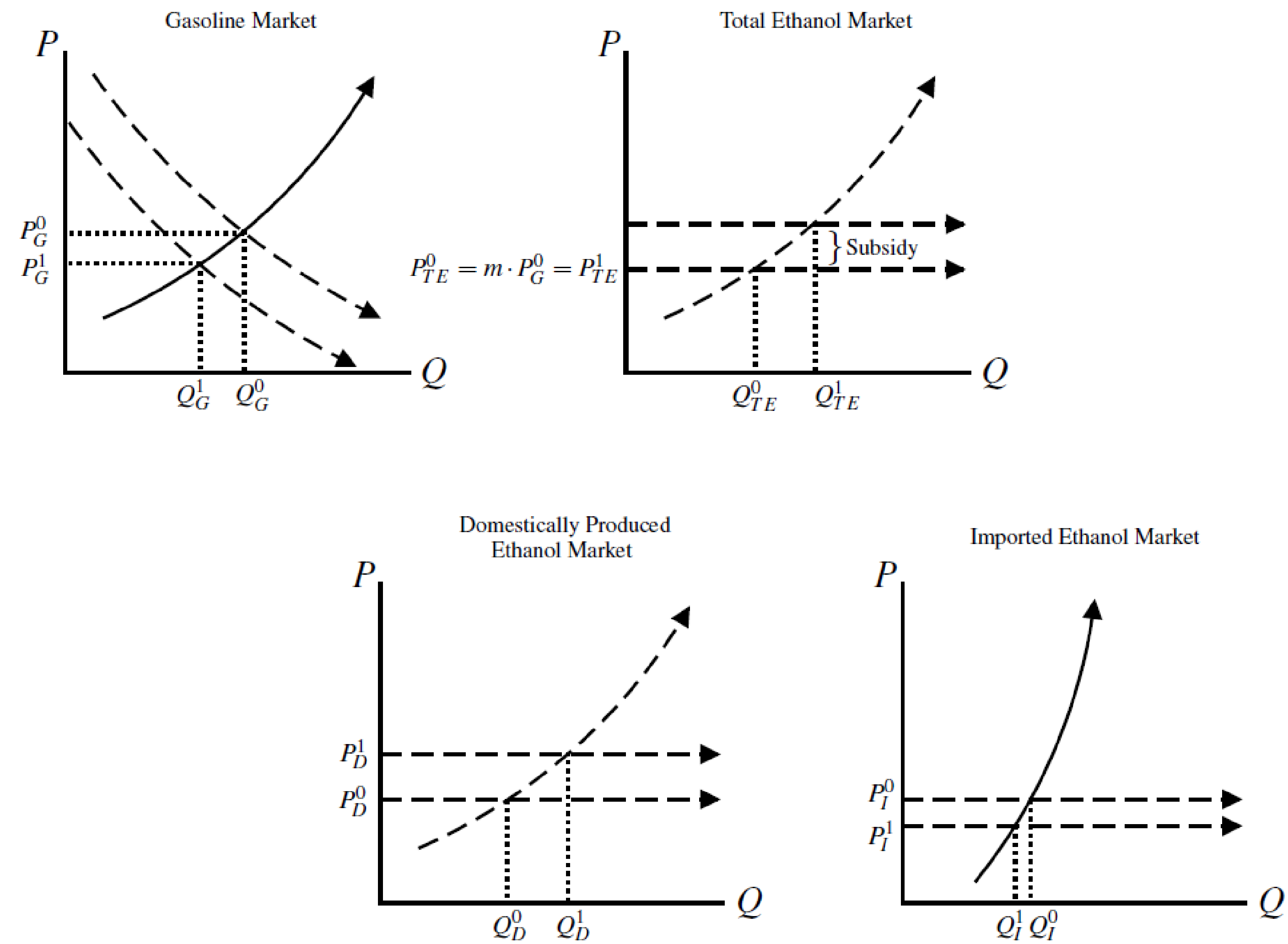
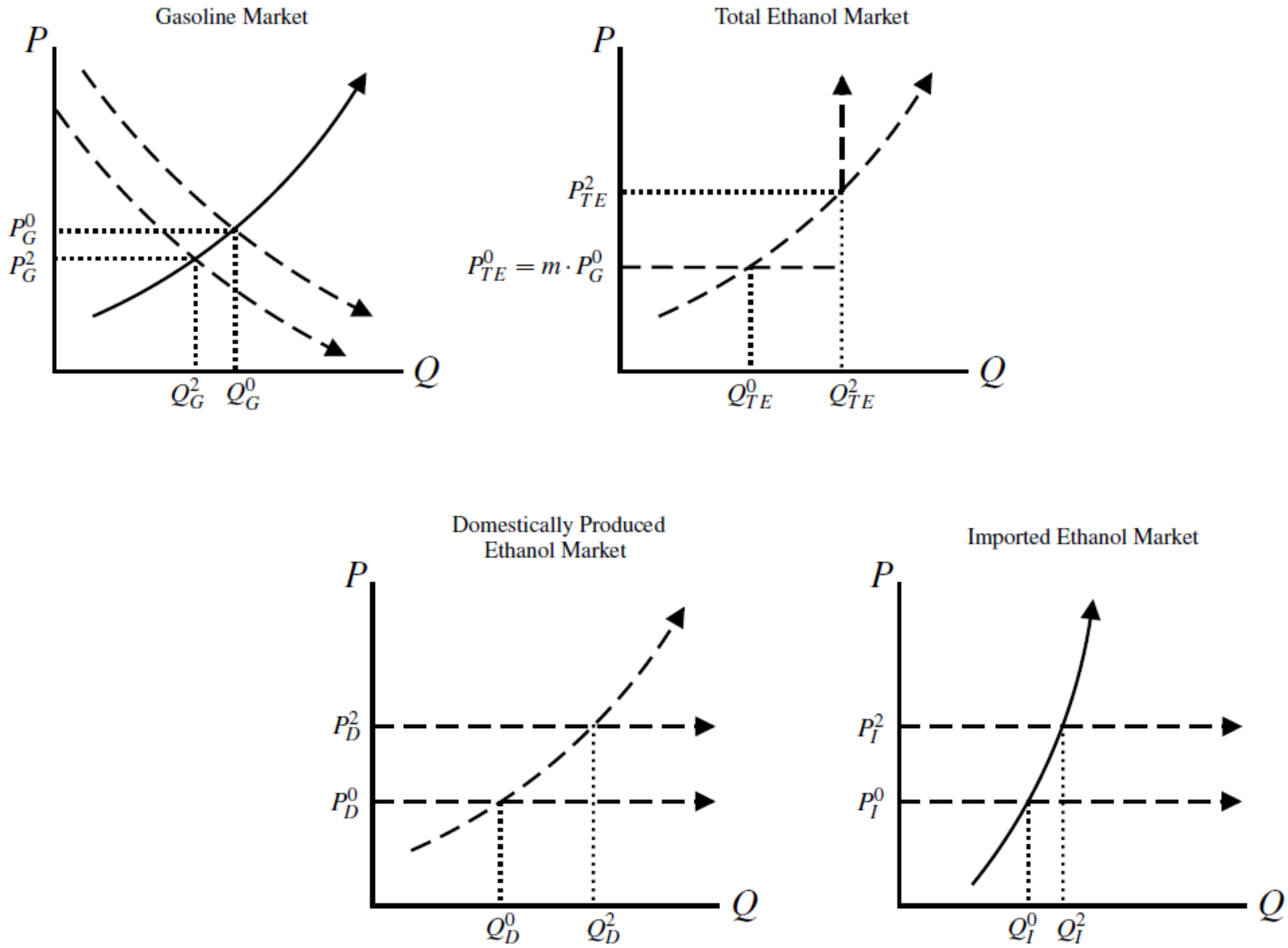


FIGURE 3: EFFECTS OF A MANDATED MINIMUM QUANTITY OF ETHANOL USE IN BLENDED FUEL



Appendix A: Specification of the Equilibrium Displacement Model

The equilibrium displacement model is specified as a 17 equation system characterized by behavioral, equilibrium, and zero-profit equations. Most variables used in the system are defined in tables 2 and 3; the remaining variable descriptions are presented in table A1. Table A2 characterizes the equations and their logarithmic approximations, which are derived following Gardner (1987).

TABLE A1: SUPPLEMENTARY DESCRIPTION OF VARIABLES USED IN MODELING THE BLENDED FUEL MARKETING CHANNEL

Description	Notation	Initial value
Mandated ethanol blending quantity	TE_R	11,223 mil. gal.
Mandate-induced wedge	θ	--
Partial derivative of ethanol production function with respect to corn	f_C	--
Partial derivative of ethanol production function with respect to non-corn inputs	f_{NC}	--
Elasticity of substitution in ethanol production between corn and non-corn inputs	$\sigma_{N,C}$	0.5
Elasticity of substitution in ethanol production between corn and corn inputs	σ_{CC}	--
Elasticity of substitution in ethanol production between non-corn and non-corn inputs	σ_{NN}	--

TABLE A2. BEHAVIORAL, EQUILIBRIUM, AND PROFIT EQUATIONS CHARACTERIZING THE BLENDED FUEL MARKETING CHANNEL

Description	Equation	Logarithmic Approximation
Behavioral equations		
Gasoline equivalent blended fuel demand	$Q_F = F(P_F)$	$E(Q_F) = \eta_F E(P_F)$
Gasoline equivalent blended fuel supply	$Q_F = Q_G + m \cdot Q_{TE}$	$E(Q_F) = B_{GF}E(Q_G) + B_{TE,F}E(Q_{TE})$
Gasoline supply	$Q_G = G(P_G)$	$E(Q_G) = \varepsilon_G E(P_G)$
Total ethanol supply	$Q_{TE} = Q_I + Q_D$	$E(Q_{TE}) = J_{I,TE}E(Q_I) + J_{D,TE}E(Q_D)$
Imported ethanol supply	$Q_I = I(P_I)$	$E(Q_I) = \varepsilon_I E(P_I)$
Domestic ethanol production	$Q_D = D(Q_C, Q_{NC})$	$E(P_D) = K_{CD}E(P_C) + K_{ND}E(P_{NC})$
Corn supply	$Q_C = C(P_C)$	$E(Q_C) = \varepsilon_C E(P_C)$
Non-corn input supply	$Q_{NC} = N(P_{NC})$	$\boldsymbol{E(Q_{NC}) = \varepsilon_{NC} E(P_{NC})}$
<u>First-order condition equation</u>		
Gasoline factor share in blended fuel	$P_F = P_G + \theta$	$E(P_F) = R_{GF}E(P_G) + E(\theta)$
Ethanol factor share in blended fuel	$P_F = J_{GF}P_G + J_{TE,F}\, P_{TE}$	$\boldsymbol{E(P_F) = K_{GF}E(P_G) + K_{TE,F}E(P_{TE})}$
Corn factor share in ethanol production	$P_D f_C - P_C = 0$	$E(Q_C) = E(Q_D) + K_{CD}\sigma_{CC}\, E(P_C) + K_{ND}\sigma_{CN}E(P_{NC})$
Non-corn factor share in ethanol production	$P_D f_{NC} - P_C = 0$	$E(Q_{NC}) = E(Q_D) + K_{CD}\sigma_{N,C}E(P_C) + K_{ND}\sigma_{NN}E(P_{NC})$
Equilibrium equations		
Domestic ethanol market	$P_D = P_{TE} + S$	$E(P_D) = R_{TE,D}E(P_{TE}) + E(S)$
Import ethanol market	$P_I = P_D - T$	$\boldsymbol{E(P_D) - R_{ID}E(P_I) = E(T)}$
Ethanol use mandate	$Q_{TE} = TE_R$	$\boldsymbol{E(Q_{TE}) = E(TE_R)}$
Zero-Profit equations		
Fuel blender	$P_F Q_F = P_G Q_G + P_{TE} Q_E$	
Ethanol producer	$P_D Q_D = P_C Q_C + P_{NC} Q_{NC}$	

Notes:
The function $E(\cdot)$ represents the proportional change of the variable to which the function is applied. For example, $E(A) = \Delta A/A$. Variable descriptions are presented in tables 2, 3, and A1.