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The Impact of Alternative Domestic and Trade Policies for Biofuels on Market Variability in the United States

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Abstract

The development of first generation biofuels, based on existing agricultural crops such as corn and sugarcane, has strengthened the linkage between agricultural commodity markets and energy markets. This paper analyzes the implications of U.S. domestic and trade policies for ethanol in the face of fluctuations in petroleum prices and the domestic supply of feedstock (corn).

The current U.S. policy mix involves a prohibitive tariff on imported ethanol, a fixed subsidy for blending ethanol with gasoline, and a blending or consumption mandate. Under this closed economy case, as the likelihood that the mandate is binding increases the variability of ethanol use declines, the impact of oil price variations on corn prices is reduced, and the impact of corn supply variations on corn prices is increased. The effect on corn prices of changes in domestic biofuel policy, such as a reduction in the level of subsidy or an increase in the mandate, depends on the source of external shocks and their relative magnitudes.

If a non-prohibitive tariff is applied corn prices would still be susceptible to fluctuations in oil prices while total ethanol use exceeds the mandated level, but the impact of domestic corn supply variability on corn prices would be reduced. The magnitude of the reduction depends on the flexibility of the use of corn for ethanol. If the mandate is binding, the impact of corn supply fluctuations on corn prices is increased, but is less than under a prohibitive tariff because blenders can adjust the use of domestic and imported ethanol to achieve the mandate. The impact of world oil price variability on corn prices under a binding mandate largely depends on how the import supply curve for imported ethanol is affected. If the minimum supply-inducing price for imported ethanol is sensitive to petroleum prices, corn prices could be affected by petroleum price fluctuations even when the U.S. ethanol mandate is binding. In the open economy case, the impact of domestic and trade policies for ethanol on the variability of domestic corn prices depends on the relative magnitudes of external shocks as well as on ethanol policies in supplying countries.

Holding the minimum supply-inducing price of imported ethanol and expected imports constant and assuming that total ethanol use exceeds the mandate, the aggregate quantity of ethanol used in the United States is less susceptible to fluctuations in petroleum prices under an *ad valorem* tariff than under a specific tariff. But with a binding mandate, fluctuations in domestic corn supply have a larger impact on corn prices with an *ad valorem* tariff than with

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a specific tariff. The use of a variable tariff for imported ethanol could stabilize corn prices under a binding mandate, but could lead to increased variability in world ethanol prices.

1. Introduction

Global biofuel production is expanding rapidly as countries pursue a range of goals, such as reducing greenhouse gas emissions and enhancing energy security. Governments have generally intervened in their domestic energy markets to promote the consumption and production of biofuels because in most cases the industry would not have developed without support[2] (Tyner and Taheripour 2008). The most popular policy instruments are subsidies (for example, tax exemptions or tax credits) provided to blenders of biofuel and gasoline, and blending or consumption mandates (de Gorter and Just 2007; Jull et al. 2007; Kojima et al. 2007; Rothkopf 2007; Steenblik 2007). The development of first generation biofuels, using feedstock such as corn and sugarcane, has strengthened the linkage between agricultural commodity markets and energy markets (Tyner and Taheripour 2008). There has been a great deal of debate on the design of biofuel policies and their impact on agricultural markets and the environment[3].

Domestic biofuel policies typically involve multiple policy instruments. Studies examining the effects of alternative policy approaches on feedstock and energy markets are scarce. In a series of papers, de Gorter and Just (2007, 2009a) use a partial equilibrium approach to analyze multiple policy instruments. They assess the economic impact of a blending or consumption mandate and an excise-tax credit, and the interaction among these policy instruments in the context of the U.S. fuel market. Considering a biofuel mandate, tax credits, and tariffs as policy options, FAPRI-MU (2009) provides a numerical analysis of the implications of hypothetical changes in U.S. ethanol policies.

Agricultural commodity and energy markets are subject to variability. The implications of alternative policy approaches in the context of fluctuations in petroleum prices and the supply of feedstock have received limited attention. McPhail and Babcock (2008a) use a stochastic partial equilibrium model to examine the effect of U.S. ethanol expansion and mandates on price risk for corn. Thompson et al. (2009) examine empirically how variations in corn yield and the petroleum price affect corn price, ethanol price, and ethanol use in the United States, with and without a mandate. Despite these contributions, the impact of alternative policy

[2] Although there are no production subsidies for ethanol in Brazil, the leading international supplier, the development of its ethanol infrastructure was dependent on taxpayer subsidies.

[3] A number of studies have evaluated the impact of biofuel programs on agricultural and fuel markets and on social welfare, using either partial or general equilibrium analysis (Lundgren 2008). Several studies have concluded that biofuel policies can have unintended economic consequences (Vedenov and Wetzstein 2008; Khanna et al. 2008). Despite such criticisms it seems inevitable that biofuels will play an important role in future energy policies in many countries.

instruments on variability in biofuel and feedstock markets has not been comprehensively evaluated.

Finally, the interaction between biofuel trade policies, particularly import tariffs, and domestic policies on domestic market variability has not been investigated. de Gorter and Just (2008b) investigate the static effects of U.S. ethanol tariffs, but their impact on market variability has not been assessed.

This paper analyzes the implications of U.S. domestic and trade policies for biofuels in the United States in the presence of fluctuations in petroleum prices and domestic feedstock supply. In the first part of the paper we employ a closed economy model (corresponding to the current situation in the United States) in which prohibitively high duties prevent imports of ethanol (currently the total US tariff is about 60 cents per gallon). Building on previous work by de Gorter and Just we develop stochastic supply-demand models to evaluate current domestic biofuel policy instruments: the provision of a fixed tax credit for blending ethanol with gasoline (the current US federal tax credit is 46 cents per gallon having recently been reduced from 51 cents)[4]; and the use of a mandate which requires a minimum blend ratio for ethanol and gasoline or minimum consumption of ethanol[5]. Our focus is on how changes in these policy measures influence market variability in the presence of short-run (annual) fluctuations in petroleum prices and the domestic supply of corn.[6]

In the second part of the paper we extend the model to investigate the effect of non-prohibitive tariffs on market variability in the United States. Allowing imports from developing countries that have a comparative advantage in the production of biofuel feedstock (e.g., cane sugar and palm oil) could allow the United States to diversify its sources of energy supply and reduce greenhouse gas emissions at a lower cost than relying exclusively on domestic supplies of biofuel[7]. With a reduced tariff, ethanol is likely to be

[4] There are also state tax credits. According to de Gorter and Just (2008b), the overall tax credit was 56.93 cents per gallon in 2006.
[5] The Energy Independence and Security Act of 2007 (EISA 2007) calls for 36 billion gallons of annual renewable fuel production by 2022. The Renewable Fuels Standard (RFS) in the Act requires 11.1 billion gallons of renewable fuel production in 2009 and an increase in ethanol production to 15 billion gallons by 2015 (Energy Independence and Security Act of 2007, 110th US Congress). Although U.S. legislation calls for a minimum annual level of biofuel consumption, the mandate is implemented through the use of a minimum blending requirement (ratio of ethanol to total fuel consumption that each fuel-producing firm must meet). This is enforced through a trading credit scheme administered by the U.S. Environmental Protection Agency (EPA). Biofuel producers generate renewable identification numbers (RINs) for each gallon of biofuel they produce. RINs are used by fuel blenders as evidence of compliance with the RFS. If their use of ethanol exceeds the RFS requirement, blenders can sell excess RINs.
[6] We do not consider the use of public storage of petroleum or corn to stabilize domestic markets.
[7] In many developing countries there is significant potential for biofuel production (Jank et al. 2007). This is because tropical and subtropical feedstocks for biofuels usually have more favorable energy and environmental

imported from Brazil, which can produce ethanol from sugarcane at lower costs than the corn feedstock used in the United States[8]. We assume that if the import tariff were reduced, the current mechanism by which the federal government supports ethanol would be modified such that the tax credit paid to blenders would apply only to domestically-produced ethanol or alternatively a production subsidy would be paid directly to domestic ethanol refiners. This would be necessary to avoid the politically unattractive option of subsidizing the use of imported ethanol (Styles 2008). With respect to mandates, we assume that the subsidy alone cannot achieve the required level of ethanol use given expected gasoline price and corn supply. Hence, if the mandate is binding the price of mixed fuels will be higher than the gasoline price.

In addition to examining the implications of reducing the specific tariff currently used by the United States we explore the alternative approaches of using either a non-prohibitive *ad valorem* tariff or a variable tariff (i.e., one that varies inversely with the price of ethanol in order to maintain a stable domestic price). We examine how the type of tariff and changes in its level would affect U.S. market variability under different domestic biofuel policies. Such analysis helps to clarify the implications of domestic biofuel policy design for stability in both the biofuel and feedstock markets and the relationship to trade policy.

Although several key variables are likely to be affected by biofuel and trade policies (such as the quantity of biofuel used[9], the price of feedstock, the price of blended fuel, blended fuel use, and gasoline use), we focus on the price of domestic feedstock (i.e., the corn price) and ethanol use. Variability in corn prices is likely to have significant domestic implications through negative impacts on the agriculture industry or even on the whole economy (Newbery and Stiglitz 1981; Grega 2002). In addition, because of the role of the United States in global markets, increased variability in corn prices could have important international implications (Elobeid and Hart 2007; Muhammad and Kebede 2009). Closer integration of the biofuel sector and agricultural markets increases the susceptibility of these markets to variability in energy prices.

The paper is organized as follows. The next section presents the closed economy model in the context of the U.S. corn-ethanol market and examines the impact of changes in domestic

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balances than crops grown in temperate latitudes. Martinez-Gonzalez et al. (2007) conclude that if distortions in the U.S. ethanol market were eliminated, both the U.S. and Brazil would reap gains from trade.

[8] According to Jank et al. (2007), there is a large potential for sugarcane ethanol production in other developing countries such as Colombia.

[9] High variability in biofuel use may have a negative impact on the biofuel industry by creating periods of boom and bust, causing episodes of bankruptcy and reduced capital investment, such as observed in the U.S. in 2007-2008 (Hochman et al. 2008).

biofuel policies on market variability. In section 3, we use a two-country trade model (U.S. and Brazil) to investigate the impact of non-prohibitive tariffs on U.S. market variability. Some implications of a non-prohibitive *ad valorem* tariff and a variable tariff are discussed in section 4. The last section provides concluding remarks.

2. The Closed Economy Model

In this section we assume that prohibitively high import duties prevent imports of ethanol, and that all domestic consumption is sourced from domestic production. This parallels the current situation in the United States. To investigate the impact of variability in petroleum prices and domestic corn supply, we first need to define the linkage between corn and energy markets and how variability is introduced. We begin with the static model presented by de Gorter and Just (2008a) employing nonlinear supply and demand curves. We then introduce variability into this model and examine the effect of domestic biofuel policies on market variability.

2.1 The linkage between corn and energy markets

Consider a competitive market with an aggregate supply curve for corn (feedstock) S_C and an aggregate non-ethanol demand for corn D_{NE} (this includes domestic food and livestock feed demand, and foreign demand for corn). Any market returns to ethanol by-products (e.g., distillers' grains) are assumed to be reflected in the demand curve. Assuming constant returns to scale, the supply of domestic ethanol S_{DE} is derived from the horizontal difference between S_C and D_{NE} (excess supply). Therefore, the intersection of the supply and demand curves for corn in the absence of ethanol production defines the equilibrium feedstock price p_{NE} and the intercept of the domestic ethanol supply curve (see figure 1)[10].

Following de Gorter and Just we assume an exogenous petroleum price[11] and perfect substitutability between ethanol and fossil fuel[12]. Suppose the energy market is also competitive. Let S_G denote the supply curve for gasoline (perfectly elastic) and p_G the gasoline price, which is the sum of the petroleum price and an excise tax. The demand for

[10] Note that ethanol processing costs are ignored in figure 1.
[11] Since the current share of biofuel in total fuel use is small, the assumption of an exogenous petroleum price is reasonable. Even if the world oil price is endogenous, our principal conclusions are expected to be robust.
[12] The majority of U.S. consumers cannot choose the blend ratio flexibly. Changes in the vehicle fleet to"flex fuel" vehicles will make such a choice possible in the future, as is currently the case in Brazil. But even if biofuel and gasoline are imperfect substitutes, variations in biofuel use are strongly related to variations in the price of gasoline, so relaxing this assumption will not affect our results.

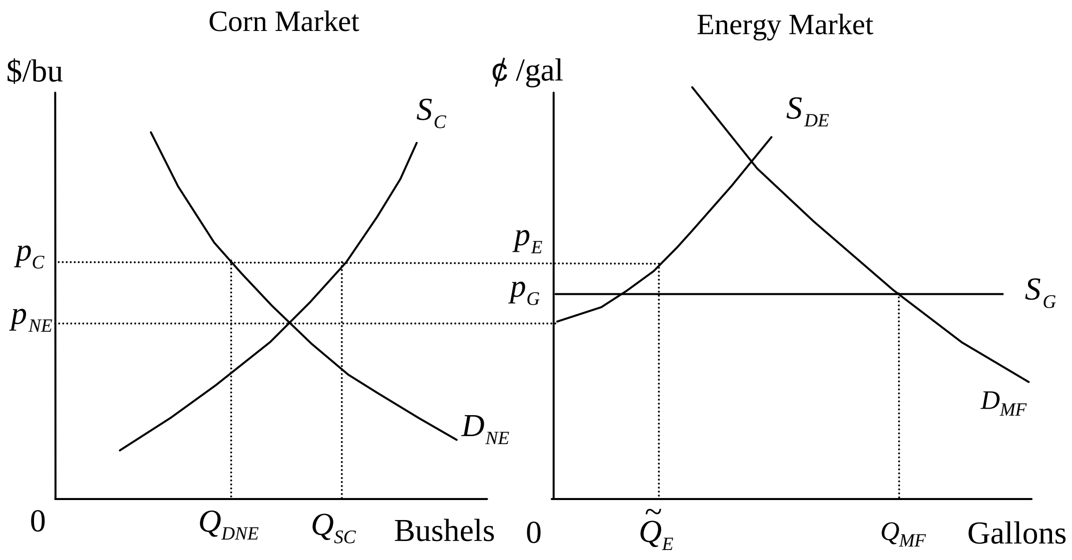

Figure 1: The linkage between domestic corn and energy markets

liquid transportation (mixed) fuel is denoted by D_{MF} . Total fuel consumption Q_{MF} is determined at the intersection of S_G and D_{MF} (if there is no ethanol production, gasoline accounts for all liquid fuel usage). The intercept of the domestic ethanol supply curve is assumed to be higher than the price of oil (the gasoline price minus the tax) in line with the historical pattern of oil prices relative to the cost of corn[13]. Thus, if there are no biofuel policy measures the quantity of domestic ethanol produced and consumed is zero.

Suppose the quantity of ethanol used is given by $\tilde{Q}_E$, then the market (supply) price, p_E , is determined by the supply curve for ethanol. The corn price is determined at p_C which is directly linked to p_E . Total corn use (net value of corn adjusted for the value of by-products) in ethanol production is $Q_{SC} - Q_{DNE}$. The relationship between the corn price and the ethanol price is:

$$p_C = \left(\frac{k}{1-\tau}\right) p_E - c \, . \tag{1}$$

where k represents units of ethanol produced from one unit of corn, τ is the proportion of the value of corn returned to the market in the form of by-products, and c is processing costs. According to de Gorter and Just (2008a; 2009b), the estimate of $k/(1-\tau)$ for corn in the

[13] This applies to most countries, with a few exceptions such as Brazil where the production of ethanol can be competitive without subsidies.

United States is 4.06, which means that the corn price is very sensitive to a change in the price of ethanol.

2.2 Variability in the petroleum price and domestic corn supply

Because we assume that the petroleum price is exogenous, the inverse supply curve for oil is perfectly elastic. The stochastic oil price is expressed as: $p_O = \overline{p}_O + \lambda$, where $\overline{p}_O$ is the expected petroleum price and λ is a random variable with mean zero and variance σ_λ^2. Thus, the inverse supply curve for oil (gasoline) shifts up or down according to the value of the stochastic component.

Introducing variability into corn supply is far more complicated because we need to take account of how such variability (assuming non-ethanol corn demand is fixed) affects the equilibrium price of corn in the absence of ethanol production and consequently derive the inverse supply curve for domestic ethanol. For simplicity, we use constant elasticity supply and demand functions for corn, and assume that output is log-normally distributed (Newbery and Stiglitz, 1981). If aggregate supply and demand elasticities are known, we can obtain the coefficient of variation of the intercept of the inverse ethanol supply curve. We assume that the inverse supply curve for ethanol has a constant coefficient of variation with respect to the ethanol supply price p_E^S whatever the level of ethanol production. In other words, multiplicative shifts in supply are assumed. Additionally, we assume that no technological change occurs and that non-ethanol corn demand is fixed in the short-run.

Let the constant elasticity (non-ethanol) corn demand function be:

$$Q_{DC} = Ap^{\varepsilon},\ \varepsilon < 0, \tag{2}$$

and let the constant elasticity corn supply be:

$$Q_{SC} = Bp^{\eta},\ \eta > 0. \tag{3}$$

where p is corn price. Suppose that the sole source of variation is on the supply side, and that output is log-normally distributed. The inverse corn supply function can be written as:

$$p = (Q_{SC} / B)^{1/\eta},\ Q_{SC} = \overline{Q}_{SC}\theta,\ E\theta = 1,\ Var\theta \cong \sigma_\theta^2,\ CV_{Q_{SC}} \cong \sigma_\theta. \tag{4}$$

By solving $Q_{DC} = \overline{Q}_{SC}$ we obtain:

$$p_{NE} = (A/B)^{\frac{1}{\eta-\varepsilon}}\theta^{\frac{1}{\eta-\varepsilon}}. \tag{5}$$

Therefore, variation in the equilibrium price of corn in the absence of ethanol production p_{NE} depends on the demand and supply elasticities (ε and η). In that case the coefficient of variation of corn price without ethanol production can be expressed as:

$$CV_{p_{NE}} \cong \frac{\sigma_\theta}{\eta - \varepsilon}. \qquad (6)$$

As the demand curve (and/or supply curve) becomes more inelastic, the coefficient of variation of corn price in the absence of ethanol production increases. Using equations (1) and (6) we can obtain the coefficient of variation of the ethanol supply price.

Graphically, if the corn supply curve S_C shifts as depicted in figure 2 (the dotted curves indicate such shifts), the equilibrium price of corn without ethanol production will vary, resulting in upward or down shifts in the minimum supply-inducing price for ethanol (the intercept of the ethanol supply curve). Consequently, the domestic ethanol supply curve S_{DE} shifts as depicted in figure 2.

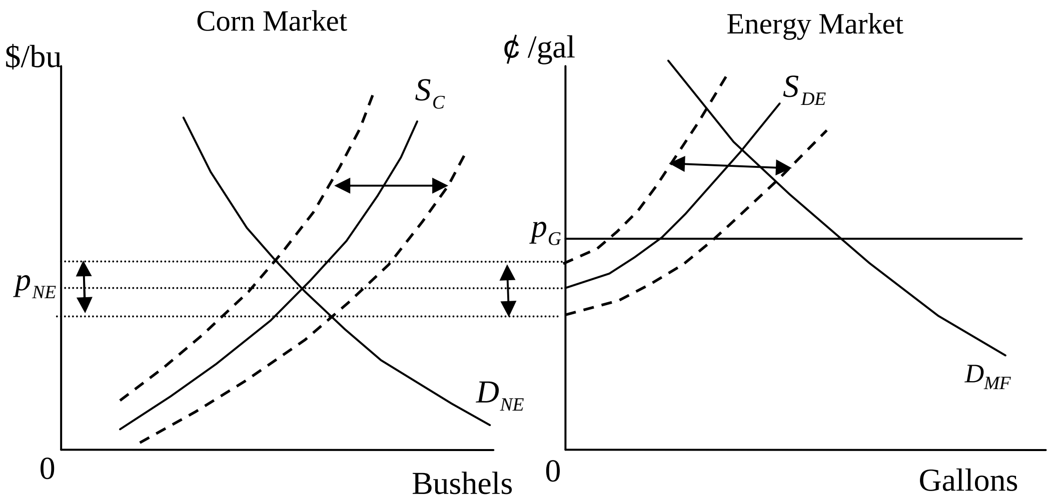

Figure 2: Corn supply variability and shifts in ethanol supply

2.3 Biofuel policies and variability

On the basis of the model presented above we can examine the impact of changes in U.S. biofuel policies on market variability. A fixed tax credit per gallon and an ethanol consumption mandate are the domestic policies considered[14] and there is a prohibitive tariff.

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[14] Domestic agricultural policies such as deficiency payments are relevant. The interaction of farm subsidies with the tax credit and import tariffs is investigated by de Gorter and Just (2009b). Deficiency payments affect the producer price for corn, resulting in a gap between the price paid by consumers and that received by

"Fixed" means that the government does not vary the level of tax credit in the short-run[15]. For ease of exposition[16] we assume that the mandate requires a minimum amount of ethanol be consumed. In reality, a blending mandate is prevalent which means that the consumption of ethanol can vary. This assumption does not affect our principal conclusions because U.S. demand for liquid fuel is inelastic in the short-run and the ethanol demand curve under a blending mandate, which is more inelastic than the fuel demand, is also expected to be very inelastic in the short-run[17]. Given these policy instruments, there are two important cases: either ethanol use exceeds the mandated level or the mandate is binding (ethanol use is equal to the minimum required level)[18]. The distributions of random variables associated with external shocks determine the probability that the mandate will actually be binding. It is useful to analyze these two cases separately to understand how external shocks affect market variability and how changes in policies affect the likelihood that the mandate will be binding.

2.3.1 Ethanol use exceeds the mandate

We assume that a fixed excise tax t per gallon is imposed on motor fuel. A fixed tax credit s per gallon is provided for ethanol. Hence, the inverse ethanol supply curve, inclusive of the tax, shifts downwards by the amount s and if $s > t$, the intercept of the tax and tax- credit-inclusive ethanol supply curve S'_{DE} is lower than that of the original curve S_{DE}. The minimum amount of ethanol consumption required is denoted by $\hat{Q}_E$. Figure 3 depicts the case when the mandated consumption level is exceeded. When the marginal cost of ethanol production with the tax credit at the required minimum level of consumption is lower than the gasoline price, blenders will increase ethanol use voluntarily up to the point at which S'_{DE} intersects p_G (this is the same situation as with a tax credit alone). This is because ethanol producers bid up the price of ethanol (demand price) p_E^D to the gasoline price in order to maximize their benefit (de Gorter and Just 2008). The quantity of ethanol used is given by Q_{DE} ($Q_{DE} > \hat{Q}_E$) and the market price of ethanol (supply price) p_E^S is determined by

producers. The redistribution from taxpayers to producers does not affect the market outcomes considered in this paper.

[15] Tyner and Quear (2006) examine the difference between a fixed and variable subsidy for corn-based ethanol. A variable subsidy could be used to stabilize markets, this may be difficult politically due to budgetary limitations.

[16] With a blending mandate the graphs become much more complicated. For a detailed analysis of a blending mandate, see de Gorter and Just (2008a).

[17] In addition, the ethanol demand curve becomes more inelastic as the minimum blend ratio is reduced. In practice, the current share of ethanol in total fuel consumption is small.

[18] For more detailed discussion of U.S. biofuel mandates, see Thompson et al. (2008).

the initial ethanol supply curve. The supply price of ethanol equals the sum of the petroleum price and the tax credit. The market price for mixed fuels is equal to the gasoline price. Total fuel consumption, Q_{MF}, does not change compared to the case with no ethanol production and gasoline is replaced by ethanol in the amount Q_{DE}. It is apparent that as the level of the tax credit increases, ethanol use increases and gasoline use decreases.

Now consider the effect of fluctuations in the world oil price and domestic feedstock supply. Both of these affect equilibrium ethanol use when this initially exceeds the mandated level. The market supply price of ethanol (corn price) is influenced by oil price fluctuations, but there is no additional impact from the ethanol market. This is because p_E^S is always equal to the oil price plus the fixed tax credit. If the oil price is increased (decreased), p_E^S is also increased (decreased). Also, if the oil price is unchanged, p_E^S is also unchanged regardless of the position of the ethanol supply curve. If there are no constraints to adjustment in ethanol demand, variations in ethanol volume absorb corn supply shocks in a competitive market. If changes in ethanol use are less flexible (e.g., through limited flexibility in the use of corn in ethanol refining)[19], the impact of fluctuations in corn supply on the short-run equilibrium corn price is increased and the impact of oil price fluctuations is reduced.

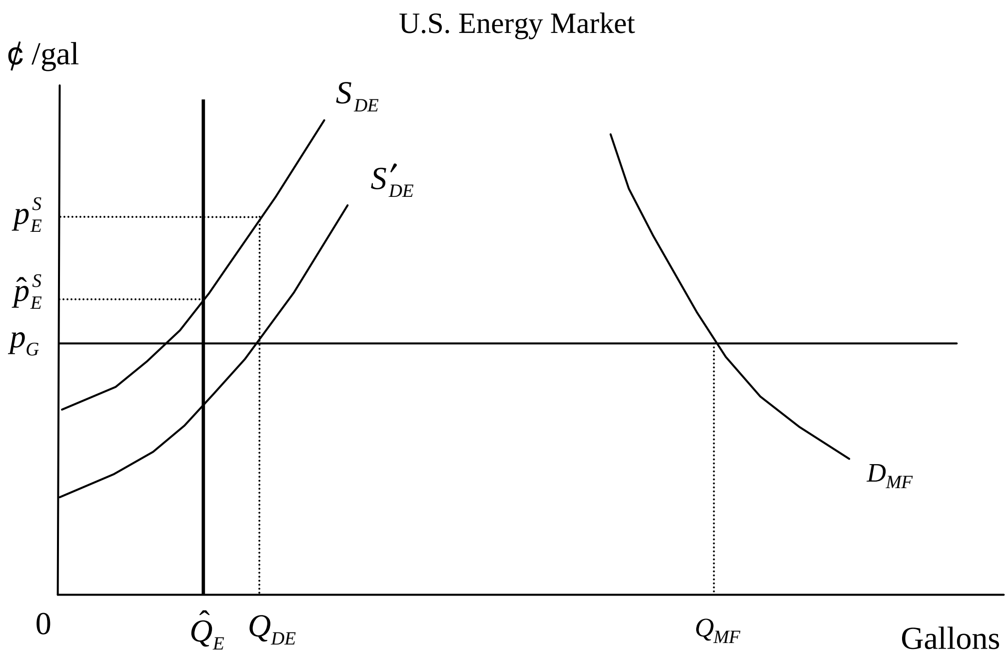

Figure 3: Consumption mandate with a tax credit when the mandate is exceeded

[19] FAPRI-MU (2008) observes that refining capacity represents an important and largely fixed determinant of supply in a given period, whatever the level of net returns to ethanol production.

2.3.2 *The ethanol mandate is binding*

If the marginal cost of ethanol production with the tax credit at the required minimum level of ethanol use is greater than the gasoline price, the demand price for ethanol would have to rise above the gasoline price to meet the mandate, otherwise blenders would be unwilling to use the required level. Thus, if the mandate is enforced[20] and nationally binding, the mixed fuel price has to be above the gasoline price.

Mathematically, since a consumption mandate[21] requires a minimum amount of ethanol $\hat{Q}_E$ be used by fuel consumers, the inverse supply curve for mixed fuels can be written as:

$$p_{MF} = \frac{\hat{Q}_E}{Q_{MF}}(\hat{p}_E^S + t - s) + \left(1 - \frac{\hat{Q}_E}{Q_{MF}}\right)p_G = \frac{(\hat{p}_E^S + t - s)\hat{Q}_E + p_G(Q_{MF} - \hat{Q}_E)}{Q_{MF}}, \tag{7}$$

where $\hat{p}_E^S = S_{DE}^{-1}(\hat{Q}_E)$ (the supply price of ethanol) and $\hat{p}_E^S + t - s \geq p_G$. Differentiating equation (7) with respect to Q_{MF} we have:

$$\frac{dp_{MF}}{dQ_{MF}} = -\frac{(\hat{p}_E^S + t - s - p_G)\hat{Q}_E}{(Q_{MF})^2}. \tag{8}$$

If $\hat{p}_E^S + t - s > p_G$, the first derivative is negative and the second derivative is positive. Therefore, the supply curve is flat at $\hat{p}_E^S + t - s = \hat{p}_E^D$ (the demand price of ethanol) until $\hat{Q}_E$ is satisfied; it is convex-decreasing in total fuel consumption beyond $\hat{Q}_E$ and asymptotic to the perfectly elastic gasoline supply curve. The mixed fuel price is determined by the intersection of the inverse supply and demand curves for mixed fuels, and is higher than the gasoline price. The binding case is depicted in figure 4.

When the mandate is binding, the oil price does not affect the market price of ethanol $\hat{p}_E^S$. It merely affects the price of mixed fuel and gasoline consumption. In addition, variations in corn supply are directly linked to variations in the market price of ethanol (corn price) because ethanol demand is perfectly inelastic and ethanol supply fluctuates.

2.3.3 *The impact of policy changes on market variability*

The tax-credit-inclusive domestic ethanol supply curve S'_{DE} shifts downward as the tax credit is increased. Hence, the likelihood that ethanol use exceeds the required level is increased, given the minimum requirement and the probability distributions for petroleum

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[20] We assume that penalties for violation are prohibitively high so that all blenders comply with the mandate. This is the same assumption as in FAPRI-MU (2008).

[21] de Gorter and Just (2007) discuss the static case of a consumption mandate.

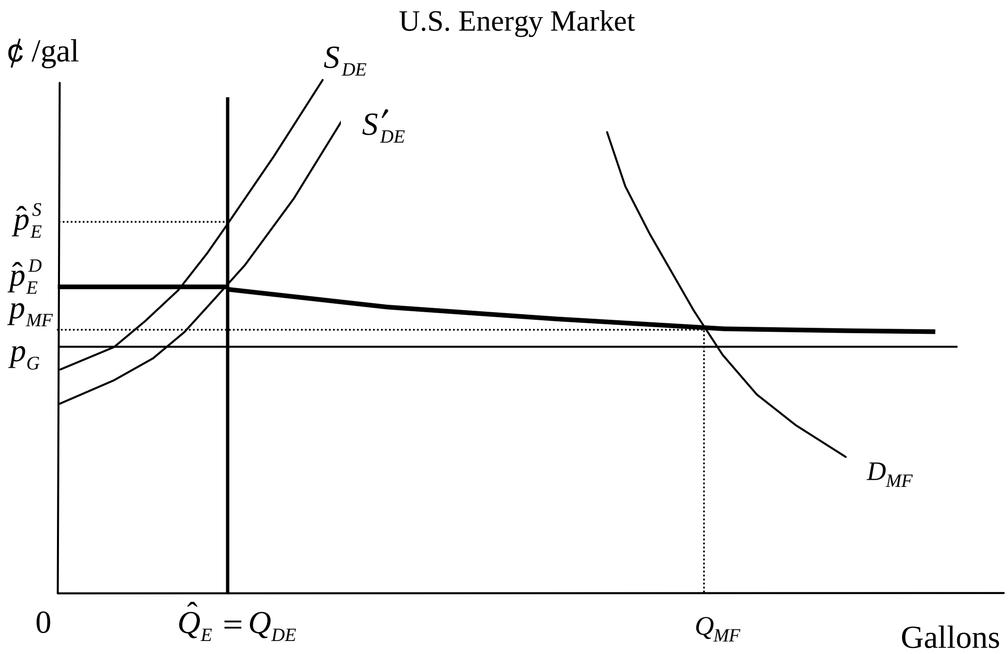

Figure 4: A binding consumption mandate with a tax credit

price and corn supply. This means that *ceteris paribus* an increase in the level of tax credit reduces the impact of corn supply fluctuations on the corn price and increases the impact of petroleum price fluctuations on that price. The variability of ethanol use is increased. The effect of changing the tax credit on corn price variability is dependent upon the relative magnitudes of external shocks. Similarly, the effect of changing the minimum mandated level of ethanol use on corn price variability also depends on the relative magnitudes of external shocks because an increase in the required level, *ceteris paribus*, reduces the likelihood of exceeding the mandated level. Thus, the impact of changes in the mandate on corn price variability again depends on the relative size of fluctuations, as explained above. For example, when fluctuations in oil prices are large relative to fluctuations in corn supply, an increase in the level of tax credit is expected to result in higher variability in corn prices and *vice versa*. When fluctuations in corn supply are relatively high, increased variability in corn prices will result from reducing the tax credit or increasing the level of the minimum requirement and *vice versa*. It is clear that reducing (increasing) the tax credit and increasing (reducing) mandated ethanol use simultaneously will have a mutually reinforcing effect on variability.

3. The Open Economy Model

In this section we extend our models to investigate the effect of non-prohibitive tariffs on market variability. With a reduced tariff, the United States is likely to import ethanol from Brazil under the current market situation. We first discuss important assumptions regarding the subsidy reform that would be required if the tariffs were reduced or eliminated, and the future level of the mandate. We then present a two-country trade model to define the minimum supply-inducing price for imported ethanol and to examine its relationship to the petroleum price. On the basis of the assumptions and the model the impact of a non-prohibitive (specific) tariff on U.S. market variability is assessed.

3.1 Non-prohibitive tariffs, subsidy reform and mandates

For political reasons, reducing or eliminating the import tariff on ethanol would require changes in the mechanism through which the federal government supports the use of domestic ethanol. As mentioned above, the U.S. government currently provides a credit of 46 cents per gallon to companies that blend ethanol with gasoline. All ethanol imported into the U.S. (except for imports under the Caribbean Basin Initiative) is subject to an import tariff and a “secondary duty” amounting to a combined total of roughly 60 cents per gallon. If the import tariff were reduced or eliminated under the current mechanism, taxpayers could end up subsidizing Brazilian ethanol producers. In other words, the tariff currently imposed on imported ethanol exists to offset the credit that foreign suppliers would otherwise receive.

Two options could be considered to avoid subsidizing foreign ethanol suppliers (Styles 2008).[22] First, the tax credit could be modified so that it applies only to domestically produced ethanol. However, administering a two-tier ethanol subsidy system could be problematic. A second option would be to shift the point of subsidy from the blender to the ethanol producer by providing an ethanol production subsidy. Although some problems may arise regarding such changes, not least through international obligations through the World Trade Organization, we assume that if the import tariff were to become non-prohibitive, the subsidy mechanism would be modified so that American tax dollars would not subsidize the use of Brazilian ethanol.

In the future, the mandated minimum level of biofuel use is to increase in the United States. If the level of tax credit or production subsidy provided to domestic ethanol producers is

[22] de Gorter and Just (2008b) assume that the tax credit is applicable to both domestic and import supplies. If the aim is solely to increase the use of ethanol in preference to gasoline this could be a cheaper alternative than subsidizing domestic production. However, it is unlikely to be feasible politically.

unchanged, the likelihood that the mandate will be binding will increase and the blended fuel price will have to rise above the gasoline price. If only domestic ethanol is available, the price of blended fuels will be high, resulting in significantly reduced fuel consumption. If Brazilian ethanol is available due to a reduction in tariffs, the blended fuel price will be reduced because blenders can replace some domestic ethanol by imports. Domestic ethanol production would be reduced and ethanol imports would increase. Whether or not the mandate is binding depends on the relative positions of the domestic and import supply curves for ethanol.

In sum, for the open economy model we assume that:

a) Subsidies are only applied to domestically produced ethanol (we shall continue to use the term "tax credit" to refer to the incentive provided to use ethanol in the United States, while recognizing the possibility that this might actually be a production subsidy).
b) Mandated ethanol use will be higher than the current level (it can not be achieved by the subsidy alone).
c) The import tariff will be reduced or eliminated (for ease of exposition we assume that this is a single tariff, rather than the compound tariff currently applied in the United States).
d) Imported ethanol is available from Brazil (this is a two-country model that does not take into account ethanol trade involving other countries)[23].
e) The excess supply curve of ethanol from Brazil is not affected by random variations in the supply of sugar cane (the only source of agriculturally-related variability in the model is attributable to short-run shifts in the supply of corn).

3.2 The trade model

Before we consider the effect of a non-prohibitive tariff on market variability, it is essential to understand the Brazilian ethanol market, how the import supply curve (in the United States) is derived, and the relationship between the "world" (i.e., Brazilian) ethanol price and the petroleum price.

First, suppose there are no U.S. imports of ethanol. What happens in the ethanol market in Brazil and what is the price of ethanol? The equilibrium price of ethanol is determined in relation to the price of gasoline in Brazil even if there is a difference in fuel efficiency. Since ethanol provides fewer miles per gallon than gasoline, Brazilian drivers know that ethanol is price-competitive only when it costs no more than 70 percent of the domestic price of

[23] Although some other countries import ethanol from Brazil, we assume for simplicity that there is no import demand except from the United States.

gasoline (Xavier 2007). de Gorter et al. (2009) argue that the ratio of miles per gallon derived from ethanol to miles per gallon derived from gasoline is estimated to be 0.70. What is the shape of the demand curve for ethanol? Because flex-fuel vehicles (FFVs) are prevalent and the share of ethanol in total fuel use is high in Brazil, consumers can choose either ethanol or gasoline (blended with anhydrous ethanol) flexibly based on their relative prices (relative consumer prices). This implies that as a substitute for gasoline the demand curve for ethanol is quite elastic given the expected gasoline price p_{GB}, inclusive of the fuel tax[24]. In addition, all fuels are required to be blended with 25 percent ethanol, which is the minimum requirement. Therefore, we assume that the demand curve for ethanol in Brazil is perfectly inelastic at the mandated level $\hat{Q}_{BE}$, and beyond that point, it is downward-sloping but quite elastic, D_{BE} as seen in figure 5. Note that perfectly inelastic demand at the mandated level is a simplifying assumption.

Suppose that Brazilian ethanol use exceeds the mandated level in the initial state, which corresponds to the current situation because Brazil's level of ethanol consumption is around 40 percent of the motor fuel market (Xavier 2007). In that case the supply price p_{BE}^{S} is determined at the intersection of the Brazilian ethanol supply curve S_{BE}[25] and the tax-inclusive demand curve D'_{BE}. The fuel tax on ethanol is currently lower than that on gasoline due to a tax exemption, but unlike in the United States this is positive[26]. Thus, the demand price of ethanol p_{BE}^{D} is higher than the supply price by the amount of the tax on ethanol and its equilibrium price is expected to be around 70 percent of the tax-inclusive price of gasoline[27]. The quantity of domestic ethanol consumed in Brazil is given by Q_{BE}.

The minimum supply-inducing price for imported ethanol, excluding the fuel tax and tariff in the United States, is the no-trade supply price of Brazilian ethanol p_{BE}^{S} plus transportation costs (about 16 cents per gallon; Tokgoz and Elobeid 2006). Hence, the intercept of the import supply curve is this minimum supply-inducing price for imported ethanol plus a fuel

[24] According to Xavier (2007), Brazilian drivers stopped using pure ethanol when the price reached $ 0.90, about 85 percent of the price of gasoline at the time. McPhail and Babcock (2008b) discuss the shape of the ethanol demand in the United States. Ethanol demand is expected to be quite elastic at increased quantities of ethanol use.
[25] There are two types of ethanol in Brazil: anhydrous ethanol (the type blended with gasoline) and hydrous ethanol (used in flex-fuel vehicles). But abstracting from differences in vehicle technology the two forms can be viewed to be essentially the same. Thus, we consider aggregate ethanol supply and demand.
[26] The fuel tax less the tax credit (or tax exemption) is negative in the United States. The supply price is higher than the demand price.
[27] This is because if the ethanol price, inclusive of tax, is lower than 70 percent of the gasoline price, consumers purchase additional ethanol. An increase in the demand for ethanol would increase the consumer price to the equilibrium level of around 70 percent of the gasoline price.

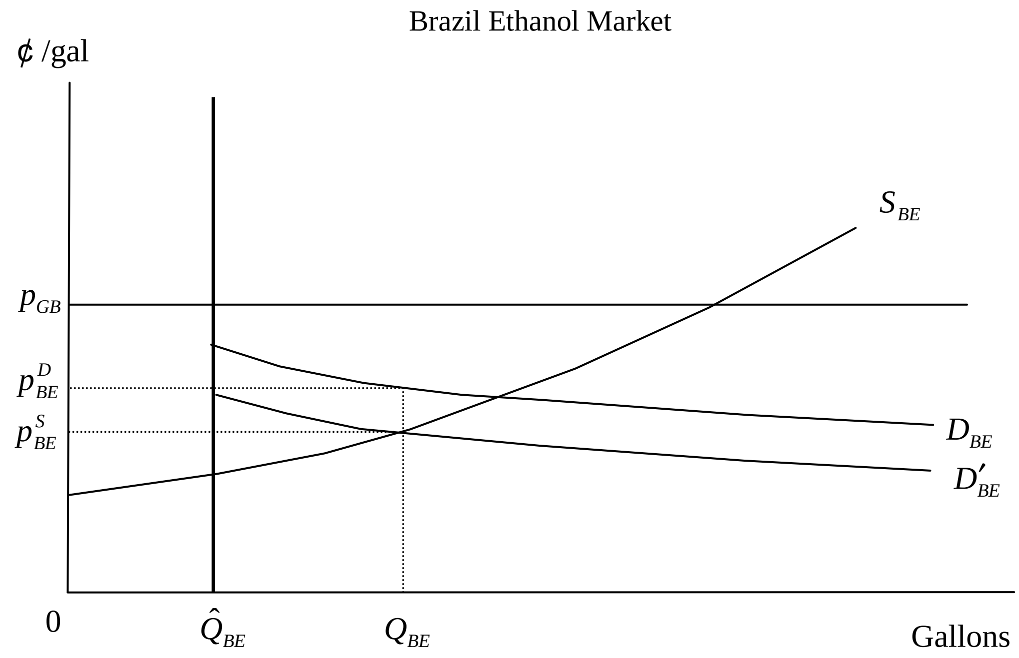

Figure 5: The Brazil ethanol market with no trade

tax if there is no tariff. If a specific import tariff is imposed, the import supply curve shifts up by the amount of that tariff. How is the shape of the import supply curve determined? Because we assume that Brazil imposes a mandate on ethanol use[28], import supply is elastic up to the price which leads to a binding mandate in Brazil, and beyond that point, it becomes more inelastic. Hence, the import ethanol supply curve S_{IE} is kinked at the price which makes the Brazilian ethanol mandate binding. At that price the quantity of imported ethanol is $Q_{BE} - \hat{Q}_{BE}$. These conditions are illustrated in figure 6.

With imported ethanol use given by $\tilde{Q}_{IE}$, the supply price of ethanol p_E^S equals the world (Brazilian) ethanol price p'^S_{BE}, which is higher than the no-trade equilibrium price (it is assumed that the United States is a large country importer). Total ethanol supplied is Q_{TES}, and the mandate is binding in Brazil (i.e., ethanol use in Brazil is $\hat{Q}_{BE}$). In this case, $\tilde{Q}_{IE} = Q_{TES} - \hat{Q}_{BE}$. The price of sugar will be increased because in Brazil the vast majority of refiners are capable of producing either sugar or ethanol, depending on relative prices, and ethanol production is increased if the price of ethanol rises (a reduction in the supply of sugar will lead to a higher sugar price). The demand price for ethanol p_E^D in the United States is

[28] Even if there is no mandate, Brazil might be expected to protect the domestic ethanol market (e.g., through an export restriction) if the price of Brazilian ethanol deviated substantially from the gasoline price in Brazil.

determined by the tax-inclusive import ethanol supply curve S_{IEt} (in figure 6, we assume that there is no tariff).

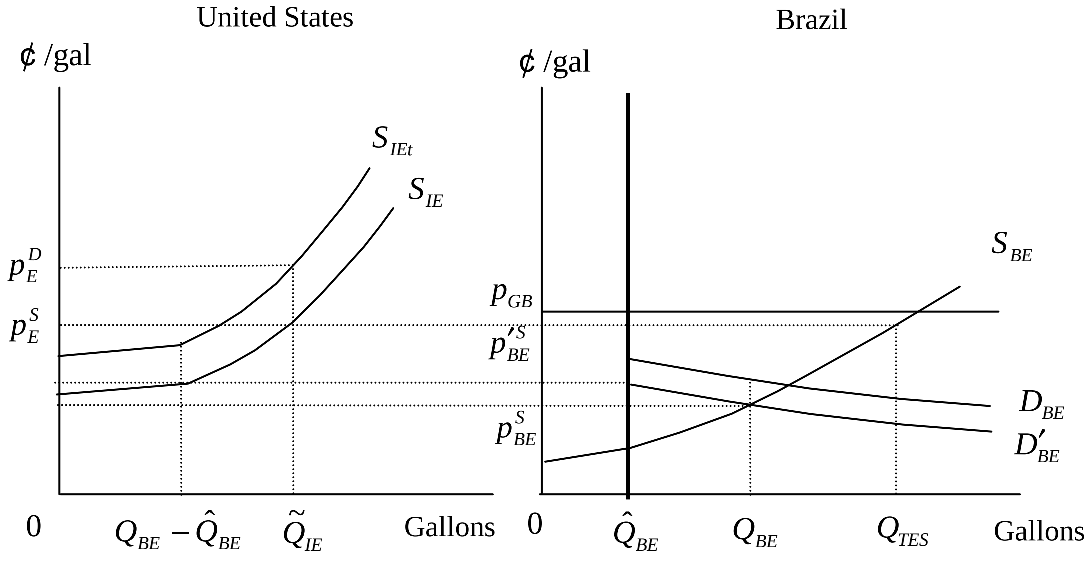

Figure 6: The Brazil ethanol market and the import supply curve in the U.S.

If the world oil price fluctuates, this affects not only the U.S. gasoline price but also the Brazilian ethanol supply price because changes in the oil price affect Brazilian ethanol demand. If the price of Brazilian ethanol changes (this depends on how the consumer price of gasoline in Brazil is affected by world oil price fluctuations), the minimum supply-inducing price for imported ethanol in the United States also changes.

The impact of petroleum price fluctuations on the import supply curve for ethanol is shown in figure 7. As in previous figures, D'_{BE} is the tax-inclusive demand curve and the no-trade equilibrium price of Brazilian ethanol is p^S_{BE}. S_{IE} is the supply curve for imported ethanol. Let us regard these as defining the initial state. If the petroleum price rises, the ethanol demand curve in Brazil will shift upwards to D''_{BE} because the gasoline price will be increased[29]. p''^S_{BE} is the new supply price of Brazilian ethanol (the minimum supply-inducing price is increased) and S''_{IE} is the new import supply curve. This curve is elastic up to the price that results in a binding mandate in Brazil and above that level it corresponds to S_{IE} because excess supply response is the same in both cases. In contrast, a reduction in the petroleum price will result in reduced domestic demand for ethanol in Brazil D'''_{BE} (providing that the consumption mandate is not binding in Brazil) and hence a lower market supply price

[29] The impact of oil price fluctuations varies between anhydrous and hydrous ethanol (Elobeid and Tokgoz 2006 and 2008). However, we are interested in the overall impact of world oil price on ethanol demand.

for ethanol p'''^{S}_{BE} . Hence the intercept of the import supply curve in the United States S'''_{IE} shifts downwards. S'''_{IE} is kinked at the price that results in the binding mandate in Brazil and becomes inelastic above that price. It corresponds to S_{IE} at the price which leads to a binding mandate with the initial demand curve D'_{BE} .

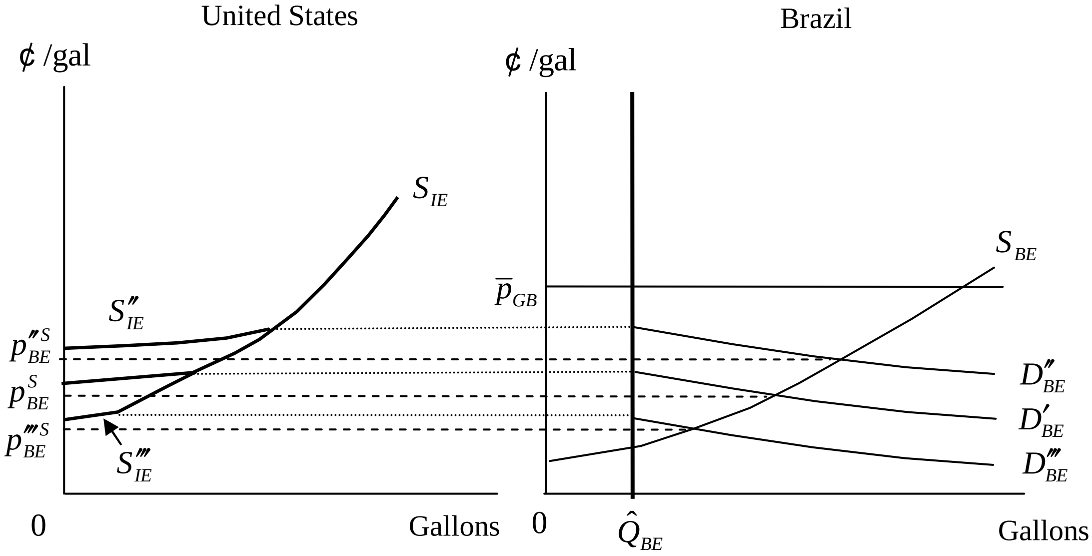

Figure 7: The impact of petroleum price fluctuations on the import supply curve

3.3 The impact of external shocks on market variability with non-prohibitive tariffs

We are now able to examine the impact of external shocks on market variability in the United States with a non-prohibitive specific tariff and a tax credit applicable only to domestically produced ethanol. As discussed above, the level of mandate is binding initially if only domestically produced ethanol is available. As in the closed economy case, we examine the two cases in which U.S. ethanol use exceeds the mandate and the mandate is binding separately. We then examine how changes in policies influence market variability.

3.3.1 U.S. ethanol use exceeds the mandate

If ethanol use exceeds the mandated level, the demand price for ethanol is equal to the demand price of gasoline in the United States because currently the share of ethanol in total fuel consumption is small and because FFVs account for small share of all vehicles. If FFVs were prevalent or if ethanol could be blended with gasoline safely above the current blend ratio (E10), the equilibrium price of ethanol could be lower than the gasoline price due to the difference in fuel efficiency, but even so, the demand price for ethanol will be tied to the gasoline price.

The aggregate ethanol supply curve S_{AE} (the bolded curve) is the horizontal sum of the domestic ethanol supply curve S'_{DE}, including the fuel tax and tax credit, and the imported ethanol supply curve S'_{IE}, including the fuel tax and import tariffs. Unless the minimum supply-inducing price for imported ethanol, inclusive of the tax and tariffs, is less than the gasoline price, ethanol use never exceeds the mandated level because we assume that the marginal cost of domestic ethanol production with the tax credit is higher than the gasoline price. Ethanol use exceeds the mandated level $\hat{Q}_E$ if the aggregate supply curve intersects the perfectly elastic gasoline supply curve at a point above the mandated level. Blenders increase ethanol use up to the point where the marginal cost is equal to the gasoline price in order to maximize their benefits. This situation is depicted in figure 8. Total ethanol use is Q_{AE}, being composed of domestic ethanol Q_{DE} and imported ethanol Q_{IE}. The demand price for ethanol is equal to the gasoline price. The supply price of domestic ethanol p_E^S is determined by S_{DE}. The supply price of Brazilian ethanol is equivalent to the gasoline price in the United States minus the fuel tax and the tariff. With a reduction in the tariff S'_{IE} shifts downwards and imports of ethanol increase.

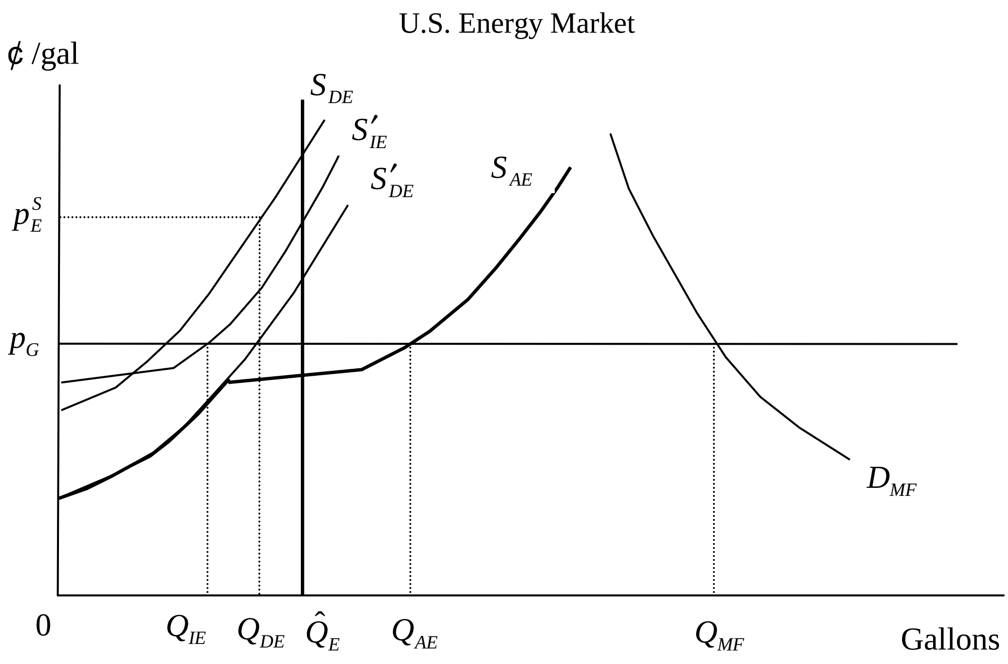

Figure 8: U.S. ethanol use exceeds the mandate with non-prohibitive tariffs

When total ethanol use exceeds the mandate, the supply price of domestic ethanol is the sum of the world oil price and a tax credit whatever the level of use. If domestic ethanol demand adjusts to external shocks rapidly enough, the corn price is sensitive to petroleum price variations but is not sensitive to domestic corn supply variations. The use of imported ethanol and the world ethanol price depend on how changes in the world oil price affect the import supply curve. If, for example, Brazilian ethanol use exceeds the mandated level and a decrease in world oil price leads to a reduction in the minimum supply-inducing price for imported ethanol, ethanol imports may be unchanged. As argued above, this depends on the sensitivity of gasoline consumer prices in Brazil to the world oil price.

3.3.2 U.S. ethanol use is at the mandated level

If the marginal cost of ethanol use (the aggregate supply curve) is above the gasoline price at the mandated level, the U.S. ethanol mandate is binding. Figure 9 illustrates this case with a non-prohibitive tariff. As in the closed economy case, the demand price of ethanol p_E^D would have to rise above the gasoline price to achieve the mandate; otherwise blenders would be unwilling to use that amount of ethanol. Again, with a binding mandate the quantities of domestic and imported ethanol are given by Q_{DE} and Q_{IE}, respectively.

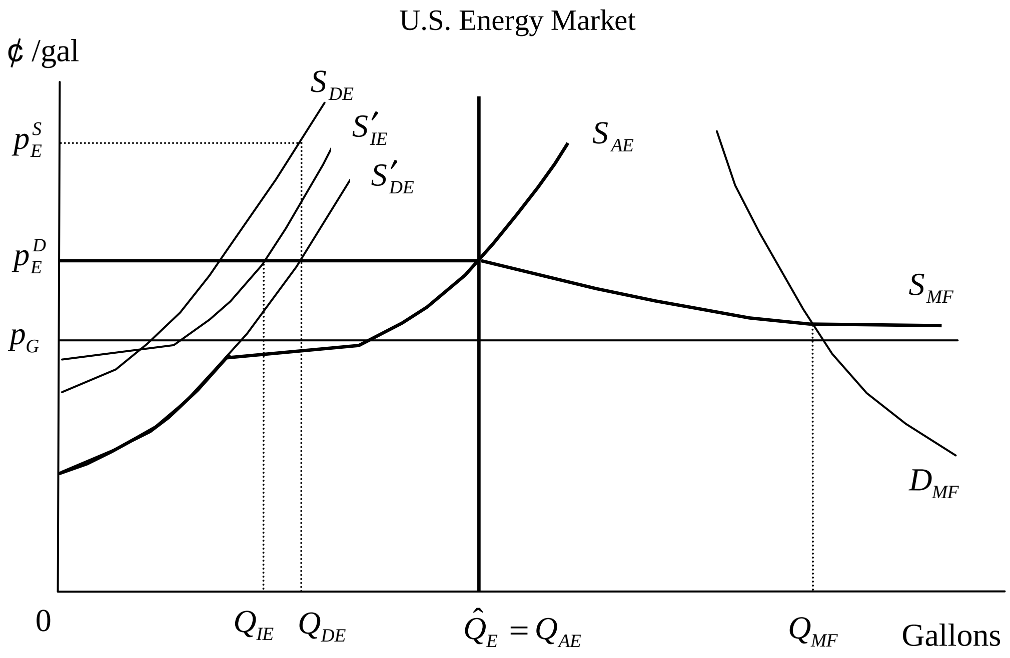

Figure 9: The binding mandate with non-prohibitive tariffs

In the closed economy model, oil price fluctuations do not affect the price of corn when the mandate is binding. With non-prohibitive tariffs, however, variability in the world oil price can affect the corn price when the mandate is binding. The U.S. has to use a certain amount of ethanol. If the world oil price is reduced, there is no impact on the U.S. domestic ethanol supply curve but the world ethanol supply price would fall due to changes in ethanol demand in Brazil (assuming flexible demand for ethanol in Brazil). If Brazilian ethanol use exceeds the mandate initially and the world ethanol supply price falls, Brazilian ethanol becomes relatively cheaper for the United States. Since the aggregate supply curve shifts downward, blenders will increase the use of imported ethanol and reduce the use of domestic ethanol, resulting in a lower price of corn. This case is depicted in figure 10. When a partial shift in the import supply curve is larger than that in the domestic ethanol supply curve due to corn supply variations, the variability in the corn price could be high. If the world oil price does not affect the world ethanol supply price, it does not affect the corn price under a binding mandate.

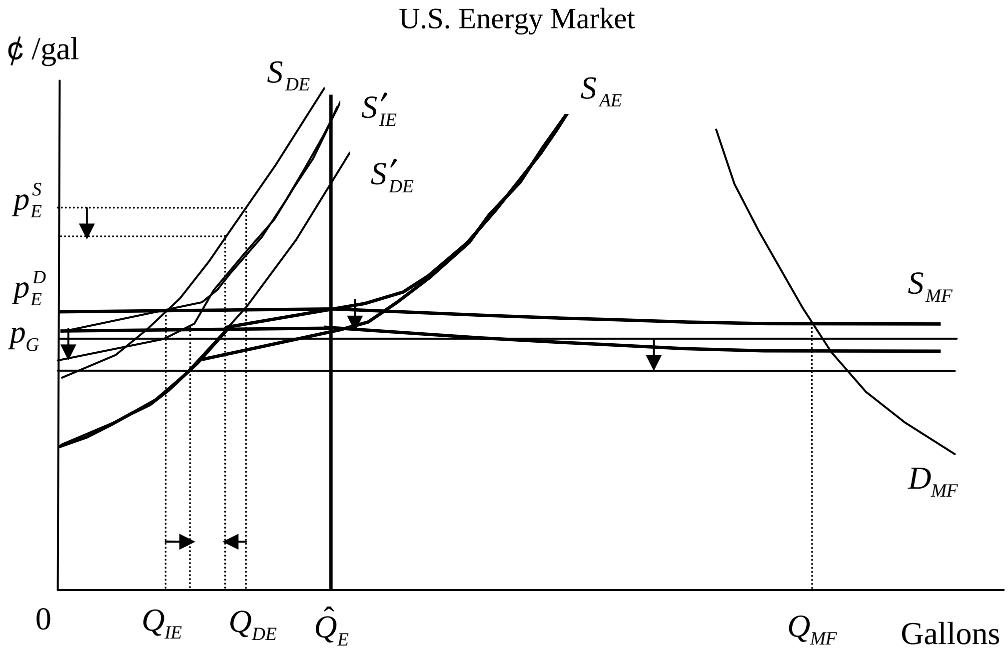

Figure 10: The impact of world oil price fluctuations on the supply price of domestic ethanol

If the mandate is binding, domestic corn supply fluctuations affect the corn price. However, it is important to note that even in this case, the impact of fluctuations in domestic corn supply on the corn price is smaller with a non-prohibitive tariff than with a prohibitive tariff. This is because blenders can change imported ethanol use to achieve the mandatory blend requirement. For example, if domestic corn supply is reduced (dotted lines), the domestic supply curve for ethanol shifts upward and so does the aggregate ethanol supply curve (the ethanol demand price is increased). If a prohibitive tariff is in place, blenders must purchase domestic ethanol, resulting in an increase in ethanol supply price and hence the corn price. If blenders can use relatively cheaper imported ethanol to achieve the mandated level, domestic ethanol use can be reduced (here we assume that the import supply curve is stable). Consequently, the impact of corn supply fluctuations on corn price becomes smaller. This example is depicted in figure 11. At the same time, world ethanol price is increased because the quantity of imported ethanol is increased. With trade part of the instability in domestic corn price caused by domestic corn supply fluctuations in the U.S. is transferred to the world ethanol market if the U.S. mandate is binding.

If both the domestic and import supply curves for ethanol shift simultaneously, variability in the corn price could be higher compared to the case with a fixed domestic ethanol demand. Suppose that domestic and imported ethanol supply curves shift upward and that the shift in import supply is larger than that in domestic supply. In this extreme case, blenders will increase domestic ethanol use even if domestic corn supply is reduced because imported ethanol becomes "relatively" more expensive. In the corn market, corn supply is decreased but corn demand is increased simultaneously, resulting in upward pressure on the corn price.

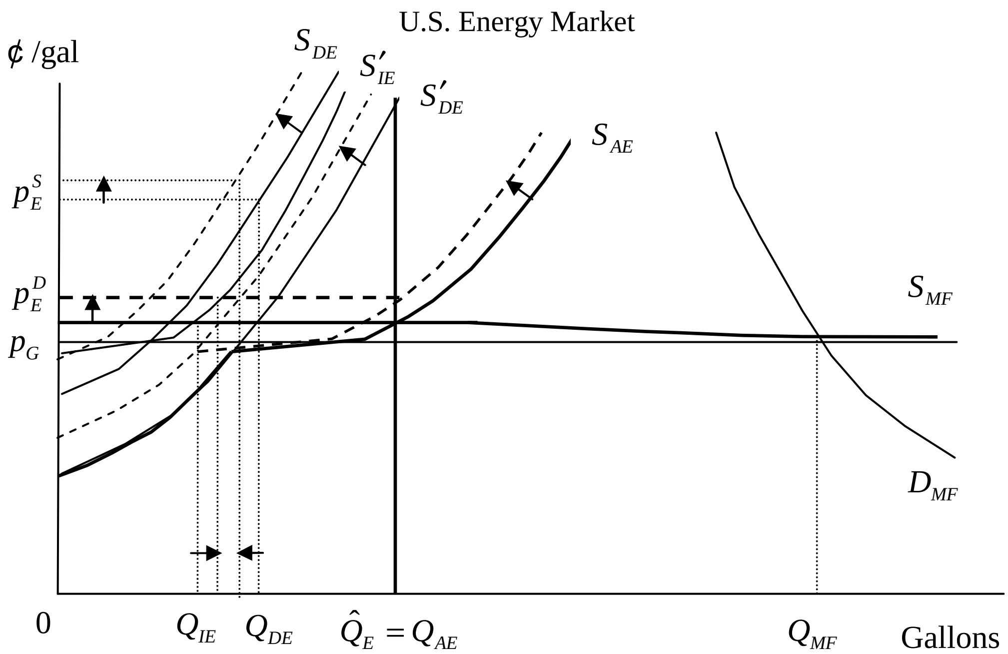

Figure 11: The impact of a reduction in corn supply on the supply price of domestic ethanol with imports

3.3.3 The impact of policy changes on market variability

Given the tax credit and minimum mandatory use, a reduction in the tariff increases the probability that total ethanol use will exceed the required level in the presence of external shocks. This increases the impact of petroleum price fluctuations on corn prices. It reduces the impact of corn supply variations if the petroleum price does not affect the supply curve for imported ethanol under a binding mandate. Even if the likelihood that the mandate becomes binding is unchanged regardless of the level of the tariff (i.e., the tax credit is reduced and/or the minimum required level of ethanol use is increased), the impact of domestic corn supply fluctuations on corn price is reduced if imported ethanol supply is sufficiently positive and relatively stable. With mandates, part of the domestic corn supply shock is transmitted to the world ethanol market[30]. If import supply is sensitive to petroleum price fluctuations, an increase in the likelihood of exceeding the mandate could result in a reduced aggregate impact on the corn price. The impact of changes in domestic and trade policies for ethanol on the variability of domestic corn prices depends on the relative magnitudes of external shocks as well as how petroleum price fluctuations affect excess supply (i.e., it depends on Brazilian policies for ethanol as well as those of other importers). This is because changes in policies influence the relative impacts of petroleum price and domestic corn supply fluctuations through changes in the likelihood that the mandate will be binding. A reduction in the tariff, an increase in the tax credit, or a decrease in the minimum mandatory use reduces the likelihood that the mandate becomes binding, *ceteris paribus*.

4 Alternative Trade Policies and Market Variability

In this section we discuss the impact of alternative trade policies on market variability. As alternative trade intervention policies a non-prohibitive specific tariff, a non-prohibitive *ad valorem* tariff, and a variable tariff (variable in the short-run) are considered.

4.1 Specific tariff versus an ad valorem tariff

With a specific tariff shifts in the supply curve of imported ethanol are parallel movements. The slope of the curve is steeper with an *ad valorem* tariff and shifts cause the curve to rotate upwards and downwards. If total ethanol use exceeds the mandate, there is no difference between the two types of supply curve in terms of the effect of external shocks on the domestic corn price. The position and slope of the import supply curve is relevant only to

[30] If there is little or no domestic ethanol production due to a reduction in tariffs and the tax credit, such a shock would still be reflected in the domestic corn price.

changes in the quantity of imported ethanol (and hence the world ethanol price) when the world oil price fluctuates (providing that the minimum supply-inducing price of imported ethanol is unchanged).

When the mandate is binding, however, specific and *ad valorem* tariffs differ in terms of their impact on U.S. (and world) market variability. As discussed above, changes in domestic corn supply affect both domestic and imported ethanol use with non-prohibitive tariffs. When ethanol import supply is stable, the impact of corn supply fluctuations on corn price is no larger with a non-prohibitive tariff than with a prohibitive tariff. Because the import supply curve for ethanol with an *ad valorem* tariff has a steeper slope than with a specific tariff, changes in the demand for both domestic and imported ethanol due to corn supply shocks are smaller. Hence, fluctuations in domestic corn supply have a bigger impact on the supply price of domestic ethanol with an *ad valorem* tariff compared to a specific tariff. Variability in imported ethanol use is smaller with an *ad valorem* tariff, resulting in less variability in the world ethanol price. In contrast, corn price variability is smaller with a specific tariff and variability in the world ethanol price is higher. This implies that there is a trade-off between domestic and world ethanol price variability[31].

4.2 A variable tariff

Rather than using a fixed specific or *ad valorem* tariff, a tariff that varies inversely with the supply price of domestic ethanol might be used.[32] If total ethanol use exceeds the mandate, the level of the tariff affects the quantity of imported ethanol. Thus, if the tariff is variable, aggregate ethanol use in the United States can be stabilized. However, variability in world prices of ethanol and sugarcane are likely to be higher compared to the case of fixed tariffs because the demand for imported ethanol becomes more variable.

If the mandate in the United States is binding, a variable tariff can help to stabilize the domestic price of corn. With a binding mandate and a constant tariff, when domestic corn supply falls, the ethanol demand price rises, domestic ethanol use falls, and the use of imported ethanol increases (see figure 11). If tariffs are reduced in this case, the ethanol demand price can be stabilized. Domestic ethanol use falls further and imports of ethanol

[31] Our argument is similar to that in Bale and Lutz (1979) who examine the effects of different trade intervention policies on international price instability. They find that an *ad valorem* tariff results in smaller price instability in an exporting country and larger price instability in an importing country in comparison to a fixed specific tariff or free trade.
[32] Variable tariffs have been used in a variety of countries as a device to stabilize domestic agricultural prices. International obligations may limit the use of such a tariff, particularly if there is a binding on the maximum tariff that can be applied.

expand more. As a result, the pressure on domestic corn prices from continued domestic production of ethanol is reduced. With a variable tariff, the opposite effects will apply when fluctuations in the supply of corn lead to lower domestic feedstock prices. Corn prices will be more stable with a countercyclical tariff on ethanol than with a fixed tariff.

Because imports of ethanol become more variable with a countercyclical tariff, variability in the world ethanol price is increased. In addition, under a binding mandate with a fixed tariff if the minimum supply-inducing price of ethanol is reduced due to changes in the world oil price, the quantities of domestic and imported ethanol will adjust, resulting in a reduced corn price under a binding mandate (see figure 10). In contrast, with a variable tariff imports and domestic ethanol use will be more stable and this will increase the stability of domestic corn prices but at the expense of higher variability in world ethanol prices. In sum, with a binding mandate a variable tariff in an importing country (U.S.) has the effect of transferring the burden of adjustment to fluctuations in the availability of the domestic feedstock (corn) onto the world market for ethanol (and presumably sugar)[33].

5 Concluding Remarks

An increase in the use of biofuel as a substitute for fossil fuels has tightened the linkage between agricultural commodity markets and energy markets. This paper investigates the impact of U.S. domestic and trade policies for biofuel in the face of fluctuations in world oil prices and the domestic supply of feedstock (corn).

With a prohibitive tariff on imported ethanol, as the likelihood that a mandate on the use of ethanol becomes binding increases, variability in ethanol use declines, the impact of variations in world oil price on corn prices is reduced, and the impact of variations in corn supply on price is accentuated. Therefore, the effects of changes in domestic biofuel policy, such as a reduction in the level of subsidy under mandates and an increase in the level of the mandate, on corn prices depend on the relative magnitudes of external shocks.

With non-prohibitive tariffs, when total ethanol use exceeds the mandated level, the corn price is susceptible to fluctuations in world oil prices but the marginal impact of ethanol production on the variability of the corn price is small or eliminated, depending on the flexibility of the use of corn in ethanol refining. If the mandate is binding, the marginal impact of domestic corn supply fluctuations on corn price is higher, but smaller than with a

[33] Again, our argument is similar to that in Bale and Lutz (1979). They mention that a variable levy results in higher price instability in an exporting country and smaller price instability in an importing country in comparison to a fixed specific tariff or free trade.

prohibitive tariff because blenders can adjust domestic and imported ethanol use to achieve the mandatory blend requirement. The impact of world oil price variability on corn prices under a binding mandate depends on how the supply curve for imported ethanol is affected. If the no-trade supply price of Brazilian ethanol is sensitive to the petroleum price, corn prices in the United States could be affected by fluctuations in the price of petroleum even if the mandate is binding. Hence, the implications of changes in domestic and trade policies for ethanol for variability in domestic corn prices depend on the relative magnitudes of external shocks as well as on Brazilian ethanol policies.

If expected imported ethanol use is constant, the minimum supply-inducing price of imported ethanol is unchanged, and total ethanol use exceeds the required level, the aggregate quantity of ethanol used in the United States is less susceptible to a petroleum price shock with an *ad valorem* tariff than with a specific tariff. Under a binding mandate, fluctuations in domestic corn supply have a larger impact on corn prices with an *ad valorem* tariff compared to a specific tariff. A countercyclical variable tariff on ethanol under a binding mandate could stabilize the corn price in comparison to a fixed tariff, but would likely result in higher variability in world ethanol prices. There is the trade-off between domestic and world ethanol supply price variability.

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Appendix

Proof of equation 6

Let the constant elasticity (non-ethanol) corn demand function be

$$Q_{DC} = Ap^{\varepsilon},\ \varepsilon < 0. \tag{1}$$

Also let the constant elasticity corn supply be

$$Q_{SC} = Bp^{\eta},\ \eta > 0. \tag{2}$$

Suppose that the source of risk lies on the supply side, and that output is log-normally distributed (θ is log-normally distributed). The inverse corn supply function can be written as:

$$p = (Q_{SF} / B)^{1/\eta},\ Q_{SF} = \overline{Q}_{SF}\theta,\ E\theta = 1,\ Var\theta \cong \sigma^2,\ CV_{Q_{SF}} \cong \sigma. \tag{3}$$

Let $\theta = e^Z$ and $Z \sim N(\mu, \sigma^2)$, then $E\theta = Ee^Z = e^{\mu+\sigma^2/2}$. Since we assume $E\theta = 1$, $\mu = -\sigma^2/2$. The variance of θ is

$$Var(\theta) = (e^{\sigma^2} - 1)e^{2\mu+\sigma^2} = e^{\sigma^2} - 1. \tag{4}$$

Since $e^x \cong 1 + x$, $Var\theta = \sigma_\theta^2 \cong \sigma^2$. By solving $Q_{DF} = \overline{Q}_{SF}$ we have

$$p = (A/B)^{\frac{1}{\eta-\varepsilon}}\theta^{\frac{1}{\eta-\varepsilon}}. \tag{5}$$

Therefore, variation in equilibrium corn price without ethanol production depends on the demand and supply elasticities (ε and η). Let $1/(\eta - \varepsilon) = \beta$. Then, expected value of corn price without ethanol production can be derived as:

$$Ep = (A/B)^{\beta} E\theta^{\beta} = (A/B)^{\beta} \exp\left(\frac{1}{2}\beta(\beta-1)\sigma^2\right), \tag{6}$$

where $E\theta^{\beta} = \exp\left(\beta\mu + \frac{1}{2}\beta^2\sigma^2\right) = \exp\left(-\frac{1}{2}\beta\sigma^2 + \frac{1}{2}\beta^2\sigma^2\right) = \exp\left(\frac{1}{2}\beta(\beta-1)\sigma^2\right)$.

The variance of corn price without ethanol production is given by:

$$\begin{aligned} Var(p) &= E\left\{((A/B)^{\beta}\theta^{\beta} - Ep)^2\right\} = (A/B)^{2\beta} E\theta^{2\beta} - (A/B)^{2\beta}(E\theta^{\beta})^2 \\ &= (A/B)^{2\beta}\left\{\exp\left(\beta(2\beta-1)\sigma^2\right) - \exp\left(\beta(\beta-1)\sigma^2\right)\right\} \\ &= (A/B)^{2\beta}\exp\left(\beta(\beta-1)\sigma^2\right)\left\{\exp\left(\beta^2\sigma^2\right) - 1\right\}. \end{aligned} \tag{7}$$

Its coefficient of variation is given by

$$CV_p = \frac{\sqrt{(A/B)^{2\beta}\exp\left(\beta(\beta-1)\sigma^2\right)\left\{\exp\left(\beta^2\sigma^2\right)-1\right\}}}{(A/B)^{\beta}\exp\left(\frac{1}{2}\beta(\beta-1)\sigma^2\right)} = \sqrt{\left\{\exp\left(\beta^2\sigma^2\right)-1\right\}}. \tag{8}$$

By Maclaurin series approximations this expression can be rewritten as:

$$CV_p \cong \sqrt{\beta^2\sigma^2} \cong \beta\sigma_\theta = \frac{\sigma_\theta}{\eta - \varepsilon}. \quad (9)$$

Note that this result relies on accuracy of approximations $e^x \cong 1 + x$. Mathematically $x > -1$ because $x \cong \log(1+x)$ or $e^x > 0$. When x is close to 0, the difference is very small, but if x is greater than 0.42, the difference is greater than 0.1, which is large. If x is large, for example 5, this approximation is apparently not accurate. But we find that it is accurate in our model because σ_θ^2 and $\beta^2\sigma^2$ are close to zero.