Competitiveness of Brazilian Sugarcane Ethanol Compared to US Corn Ethanol

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ABSTRACT

Corn ethanol produced in the US and sugarcane ethanol produced in Brazil are the world's leading sources of biofuel. Current US biofuel policies create both incentives and constraints for the import of ethanol from Brazil, and together with the competitiveness and greenhouse gas intensity of sugarcane ethanol compared to corn ethanol will determine the extent of these imports. This study analyzes the supply-side determinants of this competitiveness and compares the greenhouse gas intensity of corn ethanol and sugarcane ethanol delivered to US ports. We find that while the cost of sugarcane ethanol production in Brazil is lower than that of corn ethanol in the US, the inclusion of transportation costs for the former and co-product credits for the latter changes their relative competitiveness. We also find that the relative cost of ethanol in the US and Brazil is highly sensitive to the prevailing exchange rate and prices of feedstocks. At an exchange rate of US\$1 = R\$2.15 the cost of corn ethanol is 15% lower than the delivered cost of sugarcane ethanol at a US port. Sugarcane ethanol has lower GHG emissions than corn ethanol but a price of over \$113 per ton of CO_2 is needed to affect competitiveness.

Keywords: economic competitiveness, renewable fuel standard, ethanol trade policy

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The demand for biofuel in the US has experienced dramatic growth in the last several years. In the US, corn ethanol is currently the predominant biofuel, and is already using over 30% of the corn produced. Brazil, which uses sugarcane as a feedstock for ethanol, was the largest producer of ethanol in the world until 2005, and is still the largest exporter of ethanol. While the US has limited potential to expand total cropland and thus any increase in corn acreage must be met largely through reduction in the acreage of other crops, Brazil is using only 1.6% of its total cropland and pasture land, and 5% of its cropland for sugarcane ethanol production. It has considerable capacity to allow expansion of cropland and sugarcane production without competing with food production (Nassar et al., 2008; Goldemberg et al., 2008). Sugarcane ethanol is also more efficient than corn ethanol in its use of land, as it is possible to obtain over 45% more ethanol per unit of land than corn ethanol (RFA, 2009; USDA, 2009; CONAB, 2008).

The cost-competitiveness of sugarcane ethanol in the world market appears to be quite variable. Brazil has been exporting 16%-20% of its ethanol production for the last five years. Recent news reports, however, indicate that due to rising costs of ethanol in Brazil and supply shortfalls ethanol exports from Brazil to the US in January 2010 were 20% lower than those a year ago and there is a possibility that Brazil could even begin importing ethanol from the US (Carvalho, 2010; Agroline, 2010; REUTERS, 2009).

The observed market prices of sugarcane ethanol and corn ethanol depend on both supply-side and demand-side factors in each of the two countries and on the policies that affect biofuel trade. Demand side factors include the mandates for blending biofuel with gasoline in the two countries, the price of oil, the blender’s tax credits and the substitutability between gasoline and ethanol (which depends in part on the price of oil and the vehicle fleet structure). Serra et al.

(2009) show that when biofuel mandates are binding, the price of biofuel is determined by the price of the feedstock while if demand for biofuel is constrained by blending limits then it is more likely to be determined by the price of oil. In other cases, both demand and supply side factors influence the price of biofuels. A review of empirical studies using time series price data to explain the correlations between the price of oil, ethanol and feedstock in the US and Brazil can be found in Serra et al. (2009).

The focus of this paper is more modest. It examines the supply-side factors that influence the production costs of corn and sugarcane ethanol in the US and Brazil, their relative competitiveness and the potential for gains from trade in biofuels. Specifically, we analyze the components of the production costs of corn and sugarcane ethanol using detailed information about the production process of corn in the Midwestern US and sugarcane in São Paulo state in Brazil. We compare the costs of sugarcane ethanol delivered to the US port with that of corn ethanol in the US and explore the sources of cost advantage for each production process, as well as factors that could undermine cost competitiveness. We also analyze the sensitivity of our comparative cost estimates to exchange rates and feedstock prices. As shown in Figure 1, the exchange rate between the US dollar (US$) and Brazilian *reias* (R$) has shown significant variability in the last several years.

We also use information about the production process of each type of ethanol to obtain life-cycle greenhouse gas (GHG) emissions for both types of ethanol using a consistent methodology. We discuss the implications of our results for the potential for trade reversals between US and Brazil and the role of existing biofuel policies and a potential carbon pricing policy in influencing the competitiveness of corn ethanol and sugarcane ethanol.

A few studies have examined the evolution of ethanol production costs in the US and Brazil. The OECD (2006) estimates the cost of corn ethanol to be US$0.29 per liter and of sugarcane ethanol in Brazil (excluding transportation costs to US) to be US$0.22 per liter in 2004 prices.

Hettinga et al. (2009) used an experience curve approach to look at the change in the production cost of dry-grind ethanol in the US from 1980-2005 and reported production costs of US$0.31 – 0.32 per liter corn ethanol in 2005. Van den Wall Bake et al. (2009) also used an experience curve approach to analyze the changes in sugarcane ethanol production costs in Brazil. They reported average production costs of US$0.34 per liter sugarcane ethanol for 2000-2004, using an exchange rate of US$1 = R$2.3. Hettinga et al. (2009) also compared US production cost of ethanol with that of sugarcane ethanol production in Brazil using the results reported by Van den Wall Bake et al. (2009) and reported that total production cost of sugarcane ethanol in Brazil is 39% lower than corn ethanol in the US, in 2005, using an exchange rate of US$1 = R$3.6. Gallagher et al. (2006) use the cost of sugar (as the feedstock, instead of sugarcane) and a process based approach to obtain a theoretical estimate of the refinery cost of sugarcane ethanol and the value of its co-products in Brazil; they compare this cost with that of corn ethanol in the US. They find that neither production process has an inherent cost advantage over the other and that much of the variation in competitiveness over the years 1973-2002 is cyclical in nature. They do not, however, disaggregate the causes of the difference in competitiveness of corn and sugarcane ethanol in any period.

We find that on average (for the 2006-2008 period) the domestic production cost of sugarcane ethanol in Brazil is 24% lower than corn ethanol in the US at an exchange rate of US$1 = R$2.15. This exchange rate is the average rate for the 2006/07 agricultural year[1]. However when transport cost of sugarcane ethanol from Brazil to the US is included and co-product credit for corn ethanol is taken into account, the cost of sugarcane ethanol is 17% higher than corn ethanol. These estimates are highly sensitive to the prevailing exchange rate. The market price of feedstocks is also an important factor but to a lesser extent than the exchange rate. Direct GHG emissions of sugarcane ethanol at the US port are 53% lower than corn ethanol and 74% lower than gasoline. However, the carbon price needs to be higher than $113 per ton of

CO_2 in order for carbon pricing to affect the cost competiveness between corn and sugarcane ethanol. We discuss the implications of the cost-competitiveness and relative GHG intensity of sugarcane and corn ethanol, as well as US biofuel policies for the trade pattern in ethanol between US and Brazil, and the costs of meeting biofuel mandates in the US.

The paper proceeds as follows: In section 1, we give a brief overview of ethanol production in the US and Brazil. Section 2 presents data sources and the methodology used to calculate the cost of production of corn and sugarcane ethanol, and discusses cost components relative to each other. Section 3 presents our estimates of GHG emissions and discusses the implications of a carbon pricing policy. Section 4 presents sensitivity analysis on factors that affect cost competitiveness. Section 5 discusses policy implications and concludes.

1. Background: Ethanol Production in the US and Brazil

The US and Brazil are the two largest ethanol producers with production levels of 34 B liters and 24.5 B liters, respectively, in 2009. Both countries have been producing ethanol since the 1970s (Figure 2) with the US surpassing Brazil in production levels since 2006. The share of corn going into ethanol production has increased from 5% in 2000 to 30% in 2008 (USDA, 2009; RFA, 2009). The increase in corn ethanol production was first driven by the MTBE ban in 2005 which led to increased demand for ethanol as a fuel oxygenate. However, the bigger push came from the Renewable Fuel Standard (RFS) which initially mandated 28.35 B liters by 2012 and later increased these mandates under the Energy Independence and Security Act (EISA) of 2007. The current EISA RFS mandates the use of 136 B liters of biofuel by 2022. A portion of this mandate has to come from "advanced biofuel," that is non-starch ethanol and reduces GHG emissions by more than 50% compared to gasoline. Sugarcane ethanol from Brazil could qualify as an "advanced biofuel" depending on its GHG intensity and it could also compete directly with corn ethanol under the "traditional biofuel" category. Biofuels under the "advanced biofuel" category are allowed to meet at least 14% of the total mandate while the “traditional biofuel” category is capped at meeting 42% of the mandate in 2022.

The US provides other support for biofuels as well, such as a volumetric tax credit to blenders of ethanol (that is larger than the fuel tax and hence operates as a net subsidy on ethanol) and a tariff on imported ethanol. The tax credit on ethanol is given regardless of where it is produced and the tariff is set such that it more than offsets the subsidy. The tax credit was $0.13 per liter until 2007 and is now set at $0.12 per liter. There is also a tariff on biofuel imports of $0.14 per liter plus an ad valorem tariff of 2.5%.

In the presence of these policies, sugarcane ethanol could compete in the “traditional biofuel” classification if its delivered price at US ports plus the net tariff is lower than that of corn ethanol. Alternatively, if the price of gasoline is high enough and the domestic ethanol industry is capacity constrained, imports could still be viable since blenders would still find it profitable to blend even high-priced sugarcane ethanol with gasoline. In addition, if the corn ethanol mandate is binding and there is insufficient domestic corn ethanol production capacity in the US to meet the RFS, then sugarcane ethanol imports would occur even if it is more expensive than corn ethanol. These policies also imply that for sugarcane ethanol to meet part of the RFS mandate for “advanced biofuel” its GHG intensity should be lower by 50% relative to conventional gasoline. Under future climate legislation that puts a price on carbon, the GHG intensities of corn and sugarcane ethanol could also affect competitiveness relative to each other and relative to gasoline.

In 2007 and 2008, with oil prices in the range of US$69 – 96 per barrel, biofuel consumption in the US exceeded the RFS mandate for those years. The wholesale price of corn ethanol ranged between US$2.24 – 2.47 per liter and was similar to the volumetric price of gasoline despite its lower energy content. High profit margins for corn ethanol producers imply that entry to the industry was limited and capacity to expand production is likely to have been limited; making it profitable to import sugarcane ethanol even if it was more expensive than corn ethanol.

Brazil has been producing ethanol on a large scale since it instituted the PROALCOOL program in 1975 in response to the first oil crisis, a currency crisis, and fluctuating sugar prices (Moreira and Goldemberg, 1999). With PROALCOOL, the government provided numerous incentives to build ethanol mills, improve infrastructure for ethanol distribution, and increase the availability of ethanol-only vehicles. In 1999 ethanol and sugar markets were liberalized. Though there is less government intervention in the biofuel market in Brazil, it also has an ethanol blend mandate of 20-25%, an ethanol tax credit and an ethanol import tariff of 20%. Ethanol receives no subsidy but the fuel tax on ethanol is at least 30% lower than the tax on gasoline.

Domestic ethanol consumption in Brazil is expected to grow due to growth in demand for fuel as well as the increasing share of flex-fuel vehicles (FFVs) in the vehicle fleet. In 2008, 87.2% of new vehicle sales were FFVs (F.O. Licht, 2009). However, ethanol producers are also actively pursuing market growth outside their borders. The US is currently the largest buyer of Brazilian exports, followed by the Netherlands and Japan. Brazil exported 17% of its production from March 2008 to April 2009. In 2007, it was projected that exports will grow to 36 B liters by 2017 or almost one-third of Brazil's production (InfoFNP, 2008). However, internal demand pressures in Brazil, exchange rates and US biofuel policies will influence the extent to which these projections are realized.

2. Cost of Production

2.1 Sugarcane Ethanol

Sugar/ethanol mills in Brazil typically obtain 70% of their sugarcane from owned or leased farm land and the remaining 30% from independent producers. The cost of growing feedstock produced by mills differs from that of independent sugarcane producers because of economies of scale and the use of more advanced technology. We calculate the costs of sugarcane ethanol using sugarcane grown by independent producers and by mills themselves using a variety of data sources. Detailed data on the costs of growing sugarcane by independent producers are obtained from Brazil's annual agricultural yearbook published by FNP (InfoFNP, 2008). Costs of refinery production are obtained from mills in Sao Paulo. The cost of production for sugarcane ethanol consists of the cost of feedstock production (including operating expenses and the cost of land) as well as cost of conversion of sugarcane to ethanol at the refinery. To compare the cost of imported sugarcane ethanol to domestically produced corn ethanol, we also calculate the cost of transporting ethanol from refineries in Brazil to US ports.

2.1.1 Feedstock cost

Sugarcane is grown on a six-year cycle, where one planting year is followed by an initial harvest after 12-18 months and four succeeding harvests. *Ratoon* cultivation follows each harvest except for the last harvest which is followed by field reform in preparation for the next cycle. We average the annual costs for six years to obtain the cost of sugarcane production for independent sugarcane growers. Averaging costs over the 6-year cycle is considered reasonable since at any point in time a farmer is assumed to have one-sixth of the field in a different stage of the cycle. Table 1 shows the cost components for a typical six year cycle for an independent sugarcane producer. The average yield for an independent sugarcane ethanol producer is 75 Mt per hectare. This is lower than that observed on land owned by the mills in São Paulo which averaged 81 Mt per ha in 2007 (CONAB, 2008).

As shown in Table 1, the cost of production per hectare is highest during the first planting year and diminishes with each harvest as yield also diminishes. Based on market data, fertilizer application rate per hectare in the establishment year is 600 kg of a formula consisting of 5% nitrogen (N), 25% phosphorous (P), and 25% potassium (K). In the succeeding *ratoon* years, 500 kg with 20% N, 5% P and 20% K is used. These application rates are comparable those assumed by Macedo et al. (2008) [1]. The price per metric ton (Mt) of the NPK mix is R$940 per Mt and R$1040 per Mt for 5-25-25 and 20-5-20 formulas respectively (in 2007 prices). Price and quantities for other chemicals are obtained from FNP (InfoFNP, 2008). Chemicals included are pesticides, insecticides, nematicides, and *maturador*, or ripener, which ripens sugarcane before harvest. Herbicide, insecticide, and nematicide are applied during planting in the first year. Herbicide is also applied at a lower, fixed quantity per year for each of the five ratoon years. The ripener is applied during each of the five harvest years.

Machinery used for sugarcane production includes terracing in the first year, ratoon elimination, ratoon thinning for maximum yields, harrowing and fertilizing, chemical application, distribution of filter cake and *vinasse* (residues from the refining process used as fertilizer), and harvesting. Cost estimates are obtained from FNP (InfoFNP, 2008). The expense allocated to machinery and manual labor depends on the level of mechanization. We assume that 33% of harvest operations is mechanized, which is representative for the state of São Paulo[2] in 2007 (CONAB, 2008). The cost of feedstock transport from farm to refinery is R$6.7 per Mt of feedstock based on an average distance of 22 km from the field to the mill.

Table 2 summarizes the average cost for each component (over the six years) included in our calculations. The first column shows the cost in R$, while the next three columns show the cost in US$ using the minimum and maximum exchange rates observed from 2006-2008, as well as our central exchange rate of US$1=R$2.15. The first column shows that the total operating cost for sugarcane production is R$2,892 per hectare.

The per liter cost is obtained by dividing the per hectare cost with the ethanol yield per hectare of 6,134 liters. The ethanol yield per hectare is based on an ethanol yield of 81.6 liters of anhydrous per Mt of sugarcane, which is the 2007 yield average for São Paulo, and an average sugarcane yield of 75 Mt per hectare (CONAB, 2008; InfoFNP, 2008). The operating costs of

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[1] We assume N, P, and K application rates of 30, 150, and 150 kg per hectare respectively in the planting year and

feedstock production are, thus, calculated to be R$0.47 per liter of ethanol.

The imputed cost of land and management (C_L^{BR}) is defined as the residual returns after covering operating cost. It is calculated as the difference between the revenue per hectare and the cost of production. In Brazil, sugarcane is priced according to its ATR (*Açucar Total Recuperável* or Total Recoverable Sugar). The price of ATR (P^{ATR}) is determined both by sugarcane producers and buyers, with the goal of equitable distribution of the profits among producers and buyers. It is based on the cost of production of sugarcane as well as the prices of ethanol and sugar, which are the primary uses of sugarcane (UNICA, 2009). The following formula is used:

$$P^{ATR} = \frac{1}{Q^{ATR}}\left(P^E Q^E \times \frac{C^S}{C^E} + P^{SU} Q^{SU} \times \frac{C^S}{C^{SU}} \right) \qquad (1)$$

where the first term in parenthesis is revenue from ethanol production ($P^E Q^E$) multiplied by the share of sugarcane production cost in total production cost of ethanol (C^S/C^E) and the second term is revenue from sugar production ($P^{SU}Q^{SU}$) multiplied by the share of sugarcane production cost in total cost of sugarcane production (C^S/C^{SU}). The sum of the two terms is divided by the total available ATR (Q^{ATR}). Thus, a portion of revenues from both ethanol and sugar production is allocated to sugarcane producers, according to the share of sugarcane production cost in total cost of producing ethanol and sugar. We use the reported price of ATR, P^{ATR} which had an average value of R$0.29 per kg for 2006-2008, the average yield of sugarcane per hectare (Q_s), and an ATR value in São Paulo of 141 kg per Mt of sugarcane in 2007 to calculate C_L^{BR} as follows:

$$C_L^{BR}\ (R\$/ha) = Q_s\ (Mt/ha) \times ATR\ (kg/Mt) \times P^{ATR}\ (R\$/kg) - C_s \qquad (2)$$

where C_s is the operating cost per hectare, Q_s = 75 Mt/ha and ATR = 141 kg/Mt (CONAB, 2008). We thereby obtain C_L^{BR} to be R$182/ha or R$0.03/liter. By adding the operating cost and

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100, 20, and 100 kg per hectare in *ratoon* years. Macedo et al. (2008) assume N, P, and K application rates of 48, 125, and 117 kg per hectare respectively in the planting year and 88, 25, and 114 kg per hectare in *ratoon* years.

cost of land and management, we obtain a total feedstock cost of R$3,074 per hectare or R$0.50 per liter (Table 2).

The above approach provides the imputed opportunity cost of land for an independent producer of sugarcane who owns his own land and supplies sugarcane to a refinery at the market price of ATR. Mills that grow their own sugarcane typically lease the land at rates that are set by the market. The leasing rate is based on a fixed tonnage and ATR specified in the leasing contract. Using market data on leasing contracts in 2007, firms lease land at the value of 15 Mt of sugarcane per hectare with an ATR content of 121 kg per Mt of sugarcane. The latter is a determined by agreement between sugarcane mills and landowners. Thus, the leasing cost per hectare is:

$$\text{Leasing cost } (R\$/ha) = 15\ (Mt/ha) * 121\ (kg/Mt) * P^{ATR}\ (R\$/kg) \qquad (3)$$

At an ATR price of R$0.29 per kg this leasing cost is calculated to be R$526 per hectare or R$0.08 per liter (given a sugarcane yield of 81 Mt per hectare). Assuming that integrated production of sugarcane by the mills is at least as profitable as using purchased sugarcane from independent producers, we infer that the operating cost of sugarcane production for mills is at most R$0.42 per liter, which is at least 10% lower than the cost for independent growers. As the ATR price increases, the cost of ethanol production increases as does the imputed value of the land and its leasing cost for mill owners (with all other inputs costs unchanged).

2.1.2 Refinery cost

The refinery cost of ethanol production is obtained from the balance sheets of 20 mills producing ethanol and sugar in the vicinity of São Paulo. Our sample represents over 30% of installed capacity in Brazil in 2007 which totals 97 million Mt of crushing capacity (with more than 50 mills). As shown in Table 3 we used data on COGS (cost of goods sold) and SG&A (selling, general and administrative expenses) to obtain total cost of production for each mill. To obtain the per liter cost of ethanol, the total cost for each mill is divided by the potential production of anhydrous ethanol, based on the mill's sugarcane milling capacity. We then adjusted the cost per liter considering that mills also produce sugar and sugar production has a higher cost per Mt as well as higher revenue per Mt than ethanol production. Assuming that the cost and revenue for a mill producing only ethanol are equi-proportionately lower than the cost and revenue for a mill producing both ethanol and sugar, respectively, and using data from a mill that produces only ethanol (100%E), we adjusted the cost for the other mills using the following equation:

$$Adj.\ Cost(R\$/liter) = Cost(R\$/liter) * \frac{\mathrm{Re}venue(R\$/Milled\ (Mt)}{\mathrm{Re}venue^{100\%E}(R\$/Milled^{100\%E}(Mt)} \quad (4)$$

We calculated the total cost of ethanol production on average across these 20 mills to be R$0.86 per liter in 2007. By subtracting the average feedstock cost (estimated above as R$0.50/liter) from the total cost, the refinery cost (for industrial inputs, equipment, and management) is calculated to be R$0.36 per liter. This is the refinery cost of a plant that does not generate co-products through the sale of excess electricity. This refinery cost includes the cost-savings due to electricity generation at the mill using baggasse.[3]

To calculate the cost of imported ethanol at US ports, we assume that ethanol is transported 312 miles from the refinery to the port by truck at a cost of R$49 per cubic meter (TRANSPARANA, 2006). From the port, ethanol is then transported by an ocean tanker 7,416 miles (approximate distance from São Paulo, BR port to Philadelphia, US port) at a cost of R$130 per cubic meter (ODJFELL, 2006). The cost of transporting sugarcane ethanol is calculated to be R$0.18 per liter which brings the total cost of sugarcane ethanol at US ports to R$1.04 per liter.

2.2 Corn Ethanol

2.2.1 Feedstock cost

The cost components included for corn ethanol are similar to those for sugarcane ethanol.

The total cost per liter and the sub-total for each cost component are presented in the last column of Table 2. The per liter cost is based on an ethanol yield of 4,205 liters per hectare, which assumes a corn yield of 10 Mt per hectare (the average for Illinois in 2007) and an ethanol yield of 420 liters per Mt of corn. Feedstock cost is determined by the cost of production of corn produced using a corn-soybean rotation. Production data are based on prices, input uses and yields for the state of Illinois as reported in 2007 Illinois crop budget (Schnitkey and Lattz, 2006) and Illinois Agronomy Handbook (Hoeft and Nafziger, 2009). Fertilizer inputs include N, P, K and lime, and their per-hectare application rates based on the state average are 17 kg per unit of target yield in Mt for N, 8 kg for P, 5 kg for K, and 450 kg for lime (Hoeft and Nafziger, 2009). Feedstock transportation to the refinery is based on a round trip distance of 100 km at US$3.5 per Mt (McVey et al., 2007). As shown in Table 2, the total operating cost of corn production is US$698 per hectare or US$0.17 per liter of ethanol.

Similar to independent sugarcane producers, the imputed cost of land and management (C_L^{US}) for corn producers is the residual profit of the corn producer, defined as the difference between the revenue per hectare from selling corn at the market price and the per hectare costs of corn production. The value of C_L^{US} is calculated as:

$$\mathrm{C}_L^{US} = P_c * Q_c - C_c \qquad (5)$$

where P_c is the market price per unit of corn, Q_c is yield per hectare, and C_c is the operating cost per hectare. Using an average corn price for 2006-2008 of $144/ Mt, Q_c = 10Mt/ha, and C_c = $698/ha, we calculate C_L^{US} to be $745/ha or US$0.17 per liter of ethanol. The total feedstock cost for corn ethanol is US$1443 per hectare or US$0.34 per liter (see Table 2).

2.2.2 Refinery cost

Refinery cost is based on a 380 million-liter per year dry-mill ethanol plant, and is calculated using the Ethanol Dry Mill Simulator (FARMDOC, 2007). We use dry-milling process because a majority of ethanol produced in the US comes from dry-mill ethanol plants

(Dale and Tyner, 2006). The calculated cost of ethanol refining is $0.18 per liter, which includes chemical and energy inputs, administrative costs, taxes, depreciation and amortization, and interest expenses. Our refining cost is similar to that reported by Eidman (2007) of $0.19 per liter. Other studies have reported a lower refining cost at $0.12 per liter (Hofstrand, 2009). The discrepancy with our estimate is due to their exclusion of several administrative cost items.

The ethanol dry-milling process generates a co-product called Dry Distiller's Grain (DDGS). We assume that 386 kg of DDGS are produced per Mt of corn processed into ethanol, and sold at a price of $130 per Mt.[4] The revenue generated from the sale of co-products is subtracted from the total cost of ethanol production. Adding the feedstock cost and refinery cost gives a total cost of US$0.53 per liter. When the co-product credit of US$0.12 subtracted, the net cost of corn ethanol is US$0.41 per liter (Table 2).

2.3 Comparison of production costs

As shown in Table 2, the cost of producing corn ethanol in the US (net of co-product credit) is typically higher than the cost of producing sugarcane ethanol in Brazil (in dollar terms) except when the dollar is highly appreciated. However, when the transportation cost of shipping ethanol from Brazil to US is include the cost of corn ethanol could be lower than the delivered cost of sugarcane ethanol depending on the exchange rate. At an exchange rate of US$1=R$1.55 the cost of sugarcane ethanol delivered to the US port is $0.67 per liter while at the exchange rate of US$1=R$2.15 the cost is US$0.49,. The cost of corn ethanol, on the other hand, is $0.41 per liter.

From Table 2, feedstock costs account for 65% of total corn ethanol domestic cost (before co-product credit), while refinery costs contribute 35% to the total cost of $0.53 per liter of corn ethanol. Among the feedstock costs, over 48% comes from operating expenses (consisting of fertilizers (32%), machinery (31%), chemicals (15%), seeds (16%) and transportation (5%)) while 52% of the feedstock costs are the cost of land and management. For sugarcane ethanol, feedstock and refinery costs account for 58% and 42%, respectively, of the total domestic cost of US$0.40 per liter. For independent sugarcane producers, a majority of feedstock costs is from operating expenses (94%) while returns to land and management account for only 6% of the cost. For mills producing all their sugarcane, 84% is from agricultural operations while 16% is land leasing cost. The main components of operating costs are machinery (51%), fertilizers (19%), and transportation (17%). Seeds and other chemical inputs make up the balance.

Total operating cost per liter of sugarcane ethanol is 29% higher than that of corn ethanol. The cost disadvantage for Brazilian ethanol in operating costs is due to higher machinery and transport costs from field to mill. Transportation of sugarcane is not as efficient as corn because only 15% of it is ATR content which is transformed into ethanol. The rest of the cane is composed of water (70%) and bagasse (15%). In the case of corn, 40% of its content is transformed into ethanol. Brazil has a cost advantage in its land cost which is significantly lower than in the US. The total cost of feedstock, including operating cost and cost of land, is 32% lower in Brazil. Industrial costs at the refinery are very similar in the US and Brazil.

Cost of sugarcane ethanol within Brazil is 24% lower than the cost of corn ethanol in US. Even when transportation to the US is included, sugarcane ethanol still has a slight cost advantage compared to corn ethanol. However because corn ethanol production has a co-product credit, the net cost of ethanol produced in Brazil and delivered to US ports is 17% higher than US corn ethanol (with 1US$ = R$2.15).

3: Greenhouse Gas Emissions

GHG emissions from corn and sugarcane ethanol have been calculated separately by several studies using life cycle assessment (LCA) methods (for corn ethanol, see review in

Farrell et al., 2006; Wu et al., 2007; Liska et al., 2009; for sugarcane ethanol see Macedo et al., 2008; Macedo and Seabra, 2008). Several studies have also pointed to indirect land-use change (ILUC) as another source of emissions from biofuels. Searchinger, et al. (2008) and Fargione et al. (2008) provide estimates of the GHG emissions caused by ILUC due to the production of corn ethanol in the US. Pacca and Moreira (2009) estimate the emissions due to land use changes caused by expansion of sugarcane production in Brazil. Due to a lack of consensus on methods to calculate ILUCs accurately for either feedstock (see for example Reilly et al., 2009), they are not included in our calculations.

We use the assumptions made above for feedstock production, industrial processes and transportation of feedstocks and finished products to estimate the above ground GHG emissions intensities of corn and sugarcane ethanol. To keep our estimates for corn ethanol and sugarcane ethanol comparable we use the same approach and energy and emission coefficients for variable inputs for both biofuels.

For U.S. corn ethanol, we use coefficients from the GREET model to calculate emissions from production inputs (ANL, 2008). GHG emissions for corn ethanol are calculated using the input quantities listed above, multiplied by the appropriate emission factors from the GREET model. For nitrogen and lime, emissions include those during the production of these chemicals, as well as emissions from application. For farm machinery, the input quantity is the total weight divided by farm size and lifetime of machinery, which is multiplied by the GREET emission factor associated with the energy embodied in the farm machinery. For the refinery phase, our data are from the California Air Resource Board GREET (CA-GREET) model (CARB, 2009a). Emissions from ethanol production at the refinery depend on the milling technology (wet-mill or dry-mill). Ethanol produced in a dry-mill refinery typically has 20% lower emissions than a wet-mill plant. Consistent with our cost calculations, we consider emissions from a dry-mill ethanol plant which uses 90% natural gas and 10% electricity. Emissions from chemical inputs, ash disposal, and effluent restoration as well as energy embodied in the physical ethanol plant are included in the calculations.

For sugarcane ethanol we multiply the corresponding emission factors given by GREET by the use rates given above to calculate emissions from fertilizer and chemical inputs. Similar to corn ethanol, nitrogen and lime emissions consist of emissions from production as well as from denitrification after application. We use emission values from Macedo and Seabra (2008) for machinery, labor, and hire; trash burning; feedstock transport; and refinery operations. For ethanol transport from the refinery in Brazil to US ports, we use coefficients provided by the CA-GREET model (CARB, 2009b).

Our findings on GHG emissions are summarized in Table 4. Corn ethanol emissions equal 1.2 kg CO_2 equivalent (CO2-eq) per liter using corn grown under a corn-soy rotation, while sugarcane ethanol emissions equal 0.55 kg CO_2-eq per liter. Emissions of CO_2 from gasoline are 12 kg CO_2-eq per gallon. Our estimate of 1.2 kg CO_2-eq per liter of corn ethanol is higher than figures reported in the recent literature by Liska et al. (2009) whose estimate ranges from 0.8 – 1.05 kg CO_2-eq, but lower that those reported in older studies (Farrell et al. , 2006; Wu, Wang, and Huo 2007). The latter ranges between 1.5 and 2.5 kg CO_2-eq. The low estimates obtained by Liska et al. (2009) are based on mills that sell DDGS in its "wet" form thus saving energy used to dry the DDGS.

For sugarcane ethanol, our estimate of 0.55 kg CO_2-eq per liter falls between that of Macedo et al. (2008) who report emissions of 0.44 kg CO_2-eq per liter, and CARB (2008b) who report 0.61 kg CO_2-eq per liter. Differences in assumptions about sugarcane yield per hectare and ethanol yield per Mt of feedstock account for some of these differences. The estimate by Macedo et al. (2008) is lower than our estimate because we include emissions from transport of ethanol from Brazil to US ports. When only emissions from agricultural and industrial production are considered our estimate for emissions from sugarcane production falls to 0.47 kg

CO_2-eq per liter which is close to the estimate given by Macedo et al. (2008).

On an energy-equivalent basis, corn ethanol decreases emissions by 44% compared to gasoline, while sugarcane ethanol reduces emissions by 74%. Sugarcane ethanol has 53% less emissions than corn ethanol. Recent estimates by US EPA shows that sugarcane ethanol from Brazil reduces GHG emissions by 61% compared to gasoline after including ILUCs. According to this, sugarcane ethanol would qualify as an advanced biofuel to meet the RFS. The EPA also lists reductions achieved by corn ethanol including ILUCs. EPA's estimates range from -1% for a new coal-fired ethanol refinery to 47% for a dry mill natural gas refinery with wet DDGS including ILUCs (EPA, 2010).

In the future there is a possibility that there would be an established "carbon price" so that renewable fuels could receive credits for lowering GHG emissions relative to gasoline. Using data presented above, corn ethanol could receive a subsidy of US$0.03 per liter while sugarcane ethanol could receive US$0.05 per liter if the carbon credit is US$30 per ton of CO_2. Since sugarcane ethanol has 0.62 kg CO_2-eq less GHG emission than corn ethanol, and the net cost of corn ethanol is US$0.07 lower than sugarcane ethanol, the CO_2 price would have to be US$113 per ton of CO_2 for the cost of corn and sugarcane ethanol to be equal given current assumptions about feedstock costs, at an exchange rate of US$1=R$2.15. At a lower exchange rate of US$1=R$1.55, a CO_2 price of US$420 per ton is needed to make the cost of corn ethanol equal with that of sugarcane ethanol delivered at the US port.

4. Sensitivity Analysis

We conduct sensitivity analysis to explore the extent to which variations in the exchange rate, in the price of feedstocks and changes in US and Brazil biofuel policies affect the competitiveness of corn and sugarcane ethanol. In the graphs below, "Cost Difference" is defined as the cost of corn ethanol minus the cost of sugarcane ethanol at the US port.

4.1 Exchange Rate

Figure 4 shows the exchange rate at which the cost of production for US corn ethanol and Brazilian sugarcane ethanol would equalize. For 2006-2008 average corn and ATR prices, corn ethanol is less expensive than sugarcane ethanol up to an exchange rate of US$1=R$2.48, at which point sugarcane ethanol gains the cost advantage. The break-even exchange rate is 23% lower when the corn feedstock price is 50% higher, and 4% higher when the ATR price is 50% higher. Figure 1 shows that the years 2007-2008 have the lowest exchange rates in almost ten years, which could be attributed to macroeconomic conditions in the US and Brazil. Thus, if exchange rates were to revert to levels close to their historical high of over R$3 per one US dollar experienced from 2002-2004, it is expected that ethanol from Brazil would have a cost advantage over US ethanol.

4.1 Market Price of Feedstocks

Figure 5 below shows the change in cost difference as a function of the corn price, for different exchange rates. In the calculations below, the price of DDGS is also adjusted based on the price of corn. At a corn price less than US$170 per Mt and ATR price of R$0.29 per kg, corn ethanol maintains its cost advantage over sugarcane ethanol at an exchange rate of US$1=R$2.15. However, if the exchange rate is higher by 22% (US$1=R$2.62), the corn price needs to be lower by 26% or below US$132 per Mt for US corn ethanol to maintain its cost advantage over sugarcane ethanol. Conversely, if the exchange rate were to drop 28% to US$1 = R$1.55, corn price could go up to US$278 per Mt, and corn ethanol would still be competitive with sugarcane ethanol.

In the case of Brazil, the price of ATR affects the cost of land for independent producers and the land leasing cost paid by mills. Figure 6 shows that based on mills' own production of sugarcane, the production cost of corn ethanol is lower than that of sugarcane ethanol at any price of ATR for an exchange rate of US$1 = R$2.15 or lower. However, at an exchange rate that is 22% higher (US$1 = R$2.62), sugarcane ethanol with 100% sugarcane production by mills has a cost advantage up to an ATR price that is 78% higher (or R$0.51 per kg) than the average rate of R$0.29 per kg. In the case of independent producers, the cost of land has a lower share in the total cost compared to the share of the leasing cost for mills. Thus, at an exchange rate of US$1 = R$2.62, sugarcane ethanol retains its cost advantage up to an ATR price that is 20% higher.

4.3 Biofuel Policies in US and Brazil

If the mandate for corn ethanol is strictly binding and there is sufficient capacity to meet it using domestic ethanol, then under market conditions described above, the import tariff of US$0.14 tariff would not play a role in restricting imports, since the cost of sugarcane ethanol at the US port is higher than that of corn ethanol at the refinery gate. In that case, the exchange rate would need to increase by at least 77% to US$1 = R$3.8, or corn prices increase by 78% for the tariff to become binding. With the existing tariff, the exchange rate would have to rise by 74% or corn prices increase by 76% for sugarcane ethanol to be competitive with corn ethanol at an exchange rate of US$1 = R$2.15. The US RFS mandate requires that a certain portion of the mandate be met by "advanced biofuel." In the event that domestic cellulosic ethanol production cannot meet the advanced biofuel requirement, sugarcane ethanol would be imported to fulfill the mandate, regardless of its price relative to corn ethanol. In that case, the tariff would raise the cost of meeting the advanced biofuel mandate.

If the US has excess production of corn ethanol after meeting its corn ethanol mandate, then it could export corn ethanol to Brazil if the net-of-Brazilian tariff cost of corn ethanol delivered to the Brazilian port is lower than Brazil's cost of sugarcane ethanol. Exports would not get the blender's tax credit in the US. Assuming that the transport cost of corn ethanol from the US to Brazil is equal to the transport cost of sugarcane ethanol from Brazil to the US, and including the 20% tariff imposed by Brazil on its ethanol imports, the cost of US corn ethanol in Brazil would be US$0.51. Thus, ethanol exports from the US with assumed feedstock prices would only be feasible if exchange rate is 6% lower (US$1 = R$2.03) than our central exchange rate.

Our sensitivity analysis here assumes that a change in tariff rates will not have feedback effects on feedstock prices in the two countries. In reality, one would expect that removal of the import tariff by the US will reduce demand for corn ethanol. If the reduction in demand is large enough, it would reduce corn prices and the costs of producing corn ethanol relative to sugarcane ethanol, and offset some of the imports that might have taken place otherwise.

5. Policy Implication and Conclusions

Most studies comparing the costs of sugarcane ethanol in Brazil and corn ethanol in US have typically ignored the costs of transportation of sugarcane ethanol to the US and were undertaken in the early 2000's when the Brazilian currency was devalued relative to the US$. The results of this study show that the general perception that costs of sugarcane ethanol are lower than those of corn ethanol is not always valid and depends crucially on the prevailing exchange rate as well as the price of feedstocks, especially if one includes the cost of transportation of ethanol from Brazil to the US port and the co-product credits to US corn ethanol refineries.

In analyzing the effects of liberalizing trade in biofuel between the US and Brazil on biofuel trade volumes and patterns, it is important to consider the impact of market and macro-economic conditions. We find that under recently observed exchange rates and market conditions, and if the corn ethanol mandate is binding then the US import tariff is non-binding and its removal may have no impact on ethanol imports to the US from Brazil except to limit transfer of subsidy funds to sugarcane ethanol producers. Even without the tariff, the exchange rate would have to rise or feedstock prices increase for any importation of ethanol to be economically viable. When the corn ethanol mandate in the US is not binding (if the price of oil is high enough and there are no constraints to blending gasoline and ethanol) as was the case in 2007, the tariff (net of the tax credit) makes sugarcane ethanol even more expensive than corn ethanol. Nevertheless, imports of sugarcane ethanol could be profitable, if the domestic corn ethanol industry is capacity constrained. This may be one explanation for the observed imports of 0.44 B gallons of sugarcane ethanol by the US in 2007. Other explanations include the possibility that fluctuations in exchange rates, corn and sugar prices during the year created windows of opportunity when sugarcane ethanol was cheaper than corn ethanol.

With proposed climate legislation, carbon pricing could have some effect on the relative costs of corn ethanol and sugarcane ethanol but the carbon price would need to be very high to make a significant difference to competitiveness of sugarcane ethanol. This price would have to be at least US$133 and US$435 if exchange rates are US$1 = R$2.15 and US$1 = R$1.55, respectively.

Our analysis suggests that if prevailing market conditions continue, and the biofuel mandate is binding, then the potential for sugarcane ethanol to meet the part of the RFS mandate allocated to “traditional biofuel” even in the absence of the tariff appears limited. However, sugarcane ethanol represents one of the few options that could be scaled up in the near term to meet the “advanced biofuel” mandate for using non corn-starch based biofuels in the US. Thus, despite the relatively higher costs of sugarcane ethanol compared to corn ethanol, some imports are likely to occur. The costs of meeting this mandate are however, likely to be higher than initially anticipated if current market and macro-economic conditions persist.

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TABLES

Table 1. Annual costs of sugarcane production in São Paulo, Brazil (2007)

	Planting Year	**1st Harvest**	**2nd Harvest**	**3rd Harvest**	**4th Harvest**	**5th Harvest**	**Average**
Feedstock Yield (Mt per ha)	0	122.4	97.2	87.3	76.82	67.34	75.2
Ethanol Yield (L per ha)	0	10244.9	8135.6	7307.0	6429.8	5636.4	6134.4
Cost Items (R$ per ha)							
Fertilizers	643.95	526.50	526.50	526.50	526.50	526.50	546.1
Chemicals	413.28	184.85	184.85	184.85	184.85	184.85	222.9
Seed	868	0.00	0.00	0.00	0.00	0.00	144.7
Machinery, Repairs, Fuel, and Hire	1572.64	1859.56	1544.82	1446.24	1274.87	1156.46	1475.8
Transportation to refinery	0	818.15	649.71	583.54	513.48	450.12	502.5
Total Operating Cost (R$ per ha)	3497.87	3389.07	2905.88	2741.13	2499.70	2317.93	2891.9
Total Operating Cost (R$ per liter)							0.47

Source: FNP Agro, Market data

Table 2. Estimated cost of corn and sugarcane ethanol in the US and Brazil (2007)

	Feedstock				
	Sugarcane				**Corn**
	R$	**US$**	**US$**	**US$**	**US$**
Cost Items (per ha)		**US$1=R$1.55**	**US$1=R$2.15**	**US$1=R$2.62**	
Fertilizers	546.08	352.31	253.99	208.43	226.18
Nitrogen					134.22
Phosphorous					52.19
Potassium					29.89
Lime					9.88
Chemicals	222.92	143.82	103.68	85.08	106.26
Seed	144.67	93.33	67.29	55.22	110.78
Machinery, Repairs, Fuel, and Hire	1475.77	952.11	686.40	563.27	217.45
Transportation to refinery	502.50	324.19	233.72	191.79	37.36
Total Operating Cost per ha (a)	**2891.93**	**1865.76**	**1345.08**	**1103.79**	**698.03**
Total Operating Cost per liter	**0.47**	**0.30**	**0.22**	**0.18**	**0.17**
Return to Land and Management **(b)**	182.04	117.45	84.67	69.48	745.44
Total Feedstock Cost per ha (a+b)	**3073.97**	**1983.21**	**1429.76**	**1173.27**	**1443.47**
Feedstock Cost per liter	**0.50**	**0.32**	**0.23**	**0.19**	**0.34**
Refinery Costs per liter (c)	**0.36**	**0.23**	**0.17**	**0.14**	**0.19**
Inputs	0.30	0.20	0.14	0.12	0.16
Depreciation	0.06	0.04	0.03	0.02	0.03
Total Domestic Cost (a+b+c)	**0.86**	**0.56**	**0.40**	**0.33**	**0.53**
Transport from Refinery to US Port (d)	**0.18**	**0.12**	**0.08**	**0.07**	**N/A-**
(Co-product Credit per liter of Ethanol)	0	0	0	0	-0.12
Total Cost per liter of Ethanol (a+b+c+d)	**1.04**	**0.67**	**0.49**	**0.40**	**0.41**

Table 3. Costs of Production of Sugarcane Mills

Company	**Sugarcane Milling (Mt)**	**Net Sales (R$ M)**	**COGS (R$ M)**	**SG&A (R$ M)**	**Total Cost (R$ M)**	**Total Cost/Anhydrous Equivalent Ethanol * (R$ per liter)**
Colombo	4.4	488	295	43	339	0.72
Bazan	3.4	370	223	44	267	0.74
Guarani	8.2	790	490	113	604	0.79
Generalco	1.2	100	69	8	76	0.79
Bela Vista	2.5	265	184	21	204	0.80
Santa Adélia	2.1	232	180	0	180	0.80
Alto Alegre	3.0	462	286	80	366	0.82
S. Js da Estiva	2.2	212	145	24	169	0.82
Equipav	4.4	424	285	55	341	0.83
Cosan	36.2	3,605	2,481	528	3,009	0.86
Pioneiros	1.3	142	102	17	120	0.87
São Martinho	9.3	827	571	130	701	0.88
Santa Isabel	2.5	228	177	19	196	0.89
Mandu	1.8	150	112	19	132	0.91
Nova América	5.8	1,244	958	184	1,141	0.95
Furlan	1.5	116	102	5	107	0.96
Carolo	2.2	212	182	15	197	0.96
Itaiquara	2.2	253	183	59	242	0.98
Albertina	1.4	153	120	28	148	1.00
J. Pilon	1.0	80	66	14	80	1.03
Total	**97**	**10,352**	**7,211**	**1,406**	**8,617**	**-**
Average	**4.8**	**518**	**360**	**70**	**431**	**0.86**
Median	**2.3**	**242**	**182**	**26**	**201**	**0.87**

Source: Annual reports and financial statements from mills.

* Cost adjusted for product mix.

Table 4. GHG emissions from corn and sugarcane ethanol (kg CO_2-eq per liter)

INPUTS	**Corn****	**Sugarcane**	**Sources of data for Sugarcane**
Fertilizers	0.49	0.21	
Nitrogen	*0.39*	*0.13*	Our calculations using GREET 1.8
Phosphorous	*0.02*	*0.01*	Our calculations using GREET 1.9
Potassium	*0.01*	*0.01*	Our calculations using GREET 1.10
Lime	*0.07*	*0.06*	Our calculations using GREET 1.11
Chemicals	0.01	0.01	
Herbicide	*0.00*	*0.01*	Our calculations using GREET 1.8
Insecticide/Nematicide	*0.00*	*0.00*	Our calculations using GREET 1.9
Ripener	*0.00*		
Seed	0.00	0.00	Our calculations using GREET 1.9
Machinery repairs, fuel and hire	0.06	0.11	Macedo and Seabra (2008)
Trash Burning in field		0.08	Macedo and Seabra (2008)
Feedstock Total	**0.56**	**0.42**	
Transportation of feedstock to refinery	0.05	0.03	Macedo and Seabra (2008)
Refinery	0.81	0.02	Macedo and Seabra (2008)
Domestic Total	**1.42**	**0.47**	
Co-product Credit	-0.24	0.0	
Transportation from Refinery to US Port (Philadelphia)	N/A	0.08	Our calculations using CA-GREET
TOTAL	**1.17**	**0.55**	

***Emissions for corn ethanol are based on our calculations using coefficients from GREET 1.8, except for Refinery and Co-product Credit which are from CA-GREET.*

FIGURES

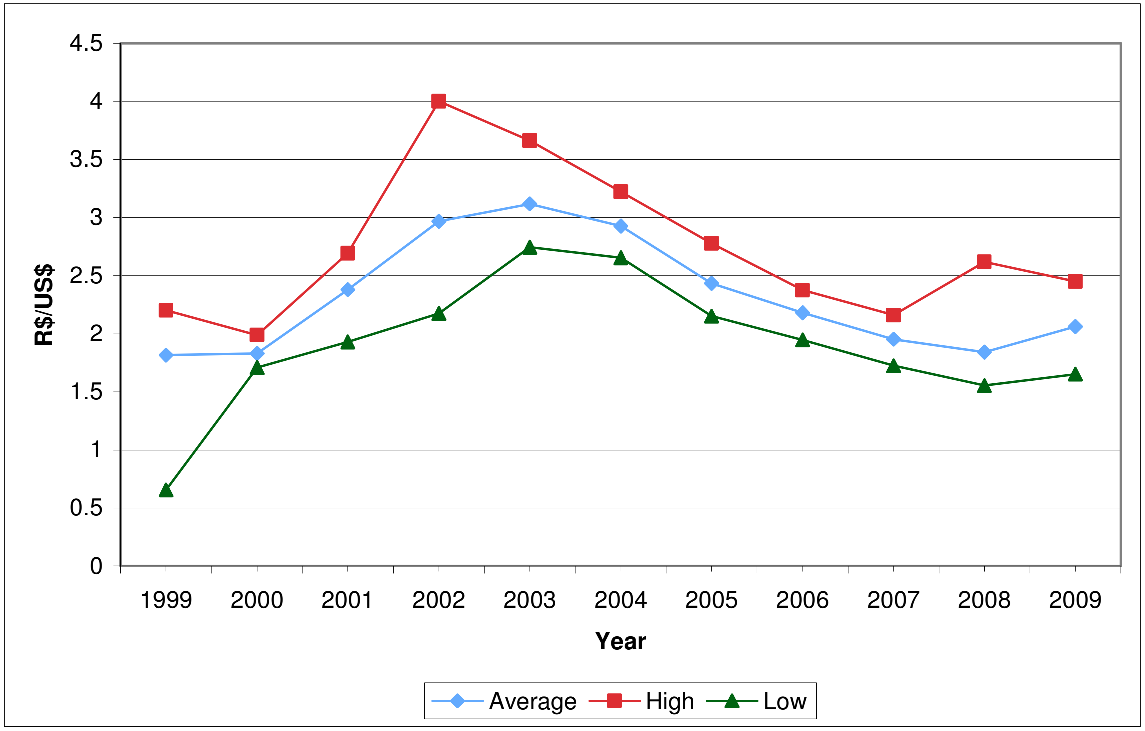

Figure 1. Exchange rates for Brazilian Reias to US Dollar (1999-2009)

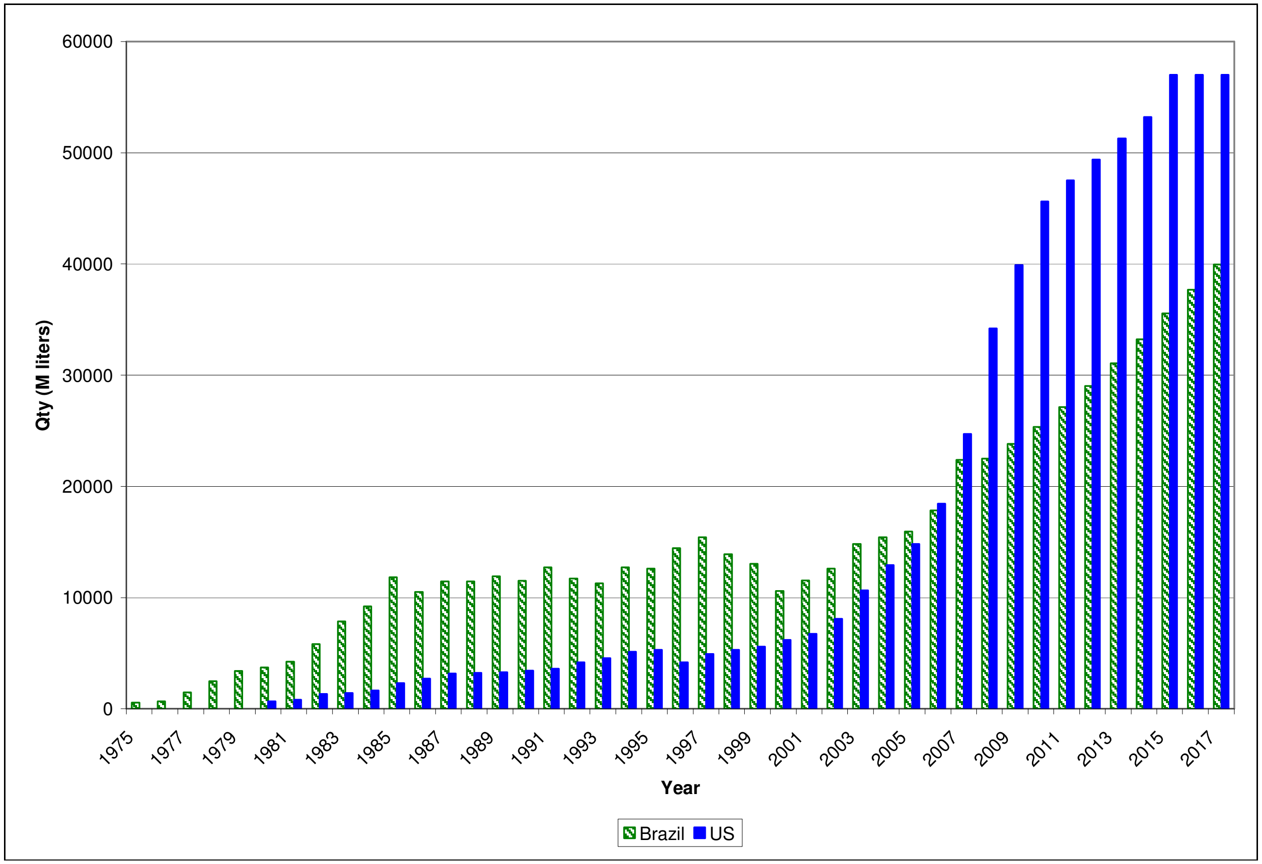

Figure 2. Historical and Projected Ethanol Production in the US and Brazil (Source: RFA, InfoFNP)

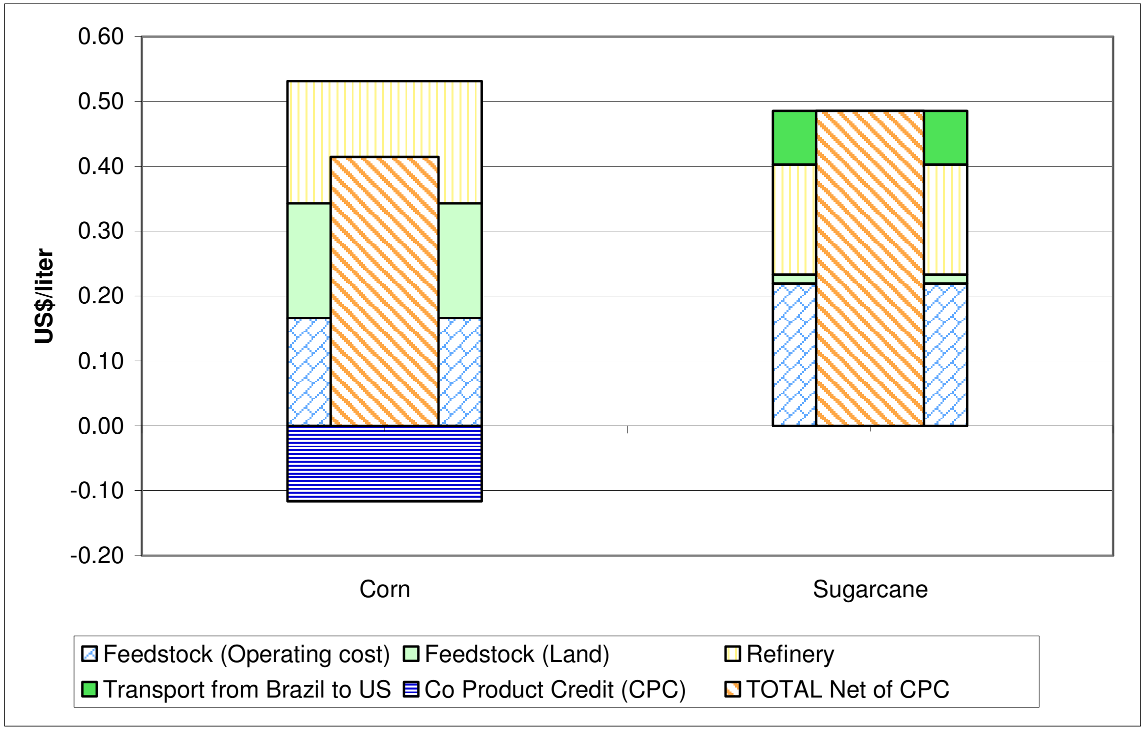

Figure 3. Cost of Ethanol Production (Data are from present research)

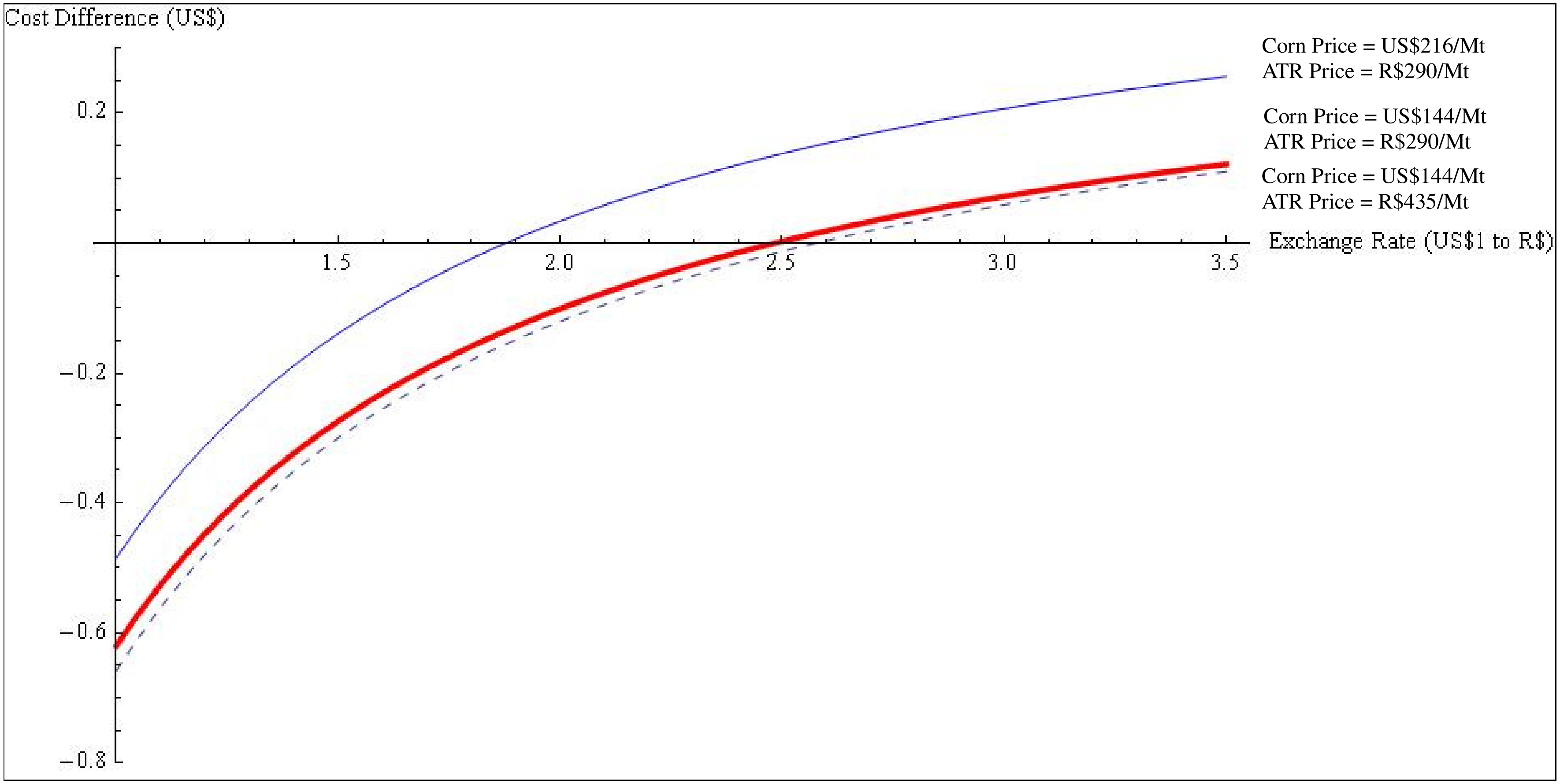

Figure 4. Sensitivity of Cost Difference to Exchange Rates

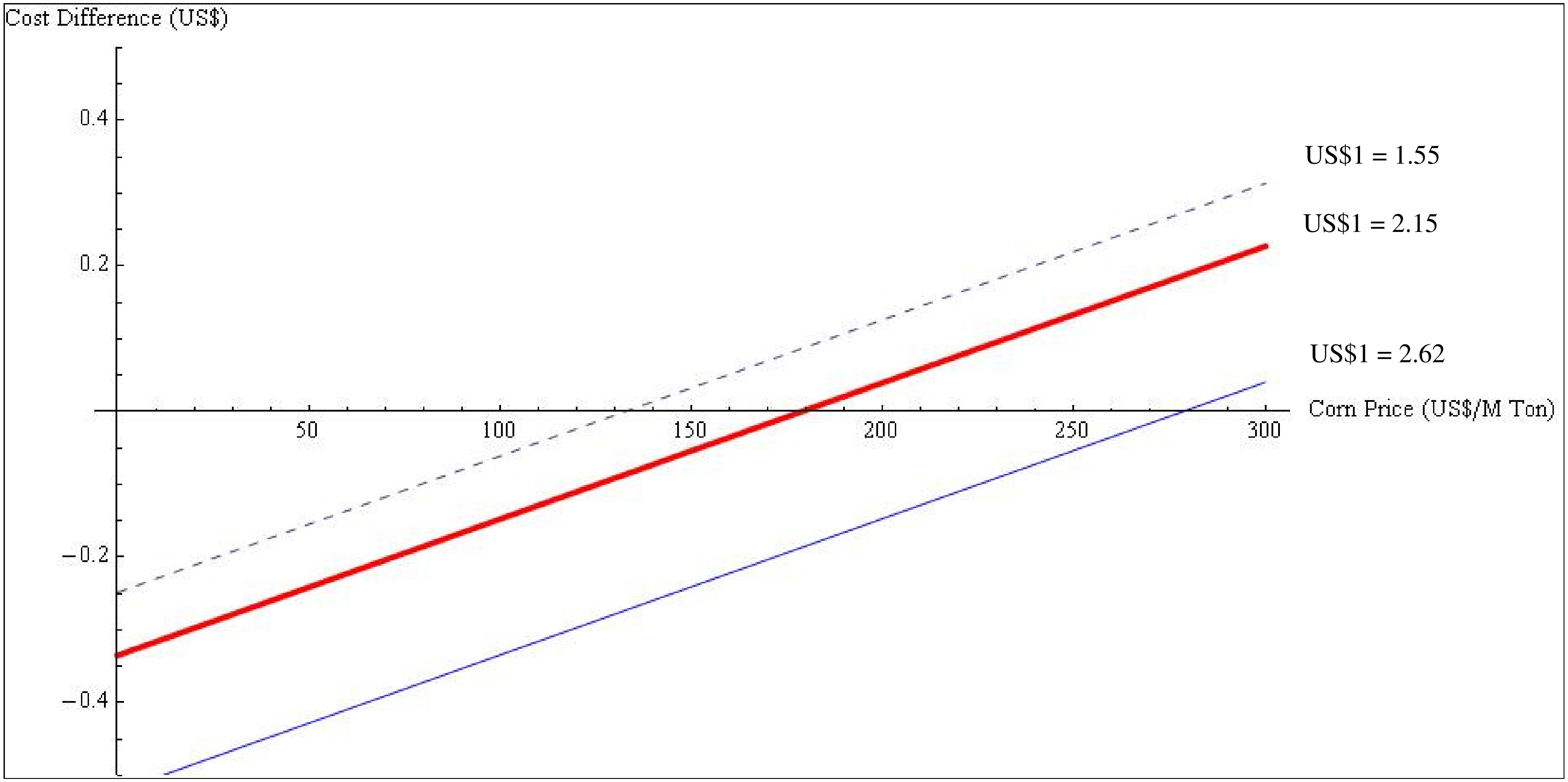

Figure 5. Sensitivity of Cost Difference to Corn Price

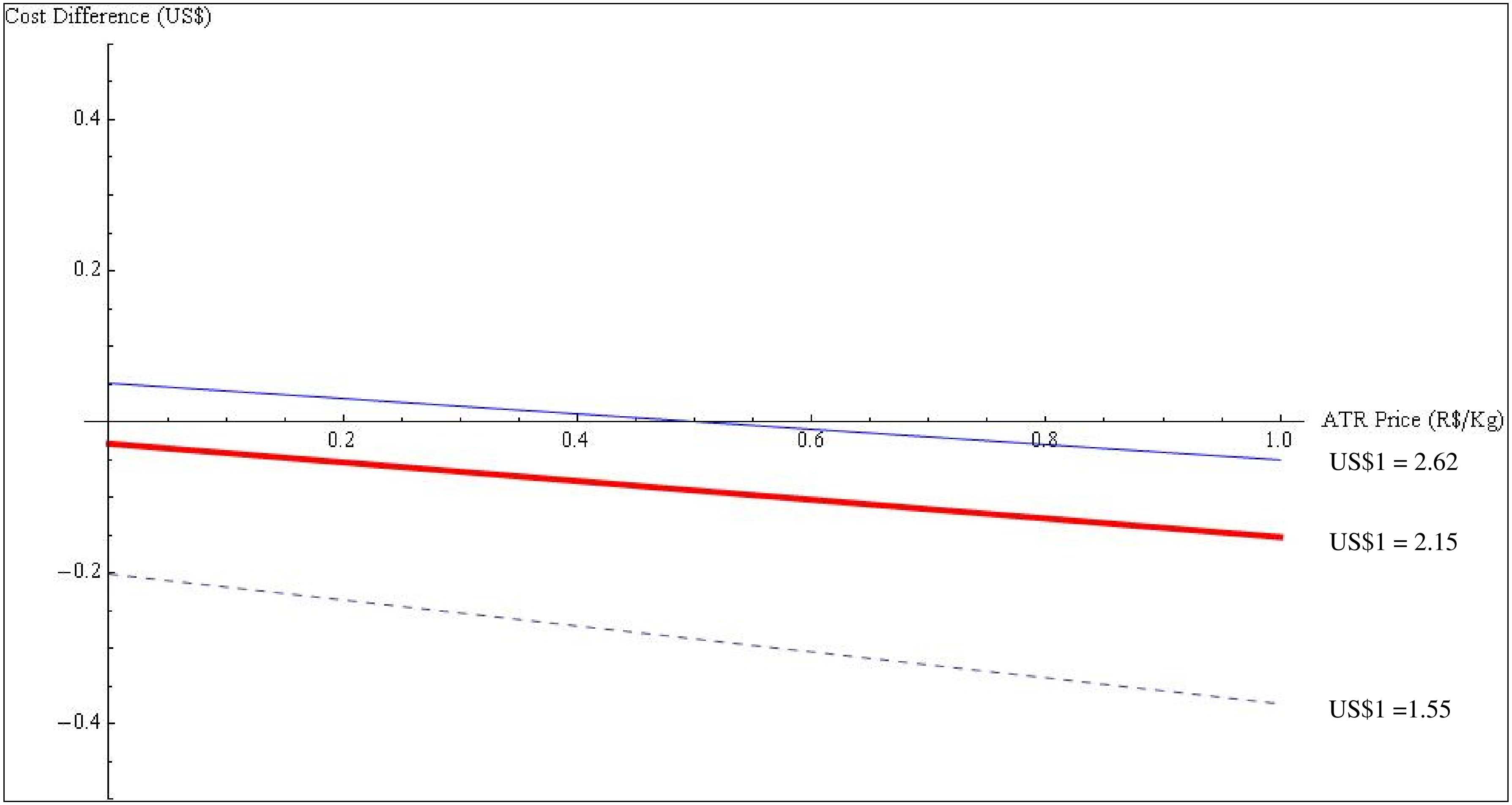

Figure 6. Sensitivity of Cost Difference to ATR Price

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[1] Unless specified, all comparisons use an exchange rate of US$1 = R$2.15.

[2] 130 mills that operate in São Paulo have signed the "Green Protocol" that aims to eradicate cane burning by 2018 (Macedo et al, 2008). The change in harvesting practice affects cane costs slightly but is more of a social and health concern as manual harvesting, which necessitates burning, poses health and physical risks to laborers (Novaes, 2007).

[3] Based on market data for mills that sell electricity, co-generation could further reduce cost by R$0.07 per liter.

[4] The DDGS price is related to the price of corn using the following equation: DDGSPrice = 1.55 + 21.98*CornPrice + 0.205*SoybeanPrice, and is capped at US$140 per ton (FARMDOC, 2007).