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Impact of the Expansion of Brazilian FFV Utilization and U.S. Biofuel Policy Amendment on the World Sugar and Corn Markets: An Econometric Simulation Approach

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The production and utilization of biofuels is promoted in many countries and regions, with Brazil and the USA being the two main bioethanol producing countries. It is estimated that both markets will expand as a result of their biofuel programs. Our study is the first to evaluate how expansion of FFV utilization in Brazil and the U. S. biofuel policy amendment will impact the world bioethanol, sugar, and corn markets. We utilize a world bioethanol market model which is linked to the world sugar and corn markets models. As a result of our econometric analysis, we conclude that both the expansion of Brazilian FFV utilization and the U. S. biofuel policy amendment are predicted to impact not only the bioethanol market but also the world corn and sugar markets.

Key words: bioethanol, Brazil, USA, sugar and corn.

1. Introduction

The production and utilization of biofuels is promoted in many countries and regions in order to deal with energy security and environmental problems as well as to increase farming income. Brazil and the USA have a long history of introducing biofuel as an alternative to fossil fuel. The world's largest bioethanol producer is the USA, followed by Brazil as the second largest bioethanol producer and the largest bioethanol exporter. The global share in bioethanol of the USA and Brazil dominates, with these two countries holding 75.6% in 2007 (F. O. Licht [6]). These two countries are the leading global biofuel markets, with most of the biofuels produced from agricultural commodities, and biofuel production is expanding around the world. The relationship between biofuel production and food availability is of wide global interest.

The world sugar and bioethanol markets have a strong influence on each other because most sugarcane is directed toward bioethanol production. Among the major sugar-producing countries, Brazil is the world's largest producer of sugarcane and sugarcane-based bioethanol. From 1994 to 2008, more than half of the sugarcane produced in Brazil (estimated as ranging from 50.6 to 60.4%) went toward bioethanol production (U. S. Department of Agriculture [23]), with the remainder going to sugar production. Therefore, developments in Brazil have considerable implications for the world sugar and bioethanol markets. Brazil is the first country to widely promote bioethanol through its National Alcohol Program (PROALCOOL), which was launched in late 1975 in response to high oil prices and declining sugar prices (Bolling and Suarez [3]). The government promoted bioethanol production by providing credit guarantees and low-interest loans for new plant construction, regulating bioethanol prices and production levels by a quota system, and implementing other policies. As a result of the success of PROALCOOL, Brazilian

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bioethanol markets have expanded since 1975. During the past three decades, the government of Brazil has implemented powerful intervention programs in the bioethanol and sugar markets. Following the deregulation of its bioethanol program in 1998-99, the government no longer exercises direct control over sugar production and exports. At present, the government can only exert influence by setting the anhydrous bioethanol blend ratio for gasoline. In the early 2000s, high crude oil prices began to boost the marketing of bioethanol, making it once again marginally profitable and competitive with gasoline. Developments in Brazil have led to the creation of flexible-fuel vehicles (FFV) capable of running on gasoline, bioethanol, or any combination of both fuels (Nass, Pereira and Ellis [14]). The sales of FFV have increased dramatically since 2003, with more than 90% of new cars manufactured in Brazil being FFV at the beginning of 2008 (ANFAVEA [2]). As a result of the increasing number of FFV, hydrated bioethanol consumption increased by 15.4% per annum, and total bioethanol consumption increased by 3.1% per annum from 2003 to 2006 (Ministry of Mines and Energy in Brazil [16]). Expanding use of FFV can be the most crucial changing factor for Brazilian bioethanol markets.[1]

Bioethanol production in the United States grew from 70 million gallons in 1980 to 2.3 billion gallons in 2007 (RFA [18]). U.S. bioethanol is produced mainly from corn. The bioethanol market was stimulated in the 1970s when oil price disruptions impacted the U.S. economy and raised government concerns that oil dependency could damage national security. The bioethanol program received a first boost from Congress in 1990 with the passage of the Clean Air Act Amendments (CAAA90). Congress mandated the use of reformulated gasoline (RFG), and this act promoted the use of bioethanol and MTBE. The second boost in bioethanol consumption is largely the result of a phase out of MTBE due to the contamination of drinking water. The recent boost results from governmental mandates. On August 8, 2005, President Bush signed the Energy Policy Act of 2005 (EPACT 2005), which established the Renewable Fuel Standard (RFS), mandating the increased use of biofuels from 4 billion gallons in 2006 to 7.5 billion gallons by 2012.[1] In addition, the Energy Independence and Security Act 2007 (EISA) was signed into law, mandating RFS requirements for the use of 36 million gallons of bioethanol per year by 2022. The enforcement of new RFS can be a crucial political factor not only for the U.S. and international biofuel markets but also for world agricultural markets.

Several studies have noted the relationship between the bioethanol and agricultural markets. Koizumi and Yanagishima [12] examined the relationship between the Brazilian sugar and bioethanol markets using econometric models. McPhail and Babcock [15] examined how eliminating RFS, the blenders' tax credit and tariff, will impact the corn markets. Tokgoz et al. [20] examined how U.S. bioethanol production would impact planted acreage, crop prices, livestock production, and livestock prices. Daniel et al. [4] projected the impacts on the U.S. agricultural sector and economy of increasing bioethanol and biodiesel production. FAPRI [8] examined how farm bill provisions and other biofuel policy options would impact the U.S. biofuel and agricultural markets. Lampe [13] examined the impact of a number of scenarios on the biofuels market, including the impact of higher crude oil prices. Elobeid and Tokgoz [5] analyzed the impact of trade liberalization and removal of the federal tax credit in the United States on the U.S. and Brazilian bioethanol markets. Tokgoz and Elobeid [19] analyzed the effect of gasoline, corn, and sugar price shocks on the bioethanol and agricultural markets in the U.S. and Brazil.

However, none of these studies dealt with how the expansion of FFV utilization in Brazil would impact the domestic bioethanol and sugar markets, the U.S. bioethanol market, or the world sugar and corn markets. In addition, none of these studies dealt with how the U.S. biofuel program amendment would impact not only the U.S. bioethanol markets, but also the Brazilian bioethanol markets and the world sugar and corn markets. In a world bioethanol market model, which is linked to the world sugar market model and world corn markets model, hydrated bioethanol consumption in Brazil is derived from the registered number of FFV and per vehicle consumption. In the U.S., bioethanol production estimates are derived from the changing ratio of net return and gasoline prices. On these points, the model, which is used for this study, is different from other economic models.

In the current study, we examine how the expansion of FFV utilization in Brazil will impact not only the domestic bioethanol and sugar markets but also the world sugar and corn markets. We also examine how the U. S. biofuel program amendment resulting from second generation biofuel R&D will impact not only the domestic bioethanol markets but also the Brazilian bioethanol markets as well as the world sugar and corn markets. Our study is the first to evaluate the impact of Brazilian bioethanol market structural changes and U. S. biofuel policy amendments on world bioethanol, sugar, and corn markets, using a world bioethanol market model linked to the world sugar and corn markets models. The next section is an explanation of the world bioethanol market model, which is linked to the world sugar markets and world corn markets models we applied to evaluate both countries' markets and policies. In the third section, we discuss the assumptions of the models, and in the fourth section we cover the market impacts. The last section summarizes our conclusions.

2. The Model Structures of the World Bioethanol Market Model and Linked Models

1) Overview of the models

The world bioethanol market model is linked to the world sugar market model and the world corn markets model, [2] and was developed in order to analyze how bioethanol energy policies in major bioethanol-producing countries affect agricultural markets. These models are developed as a dynamic partial equilibrium model. The world sugar market model consists of 11 major countries and regions (Brazil, USA, EU27, Australia, Mexico, Japan, India, China, Thailand, Russia and the rest of the world) in this study. [3] The world corn market model consists of 11 major countries and regions (USA, China, Argentina, Brazil, Japan, Korean Republic, South Africa, Canada, EU27, Mexico, and the rest of the world) in this model. [4] The world bioethanol model consists of 3 major bioethanol producing countries and regions (Brazil, the U. S., and the rest of the world). FFV is covered endogenously in the world bioethanol market. Hydrated and anhydrous bioethanol consumption composes the Brazilian market. Brazilian hydrated consumption is calculated from the registered number of FFV and hydrated bioethanol consumption per vehicle. The registered number of FFV is found from the total number of registered light vehicles, which is solved endogenously. World bioethanol price refers to the Brazilian anhydrous bioethanol price. The Brazilian bioethanol market is linked with the sugar market. In the Brazilian market, a "sugarcane allocation ratio variable" is defined as the relative proportions of sugarcane that go to bioethanol and sugar production. The main driving factor that determines the production levels of sugar and bioethanol is the relationship between the domestic sugar price and the domestic hydrated bioethanol price. The reaction of producers to a change in the market price is replicated in the model by means of an allocation ratio variable, which enables instantaneous bioethanol and sugar production adjustments corresponding to the relative sugar-hydrated bioethanol price ratio.

In the U. S. bioethanol market, the net return of bioethanol is covered. The net return of bioethanol production resulting from high energy and feedstock prices is a crucial factor for operating bioethanol production. Conventional bioethanol production heavily depends on the net return of bioethanol production, which is derived from corn prices, corn product prices, by-products of bioethanol, and natural gas prices. The world sugar market model is a dynamic partial equilibrium model that extends to the world sugar markets. The fundamental concept of our model and link to the world sugar market model and corn market model are illustrated in the following chart (Figures 1 and 2).

2) Model Structures

The bioethanol sector is described by equations for production, per capita consumption, imports, and exports. Bioethanol market data in Brazil is derived from the Ministry of Mines and Energy in Brazil [16], the U. S. bioethanol data is derived from the U. S. Department of Energy [25], and the world data is derived from F. O. Licht [6]. The base year is 2006/07 (3-year average) and the model projects for the year of 2017/18.

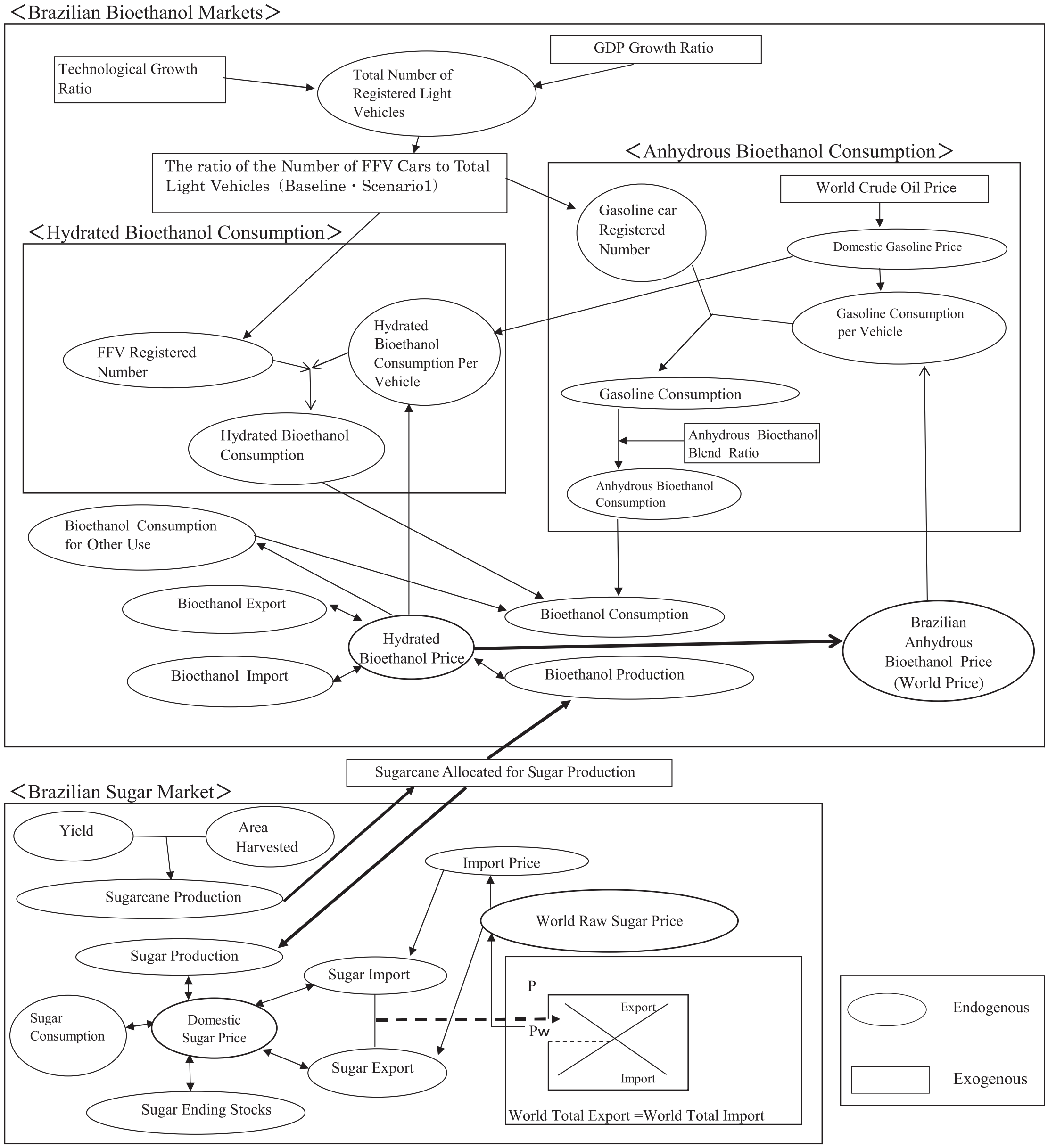

Figure 1. Brazilian bioethanol and sugar market model

Note: For the World Sugar Market Model, please refer to Koizumi and Yanagishima [12].

The endogenous sugar data for all countries and regions are changed from FAOSTAT to F. O. Licht data [7].[5] The endogenous corn data for all countries and regions are derived from USDA-FAS[24]. For world sugar and corn markets, each base year is 2006/07 (3-year average) and each model projects for the year of 2017/18.

Our model is a policy simulation model, and we deem each equation to be necessary with a reasonable magnitude for each parameter. Sign conditions of each parameter are also reasonable. The t-values, coefficients of determination, and levels of significance are not high, so we provide Appendix 2 to enable the reader to better understand the model

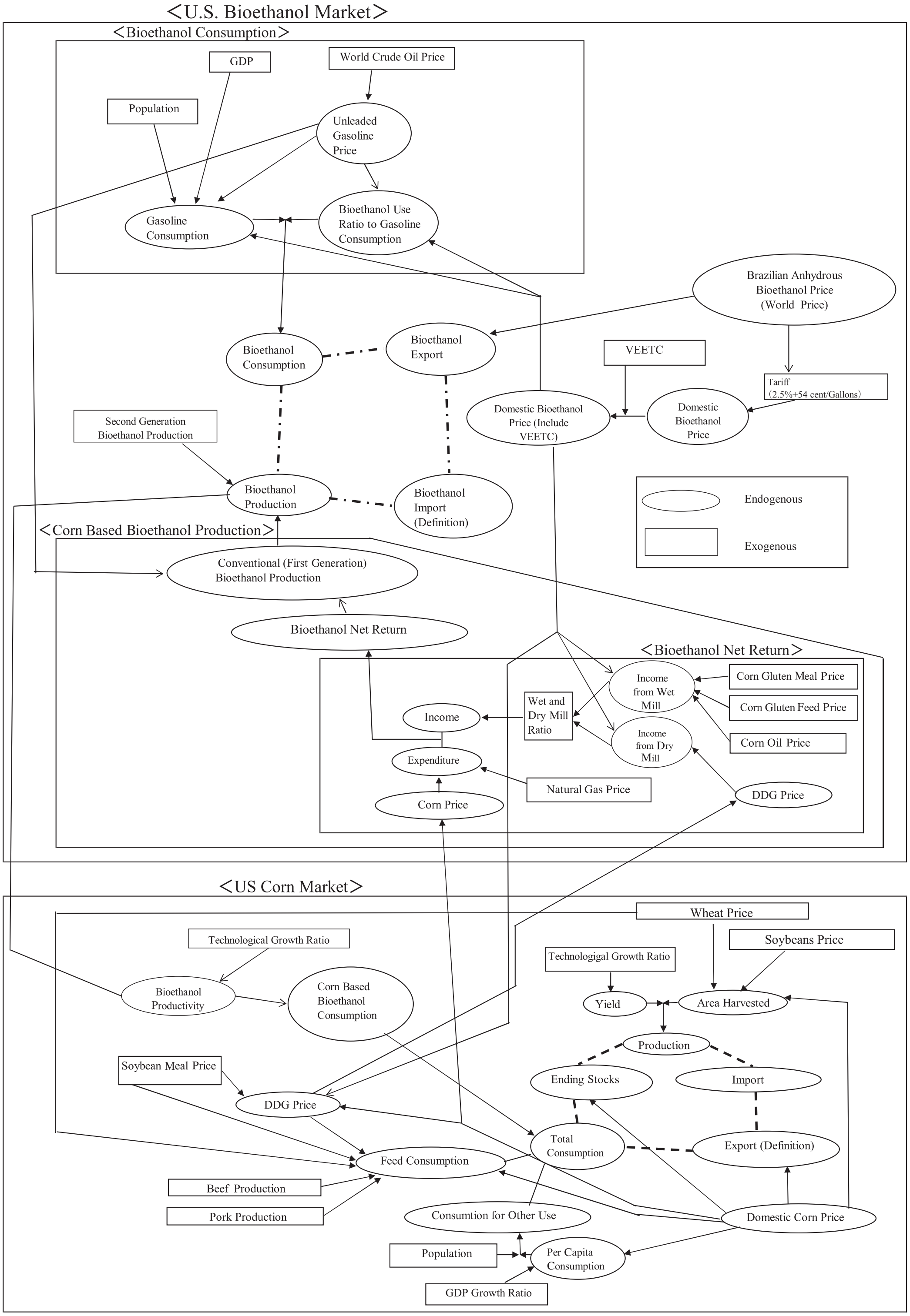

Figure 2. U.S. bioethanol and corn market model

Note: For the World Corn Market Model, please refer to Koizumi and Ohga [11].

structure. We recognized that the number of sample data for evaluating each parameter is quite limited, because the biofuel market has developed and expanded for only a quite short period after 2000. Although we could get a constant term to estimate each parameter, we did not use constant terms to build this model. Instead of a statistically estimated constant term, we applied a calibrated constant term[6)] to improve reality for the model projection activity. Bioethanol consumption in Brazil is specified as the sum of anhydrous and hydrated consumption. Hydrated bioethanol consumption is calculated by multiplying the registered number of FFV by hydrated bioethanol consumption per vehicle. Hydrated bioethanol consumption per vehicle depends on the domestic gasoline[7)] and hydrated bioethanol prices.[8)] The FFV registered number is solved from the total number of registered light vehicles[9)] and the FFV utilization ratio. The registered number of light vehicles depends on technological growth and the GDP growth ratio. The FFV utilization ratio is decided exogenously from Brazilian automobile data (ANFAVEA [1]).

$$BRQCE_t = BRQCEH_t + BRQCEA_t$$

$$BRQCEH_t = BRPQCEH_t * FLEXNUM_t$$

$$\log(BRPQCEH_t/BRPQCEH_{t-1}) = 0.2652*\log(BRDPG_t/BRDPG_{t-1}) + (-0.3614)*\log(HEP_t/HEP_{t-1}) - 0.243$$

$$FLEXNUM_t = TOTALNUM_t * FLEXRAT_t$$

$$\log(TOTALNUM_t/TOTALNUM_{t-1}) = 0.3754*\log(BRGDP_t/BRGDP_{t-1}) + 0.0343*\log(BRTECH_t/BRTECH_{t-1})$$

where *BRQCE* is total bioethanol consumption, *BRQCEH* is hydrated bioethanol consumption, *BRQCEA* is anhydrous bioethanol consumption, *BRPQCEH* is per capita hydrated bioethanol consumption, *FLEXNUM* is FFV number, *BRDPG* is the domestic gasoline price of Brazil, *HEP* is the hydrated bioethanol price, *TOTALNUM* is the registered number of light vehicles, *FLEXRAT* is the ratio of the number of FFV cars to total light vehicles, *BRGDP* is the real GDP growth ratio of Brazil, *BRTECH* is the technological growth ratio in Brazil,[10)] and t is the time index. The price elasticity of the domestic gasoline price for hydrated bioethanol consumption is 0.2652, while −0.3614 is the price elasticity of the domestic hydrated bioethanol price for hydrated bioethanol consumption, −0.243 is the calibrated coefficient for hydrated bioethanol consumption, which is applied to 2007/08, 0.3754 is income elasticity for the registered number of light vehicles, and 0.0343 is elasticity of the technical growth ratio for the registered number of light vehicles.

Anhydrous bioethanol consumption depends on the blend ratio relative to gasoline. Gasoline consumption is solved from gasoline consumption per vehicle and the registered number of gasoline-running cars. Gasoline consumption per vehicle depends on the domestic gasoline price and anhydrous bioethanol price. The registered number of gasoline-running cars is derived from the registered number of light vehicles, FFV, ethanol cars,[11)] and natural gas-running cars. The domestic gasoline price depends on the world crude oil price.

$$BRQCEA_t = (BRQCG_t/(1-BLEND))*BLEND$$

$$BRQCG_t = BRPQCG_t * BRGASNUM_t$$

$$GASNUM_t = TOTALNUM_t - FLEXNUM_t - ETHANUM_t - NATNUM_t$$

$$\log(BRPQCG_t/BRPQCG_{t-1}) = (-0.2696)*\log(BRDPG_t/BRDPG_{t-1}) + (-0.1522)*\log(AEP_t/AEP_{t-1}) + 0.0148$$

$$\log(BRDPG_t/BRDPG_{t-1}) = 0.8809*\log*(WOP_t/WOP_{t-1})$$

where *BRQCG* is gasoline consumption, *BLEND* is the anhydrous ethanol blend ratio relative to gasoline, *BRPQCG* is per vehicle consumption of gasoline, *BRGASNUM* is the number of gasoline cars, *ETHANUM* is the number of ethanol cars, *NATNUM* is the number of natural gas-running cars, *AEP* is the anhydrous bioethanol price, and *WOP* is the world crude oil price. The price elasticity of the domestic gasoline price for per vehicle consumption of gasoline is −0.2696, while −0.1522 is the price elasticity of the anhydrous bioethanol price for per vehicle consumption of gasoline, 0.0148 is the calibrated coefficient of per vehicle gasoline consumption, which is applied to 2007/08, and 0.8809 is the price elasticity of the world crude oil price for the domestic gasoline price. Bioethanol production in Brazil is defined as a residual from sugarcane used for sugar production. For the Brazilian sugar market, the sugarcane allocated ratio for sugar production is a crucial factor in determining the sugar production. None of the previous studies have dealt with the Brazilian sugarcane allocated ratio, which depends on the domestic sugar and hydrated bioethanol price. On this point, this study is the first to estimate the Brazilian sugarcane allocated ratio for sugar production. The allocation ratio depends on the domestic sugar and hydrated bioethanol price. The bioethanol extraction ratio depends on technological growth.

$$BRQPE_t = ((BRHS_t{*}BRYSC_t) - SUAL_t){*}BRERE_t$$

$$\log(SUAL_t/SUAL_{t-1}) = 0.2477{*}\log(DSP_t/DSP_{t-1}) + (-0.0978){*}\log(HEP_t/HEP_{t-1})$$

$$\log BRERE_t = 1.0001{*}\log BRERE_{t-1}$$

where *BRQPE* is bioethanol production, *BRHS* is area harvested of sugarcane, *BRYSC* is yield of sugarcane, *SUAL* is the sugarcane allocated for sugar production, *DSP* is the domestic sugar price, *BRERE* is the bioethanol extraction ratio, 0.2477 is the price elasticity of the domestic sugar price change for the sugarcane allocated ratio, −0.0978 is the price elasticity of the hydrated bioethanol price change for the sugarcane allocated ratio and 1.0001 is an econometrically estimated bioethanol extraction efficiency growth rate in Brazil. As for the estimated equation of the sugarcane allocated ratio for sugar production, please see Appendix 2. Although we recognized that the *t*-values, coefficients of determination are not high, sign conditions of each parameter are reasonable and we decided this equation is acceptable to apply in this model. In this equation, the absolute value of sugar price elasticity (0.2466) is much higher than that of hydrated bioethanol price elasticity (−0.0978). It means that the domestic price change has a bigger impact on the sugarcane allocated ratio, compared to the hydrated bioethanol price change.

Brazilian bioethanol exports depend on the anhydrous and hydrated bioethanol prices as follows, [12)]

$$\log(BREXE_t/BREXE_{t-1}) = 0.3175{*}\log(AEP_t/AEP_{t-1}) + (-0.4047){*}\log(HEP_t/HEP_{t-1})$$

where *BREXE* is bioethanol exports, 0.3175 is the price elasticity of the anhydrous bioethanol price for bioethanol export, and −0.4047 is the price elasticity of the hydrated bioethanol price for bioethanol export.

In the U. S., 99% of bioethanol used was blended for gasoline and 1% of bioethanol used was for E85 (FFV) in 2006 (U. S. Department of Energy [26]). Bioethanol blended for gasoline use is very popular in the U. S. The figure for U. S. bioethanol consumption is solved from the ratio of bioethanol use to gasoline consumption. The bioethanol use ratio for gasoline depends on the domestic unleaded gasoline and domestic bioethanol prices. Gasoline consumption depends on the domestic unleaded gasoline price, GDP growth ratio, and population. The domestic unleaded gasoline price depends on the world crude oil price.

$$USQCE_t = USQCGAS_t{*}USETHAUSE_t$$

$$\log(USETHAUSE_t/USETHAUSE_{t-1}) = 0.3562{*}\log(UGP_t/UGP_{t-1}) + (-0.2894){*}\log(UDEP_t/UDEP_{t-1}) + 0.396$$

$$\log(USQCGAS_t/USQCGAS_{t-1}) = (-0.1356){*}\log(UGP_t/UGP_{t-1}) + 0.1560{*}\log(USGDP_t/USGDP_{t-1}) + 0.3771{*}\log(USPOP_t/USPOP_{t-1}) + 5,746.3$$

$$\log(UPG_t/UPG_{t-1}) = 0.8798{*}\log(WOP_t/WOP_{t-1})$$

where *USQCE* is bioethanol consumption, *USQCGAS* is gasoline consumption, *USETHAUSE* is the ratio of bioethanol use to gasoline consumption, *UGP* is the unleaded gasoline price, *UDEP* is the domestic bioethanol price, 0.396 is the calibrated coefficient for the ratio of bioetahnol use to gasoline consumption, which is applied to 2008/09, [13)] *USGDP* is the GDP growth ratio, and *USPOP* is population. The price elasticity of the unleaded gasoline price for the ratio of bioethanol use to gasoline consumption is 0.3562, while −0.2894 is the price elasticity of the domestic bioethanol price for the ratio of bioethanol use to gasoline consumption, −0.1356 is the price elasticity of the unleaded gasoline price for gasoline consumption, 0.1560 is income elasticity for gasoline consumption, 0.3771 is the elasticity of population growth for gasoline consumption, 5,746.3 is the calibrated coefficient of gasoline consumption which is applied to 2007/08,[6] and 0.8798 is the price elasticity of the world crude oil price for unleaded gasoline price.

U.S. bioethanol production is divided into conventional (corn-based) and second-generation biofuel. Conventional bioethanol production depends on net return, technological growth, and the domestic gasoline price. Net return is derived from income and expenditure, where income is the weighted average from wet and dry mill income. The wet mill income is derived from the domestic bioethanol, corn gluten meal, corn gluten feed, and corn oil prices. The dry mill income is derived from the domestic bioethanol and DDG prices. Expenditure is the sum of the domestic corn and natural gas prices. DDG price depends on the domestic bioethanol, corn, and soybean meal prices.

$$USQPE_t = USQPEC_t + USQPES_t$$

$$\log(USQPEC_t/USQPEC_{t-1}) = 0.6206*\log(NETR_t/NETR_{t-1}) + 0.1702*\log(TEC_t/TEC_{t-1}) + (-0.1744)*\log(UGP_t/UGP_{t-1}) + 3,939$$

$$NETR_t = ((DRYR_t*DRYINC_t) + (1-DRYR_t)*WETINC_t) - (DPC_t + 0.0038*NGP_t)$$

$$DRYINC_t = 2.8*UDEP_t + 0.0870*DDGP_t$$

$$WETINC_t = 2.8*UDEP_t + 0.0015*CGMP_t + 0.0057*CGFP_t + 0.0008*CGOP_t$$

$$\log(DDGP_t/DDGP_{t-1}) = 0.1294*\log(UDEP_t/UDEP_{t-1}) + 0.6864*\log(DPC_t/DPC_{t-1}) + 0.0449*\log(SOYMP_t/SOYMP_{t-1})$$

where *USQPE* is U.S. bioethanol production, *USQPEC* is conventional bioethanol production, *USQPES* is second-generation bioethanol production, *NETR* is the net return of conventional bioethanol production, *TEC* is the technological growth ratio, *DRYR* is the dry mill ratio to total bioethanol facilities, *DRYINC* is dry mill income, *WETINC* is wet mill income, *DPC* is the domestic corn price, *NGP* is the domestic natural gas price, *DDGP* is the domestic DDG price, *CGMP* is the corn gluten meal price, *CGFP* is the corn gluten feed price, *CGOP* is the corn oil price, and *SOYMP* is the soybean meal price. The elasticity of net return for conventional bioethanol production is 0.6206, while 0.1702 is the elasticity of the technological growth ratio for conventional bioethanol production, −0.1744 is the price elasticity of the domestic unleaded gasoline price for conventional bioethanol production, 3,939 is the calibrated coefficient for bioethanol production which is applied to 2007/08,[6] 2.8 is the bioethanol convert coefficient, and 0.0870 is the DDG convert coefficient from one bushel of corn in the dry mill process. The structure of net return equation and these convert coefficients are derived from Elobeid and Tokgoz [5]. The bioethanol convert coefficient is 2.8, while 0.0015 is the convert coefficient of gluten meal, 0.0057 is the convert coefficient of corn gluten feed, and 0.0008 is the corn oil convert coefficient from one bushel of corn in the wet mill process. The price elasticity of the domestic bioethanol price for the DDG price is 0.1294, while 0.6864 is the price elasticity of the domestic corn price for the DDG price, and 0.0449 is the price elasticity of the soybean meal price for the DDG price. The U.S. bioethanol import is the exportable domestic market balance deficit remaining after domestic consumption has been satisfied, as follows:

$$USIME_t = USQCE_t - USQPE_t + USSTE_t - USSTE_{t-1}$$

where *USIME* is the bioethanol import in the U.S., and *USSTE* is the ending stock of bioethanol in the U.S. The U.S. bioethanol ending stock depends on the domestic bioethanol price and consumption, as follows:

$$\log(USSTE_t/USSTE_{t-1}) = (-0.4369)*\log(UDEP_t/UDEP_{t-1}) + (0.4012)*\log(USQCE_t/USQCE_{t-1})$$

where −0. 4369 is the price elasticity of the domestic bioethanol price for bioethanol ending stock, and 0. 4012 is the price elasticity of bioethanol consumption for bioethanol ending stock. Corn-based bioethanol consumption is conventional bioethanol production multiplied by bioethanol productivity, as follows:

$$USQCEU_t = USQPEC_t{*}USEPF_t$$

$$\log(USEPF_t/USEPF_{t-1}) = 0.1702{*}\log(TECE_t/TECE_{t-1})$$

where *USQCEU* is corn consumption for bioethanol use in the U. S., *USEPF* is bioethanol productivity, and *TECE* is the technical growth ratio for bioethanol production, while 0. 1702 is the elasticity of technical growth for bioethanol productivity. The bioethanol production, consumption, and export of the rest of the world depend on the international biofuel price (Brazilian anhydrous bioethanol price), as follows:

$$\log(OTQPE_t/OTQPE_{t-1}) = 0.3064{*}\log(AEP_t/AEP_{t-1})$$

$$\log(OTQCE_t/OTQCE_{t-1}) = (-0.1559){*}\log(AEP_t/AEP_{t-1})$$

$$\log(OTEX_t/OTEX_{t-1}) = 0.3208{*}\log(AEP_t/AEP_{t-1})$$

where *OTQPE* is bioethanol production in the rest of the world, *OTQCE* is bioethanol consumption in the rest of the world, and *OTEX* is bioethanol exports in the rest of the world, while 0. 3064, is the price elasticities of the world bioethanol price for bioethanol production, −0. 1559 is the price elasticity of the world bioethanol price for bioethanol consumption, and 0. 3208 is the price elasticity of the world bioethanol price for bioethanol export. Bioethanol imports are equal to the exportable domestic market balance deficit remaining after domestic consumption has been satisfied,

$$OTIME_t = OTQCE_t - OTQPE_t + OTEX_t$$

where *OTIME* is bioethanol imports in the rest of the world.

The U. S. sugar import is incorporated into exogenous variables,[14] which reflects the U. S. sugar import policy trend. U. S. sugar import is composed as TRQ, re-export program imports and other imports. These imports depend on U. S. sugar policy.

3) Market equilibrium and price linkage

As for the bioethanol market, the model determines gross exports and imports for each country and region in each simulation year. A world market equilibrium price is then obtained from the following equilibrium conditions through the use of the Gauss-Seidel algorithm. In this model, the Brazilian anhydrous bioethanol price (State of Sao Paulo wholesale price) is the world bioethanol price, and it is assumed to be the world bioethanol market clearing price,

$$\Sigma EXE_{r,t} = \Sigma IME_{r,t}$$

where *EXE* is bioethanol exports and *IME* is bioethanol imports, r is each country and region, and t is the time index. As for the Brazilian bioethanol market, the model determines production, imports, consumption, and exports for each simulation year. A world market equilibrium price is then obtained from the following equilibrium conditions through the use of the Gauss-Seidel algorithm. The Brazilian hydrated bioethanol price refer to the domestic bioethanol market clearing price,

$$BRQPE_t = BRQCE_t + BREXE_t$$

where *BRQPE* is Brazilian bioethanol production, *BRQCE* is Brazilian bioethanol consumption, and *BREXE* is Brazilian bioethanol exports. The U. S. bioethanol price is linked to the international bioethanol price as follows:

$$UDEP_t = ((AEP_t/0.64)/1000{*}1.025+0.143) + VEETC_t + 0.29$$

where *UDEP* is the U. S. bioethanol domestic price, *AEP* is the anhydrous bioethanol price, and *VEETC* is the Volumetric Ethanol Exercise Tax Credit. *VEETC* is 0. 135 US$/L from 2006/07 to 2008/09 and 0. 119 US$/L after 2009/10. The currency adjustment from Brazilian Real to U. S. Dollar is 0. 64, 1, 000 is the conversion from KL to L, 1. 025 is an ad valorem tariff of bioethanol, 0. 143 is a secondary tariff of one dollar per liter, and 0. 29 is a bioethanol transportation cost of one dollar per liter from Brazil to the USA (F. O. Licht [6]).

As for the sugar market, the model determines gross exports and imports for each country and region for each simulation year. A world market equilibrium price is then obtained from the following equilibrium conditions through the use of the Gauss-Seidel algorithm. In this model, the world raw sugar price (No. 11 f.o.b.) is assumed to be the world raw sugar market clearing price,

$$\Sigma EXS_{r,t} = \Sigma IMS_{r,t}$$

where EXS is sugar exports, IMS is sugar imports, r is each country and region, and t is the time index. The domestic sugar price is transmitted from the world raw sugar price as follows:

$$DSP_{r,t} = WRP_{r,t} * PDIFS_{r,t}$$

where DSP is the domestic sugar price, WRP is the world raw sugar price and $PDIFS$ is internal and external price differences of sugar. [15] As for the corn market, the model determines gross exports and imports for each country and region for each simulation year. A world market equilibrium price is then obtained from the following equilibrium conditions through the use of the Gauss-Seidel algorithm. In this model, the world corn price (No. 2, Yellow, Chicago) is assumed to be the world corn market clearing price,

$$\Sigma EXC_{r,t} = \Sigma IMC_{r,t}$$

where EXC is corn exports, IMC is corn imports, r is each country and region, and t is the time index. The domestic corn price is transmitted from the world raw sugar price as follows:

$$DPC_{r,t} = WPC_{r,t} * PDIFC_{r,t}$$

where DPC is the domestic corn price, WPC is the world corn price, and $PDIFC$ is internal and external price differences of corn. [16]

3. Assumptions of Baseline Projection and Two Alternative Scenarios

1) Baseline assumptions

Our baseline projection is based on a series of assumptions about the general economy, agricultural policies, and technological changes in the exporting and importing countries during the projection period. The exogenous assumption regarding the projected world crude oil price was derived from the U. S. Department of Energy's Annual Energy Outlook 2008 [25]. In this USDE high price of world crude oil price case scenario, the world crude oil price is expected to increase at a rate of 3.7% per year from 2006 to 2017. [17] The exogenous agricultural domestic price and livestock and dairy production were taken from FAPRI [8], OECD-FAO [17], and USDA [22]. Population data for all countries were taken from official United Nations population estimates (medium variant) (United Nations [21]). Per capita real GDP was also treated as an exogenous variable and GDP growth rate assumptions were based on OECD and USDA economic forecasts. [18]

We also assumed that current agricultural policies will continue in all countries throughout the projection period. Following the general adopted procedures, we assumed normal weather and historical rates of technological innovation. New WTO agricultural agreements were not taken into account in the model. Market access was frozen at levels prevailing in 2007. Regional free trade areas were assumed not to expand.

It is assumed that the anhydrous bioethanol blend ratio will remain at a maximum level of 25% throughout the projection period. The FFV utilization ratio to all registered light vehicles in Brazil will increase from 12.5% in 2006/07 to 46.3% in 2017/18 (ANFAVEA [1]). In EISA 2007 mandates, a total RFS (Renewable Fuel Standard) credit requirement of 36 billion gallons, with 15 billion gallons from conventional biofuels (corn-based bioethanol) and 21 billion gallons from advanced biofuel, is required in 2022. In advanced biofuel, 16 billion gallons of cellulosic bioethanol use by 2022 and 5 billion gallons of biodiesel by 2012. Cellulosic biofuel production is not expected to increase rapidly enough to provide the credits which will be needed to meet the advanced biofuel requirement. In this baseline, bioethanol production from cellulose is expected to increase from 38 thousand KL in 2008/09 to 10.6 million KL by 2017/18 (FAPRI [9]). The petition of waiver of the renewable fuels mandate[19] is authorized in EISA 2007. However, the requirements of waiver are not defined clearly and the petition of waiver hasn't been approved by EPA. In this baseline, it is assumed that the petition of waiver will not be approved by EPA during the projection period.

U. S. biodiesel consumption is expected to increase from 932 thousand KL in 2006 to 3, 785 thousand KL in 2017/18 (FAPRI [9]), with production about the same. In this baseline, the RFS of undifferentiated advanced biofuel is set at 3. 5 billion gallons in 2017/18. The other advanced biofuel technology of BTL (biomass to liquid) is expected to be promoted after the year of 2013/14. The BTL production is expected to increase to meet the differences between total RFS of undifferentiated advanced biofuel and biodiesel consumption. The BTL production and consumption is expected to increase from 2, 839 thousand KL in 2013/14 to 9, 462 thousand KL in 2017/18. The U. S. government imposed two duties for imported bioethanol. The first is an ad valorem tariff of 2. 5% and the second is a tariff of 0. 54 $/gallon, which is applied after the ad valorem tariff. The second tariff will be applied until 2010 by the "*Food, Conservation, and Energy Act.*" In this baseline projection, the second tariff remains during the projection period. Under the Volumetric Ethanol Excise Tax Credit (VEETC), blenders are eligible for a tax credit of 0. 51 $/gallon of blended bioethanol. The credit is scheduled to decrease to 0. 45 $/gallon after 2009/10 as a result of the enactment of the *Food, Conservation, and Energy Act* (*the 2008 farm bill*). In this baseline assumption, the VEETC will be applied during the projection period. The area enrolled in the Conservation Reserved Program (CRP) is assumed to decline because of high returns to many crops. CRP acreage is assumed to decline from 14. 6 million ha in 2006/07 to 12. 1 million ha in 2017/18 (FAPRI [8]).

2) Scenario 1

The expansion of Brazilian FFV utilization is the most crucial factor for Brazilian bioethanol markets. In the baseline projection, the Brazilian FFV utilization ratio to all light registered vehicles will increase to 46. 3% by 2017/18. This information is derived from ANFAVEA [1] projection data. However, the Brazilian Ministry of Agriculture and Livestock and the Ministry of Energy and Mines are estimated to increase the FFV utilization ratio up to 80% in the future.[20] In Scenario 1, the Brazilian FFV utilization ratio to total registered light vehicles will increase to 80. 0 % by 2017/18 (Table 1). As a result of the expansion of FFV utilization, the registered number of FFV is projected to increase from 2, 791 thousand vehicles in 2006/07 to 22, 223 thousand vehicles in 2017/18.[21] The registered number of FFV is to increase by 72. 8%, compared with the baseline projection in 2017/18. In contrast to this, the registered number of gasoline cars is projected to decrease from

Table 1. Future projections for the number of Brazilian vehicles

	UNIT	2006/07 (Base Year)	2007/08	2008/09	2009/10	2010/11	2011/12	2012/13	2013/14	2014/15	2015/16	2016/17	2017/18
Number of registered light vehicles (1)	1, 000 Vehicles	***22,332***	***23,157***	***23,813***	***24,388***	***24,912***	***25,413***	***25,889***	***26,355***	***26,805***	***27,252***	***27,696***	***27,779***
FFV utilization ratio up to 46. 3% (Baseline)	%	12. 5	18. 6	24. 6	30. 4	36	41. 1	46. 3	46. 3	46. 3	46. 3	46. 3	46. 3
FFV utilization ratio up to 80% (Scenario 1)	%	12. 5	19. 1	26. 9	33. 7	39. 8	45. 5	51. 3	57. 0	62. 8	68. 5	74. 3	80. 0
FFV registered number (Baseline) (2)	1, 000 Vehicles	2, 791	4, 307	5, 858	7, 414	8, 968	10, 445	11, 986	12, 202	12, 411	12, 618	12, 823	12, 862
FFV registered number (Scenario 1) (3)	1, 000 Vehicles	2, 791	4, 423	6, 406	8, 219	9, 915	11, 574	13, 277	15, 030	16, 826	18, 672	20, 567	22, 223
Ethanol car ratio (Baseline・Scenario 1)	%	7. 99	6	5	3	2	1	1	1	1	1	1	1
Natural gas-running car ratio (Baseline・Scenario 1)	%	5. 785	6	7	8	8	8	8	8	8	8	8	8
Number of ethanol cars (4)	1, 000 Vehicles	1, 784	1, 389	1, 191	732	498	254	259	264	268	273	277	278
Number of natural gas-running cars (5)	1, 000 Vehicles	1, 292	1, 389	1, 667	1, 951	1, 993	2, 033	2, 071	2, 108	2, 144	2, 180	2, 216	2, 222
Number of registered gasoline cars (Baseline): (6) = (1) − (2) − (4) − (5)	1, 000 Vehicles	16, 464	16, 071	15, 097	14, 291	13, 453	12, 681	11, 572	11, 781	11, 982	12, 182	12, 380	12, 417
Number of regitered gasoline cars (Scenario 1): (7) = (1) − (3) − (4) − (5)	1, 000 Vehicles	16, 464	15, 956	14, 549	13, 486	12, 506	11, 552	10, 281	8, 953	7, 567	6, 128	4, 637	3, 056

Note: 1) Number of registered light vehicles estimated by authors.
2) FFV utilization ratio of the baseline, number of ethanol cars, and number of natural gas-running cars are derived from ANFAVEA [1].
3) FFV utilization ratio of Scenario 1 from 2006/07 to 2011/12 is derived from ANFAVEA [2].
4) Diesel vehicles are excluded from these numbers.

Table 2. U.S. biofuel production and consumption

(1, 000 KL)

	2006/07	12/13	13/14	14/15	15/16	16/17	17/18
BTL production (Baseline)	0	0	2, 839	3, 785	5, 678	7, 570	9, 462
BTL production (Scenario 2)	0	0	0	0	0	0	0

Note: The production volume of BTL is the bioethanol equilibrium.

16, 464 thousand vehicles in 2006/07 to 3, 056 thousand vehicles in 2017/18.

3) Scenario 2

In the baseline projection, the second-generation biofuel technology of BTL (biomass to liquid) is expected to increase after 2013. However, some researchers and government officials doubt whether second-generation biofuel production will expand after 2013.[22] The crucial point of the potential of second-generation biofuel production is whether the production cost of BTL is economically viable or not. At present, second-generation biofuel technology is not advanced and BTL is not economically viable.[23] It is assumed that the mass production of BTL will be very difficult and will depend on the R&D of BTL. In Scenario 2, it is assumed that BTL will not be produced after 2013 (Table 2). This means that the U. S. will have additional bioethanol consumption to meet the undifferentiated advanced biofuel's RFS.

4. Impact of the Brazilian FFV and U. S. Biofuel Program Amendment on Global Sugar and Corn Markets

1) Projected world bioethanol, sugar, and corn markets to the year 2017/18 (baseline projections)

World bioethanol consumption is projected to increase by 6. 8% per annum from 2006/07 to 2017/18, with the U. S. contributing the most.[24] The U. S. biofuel consumption is projected to increase by 11. 0% per annum during the projection period. As a result of the expansion of FFV utilization, Brazilian bioethanol consumption is projected to increase by 10. 4% per annum. World bioethanol production is projected to increase by 6. 8% per annum from 2006/07 to 2017/18, with the U. S. contributing most. U. S. biofuel production is projected to increase by 11. 4% and Brazilian bioethanol production is projected to increase by 4. 8% during the projection period. World bioethanol exports are projected to increase by 0. 9%. Brazilian bioethanol export is projected to increase by 12. 3% per annum, occupying a dominant share (69. 7%) of world bioethanol exports in 2017/18. World bioethanol imports are projected to increase by 1. 5% and U. S. bioethanol imports are projected to decrease by 8. 5% in 2017/18. The U. S. is expected to be the biggest bioethanol producer and Brazil is expected to be the biggest bioethanol exporter during this period. The world bioethanol price (Brazilian anhydrous bioethanol price) is projected to decrease from 988. 1 R$/KL in 2006/07 to 939. 9 R$/KL in 2017/18.

World sugar production (in raw sugar equivalent) is projected to expand by 1. 6% per annum from 2006/07 to 2017/18, with Brazil being the main contributor to this increase.[25] Global sugar consumption is projected to expand by 2. 0% per annum during this period, with India contributing most, while world sugar exports (raw sugar equivalent) are projected to increase by 1. 8% and imports (raw sugar equivalent) are projected to increase by 2. 1% per annum during this period. The world raw sugar price was 12. 8 USC/lb in 2006/07, and is expected to follow cyclic fluctuations during the projection period because of the inevitable time lag involved in sugarcane production. The world raw sugar price in 2017/18 is projected to be 12. 0 USC/lb. Brazil's sugarcane production is predicted to increase by 4. 5% per annum during the period from 2006/07 to 2017/18, supported by projected steady growth in terms of the area harvested and the yield. Brazil's sugar production is predicted to increase by 3. 5% per annum during this period, while exports are predicted to grow by 4. 8% per annum; Brazil is expected to be the largest global sugar exporter by 2017/18.[26]

World corn consumption and production were projected to increase by 2.1% per annum from 2006/07 to 2017/18.[27] The U. S. is expected to contribute most to this increase in world corn consumption. World corn exports and imports are projected to increase by 1.1% per annum during this period. The world corn price is projected to increase steadily from $3.0 a bushel in 2006/07 to $7.7 a bushel in 2017/18. As a result of the expansion of bioethanol consumption, corn consumption for bioethanol is projected to increase by 9.0% per annum from 2006/07 to 2017/18. Total U. S. corn consumption is projected to increase by 2.0% per annum during this period, and U. S. corn production is projected to increase by 2.0% per annum from 2006/07 to 2017/18, while U. S. corn exports are projected to increase by 0.7% per annum, occupying a dominant share (60.3%) of world corn exports in 2017/18. The U. S. is expected to be the biggest corn producer and exporter during this period.[28]

2) Impact of Brazilian FFV expansion on global sugar and corn markets (Scenario 1)

As a result of Scenario 1 (Brazilian FFV utilization ratio to registered number of light vehicles will increase to 80.0% in 2017/18), Brazilian bioethanol consumption is predicted to increase by 20.7% in 2017/18 (Table 3), and Brazilian bioethanol production is predicted to increase by 9.8% in 2017/18. In Brazil, the domestic anhydrous bioethanol price is predicted to be much higher than the anhydrous bioethanol price (world price). Most of the producers will provide bioethanol for domestic hydrated markets rather than the international market. Brazilian bioethanol exports are predicted to decrease by 53.9% in 2017/18, while the Brazilian hydrated bioethanol price is predicted to increase by 32.0% and the anhydrous price is predicted to increase by 6.2% in 2017/18. Brazilian bioethanol exports will decrease and the world bioethanol price will increase, while U. S. biofuel imports are predicted to decrease by 53.9% in 2017/18. U. S. biofuel consumption is predicted to decrease by 2.3% in 2017/18.

Due to the higher domestic bioethanol price from Scenario 1, Brazilian sugar production is predicted to shift from sugar to bioethanol production. In 2017/18, the domestic bioethanol price is also predicted to be much higher than the domestic sugar price in Brazil. The price ratio[29] is predicted to be 0.0376, in contrast to a ratio of 0.0143 in the baseline projection. Consequently, the allocation ratio for sugar is predicted to fall from 44.3% to 40.9% in 2017/18, and Brazilian sugar production is predicted to decrease by 4.3% in 2017/18 (Table 4), with exports predicted to decrease by 5.4% (Table 4). Brazil's domestic sugar price is also expected to increase by 10.3% in 2017/18 (Table 6). On account of this shift in sugarcane allocation from sugar to bioethanol production in Brazil, world sugar production is predicted to decrease by 0.4% (Table 4), with world sugar exports predicted to decrease by 1.1% compared to the baseline case (Table 4). As a result, the world raw sugar price is predicted to increase by 4.7% (Table 6).

Table 3. Impacts on bioethanol market

(2017/18, Scenario 1/Baseline)

	World	Brazil	USA
Production	1.8%	9.8%	1.2%
Consumption	1.8%	20.7%	−2.3%
Export	−28.3%	−53.9%	—
Import	−28.3%	—	−172.7%

In the U. S. bioethanol production is predicted to increase by 1.2%, compared with the baseline projections in 2017/18. As a result of increasing bioethanol production, corn consumption for bioethanol use is predicted to increase by 2.4%, compared with the baseline in 2017/18. As a result of expansion of bioethanol production, U. S. corn consumption is predicted to increase by 0.9% in 2017/18 (Table 5). U. S. corn production is predicted to increase by 0.2%, compared with the baseline in 2017/18 (Table 5), and the changing rate of U. S. corn production is assumed to be much lower than that of consumption (1.5%). U. S. corn exports are predicted to decrease by 3.2% in 2017/18 (Table 5). As a result, world corn exports are predicted to decrease by 1.4%, and world corn prices are predicted to increase by 1.2% in 2017/18 (Table 6).

Table 4. Impacts on world sugar market (2017/18, Scenario 1/Baseline)

	World	Brazil	USA	EU27	Australia	Mexico	Japan	India	China	Thailand	Russia
Production	−0.4%	−4.3%	0.4%	0.0%	1.3%	1.2%	0.0%	0.6%	1.4%	1.5%	1.4%
Consumption	−0.4%	−2.4%	−0.5%	0.0%	−1.1%	−0.3%	0.0%	−0.6%	0.0%	0.0%	−0.2%
Export	−1.1%	−5.4%	2.1%	0.9%	1.8%	7.1%	0.0%	17.3%	1.3%	2.1%	0.7%
Import	−1.1%	−	0.0%	0.0%	−0.5%	−0.5%	0.0%	−0.8%	−4.8%	−	−2.6%

Table 5. Impacts on world corn market (2017/18, Scenario 1/Baseline)

	World	USA	China	Argentina	Japan	Brazil	Korea	South Africa	Canada	Mexico	EU27
Production	0.2%	0.2%	0.1%	0.6%	0.0%	0.3%	0.1%	0.0%	0.1%	0.1%	0.0%
Consumption	0.2%	0.9%	−0.1%	−0.3%	−0.1%	−0.2%	−0.3%	−0.1%	−0.3%	−0.1%	0.0%
Export	−1.4%	−3.2%	0.2%	0.9%	−	5.8%	−	0.5%	0.8%	0.1%	0.3%
Import	−1.4%	0.0%	−1.1%	−0.8%	−0.1%	−0.3%	−0.4%	−0.5%	−0.8%	−0.4%	−0.1%

Table 6. Impacts on bioethanol, world corn and sugar prices (2017/18)

	Scenario 1/ Baseline
Brazilian hydrated bioethanol price	32.0%
Brazilian anhydrous bioethanol price (world price)	6.2%
U.S. bioetahnol price	5.9%
Brazilian domesic sugar price	10.3%
World raw sugar price	4.7%
World white sugar price	4.4%
World corn price	1.2%

Table 7. Impacts on bioethanol market (2017/18, Scenario 2/Baseline)

	World	Brazil	USA
Production	6.6%	3.0%	9.1%
Consumption	6.6%	−9.4%	8.6%
Export	34.5%	76.8%	−
Import	34.5%	−	90.4%

3) Impact of the U.S. biofuel program on global sugar and corn markets (Scenario 2)

As a result of Scenario 2 (BTL will not be produced after 2013/14), the U.S. will have additional bioethanol consumption to meet the undifferentiated advanced biofuel's RFS. U.S. biofuel imports are predicted to increase by 90.4% in 2017/18 (Table 7), while U.S. biofuel consumption is predicted to increase by 8.6%. Brazilian bioethanol exports are predicted to increase by 76.8% in 2017/18, and Brazilian bioethanol production is predicted to increase by 3.0%, with its consumption predicted to decrease by 9.4%. The Brazilian anhydrous bioethanol price is predicted to increase by 40.3% and the hydrated bioethanol price is predicted to increase by 29.5% in 2017/18 (Table 10).

Due to the higher domestic bioethanol price from Scenario 2, Brazilian sugar production is predicted to shift from sugar to bioethanol production. After 2013/14, the domestic bioethanol price is also predicted to be much higher than the domestic sugar price in Brazil. The allocation ratio for sugar production is predicted to be 43.1% in 2017/18 compared to 44.3% in the baseline case, while Brazil's sugar production is predicted to decrease by 1.8% in 2017/18 (Table 8), with exports predicted to decrease by 2.1% (Table 8). Brazil's domestic sugar price is also expected to increase by 4.2% in 2017/18 (Table 10). On account of this shift in sugarcane allocation from sugar to bioethanol products in Brazil, world sugar production is predicted to decrease by 0.2% (Table 8), with world sugar exports predicted to decrease by 0.4% compared to the baseline case (Table 8). As a result, the world raw sugar price is predicted to increase by 2.3% in 2017/18 (Table 10).

In the U.S., bioethanol production is predicted to increase by 9.1% in 2017/18. As a result of bioethanol production, corn consumption for bioethanol use is predicted to

Table 8. Impacts on world sugar market (2017/18, Scenario 2/Baseline)

	World	Brazil	USA	EU27	Australia	Mexico	Japan	India	China	Thailand	Russia
Production	−0.20%	−1.8%	0.1%	0.0%	0.4%	0.3%	0.0%	0.2%	0.4%	0.4%	0.4%
Consumption	−0.20%	−1.0%	−0.3%	0.0%	−0.6%	−0.2%	0.0%	−0.3%	0.0%	0.0%	−0.1%
Export	−0.40%	−2.1%	1.0%	0.4%	0.8%	2.4%	0.0%	6.4%	0.6%	0.7%	0.4%
Import	−0.40%	−	0.0%	0.0%	−0.3%	−0.2%	0.0%	−0.4%	−1.3%	−	−1.0%

Table 9. Impacts on world corn market (2017/18, Scenario 2/Baseline)

	World	USA	China	Argentina	Japan	Brazil	Korea	South Africa	Canada	Mexico	EU27
Production	1.1%	1.1%	0.2%	3.3%	0.0%	1.5%	0.3%	0.1%	0.6%	0.7%	0.1%
Consumption	1.1%	5.4%	−0.3%	−1.8%	−0.6%	−1.3%	−2.3%	−0.8%	−1.7%	−0.4%	0.0%
Export	−9.3%	−20.5%	1.2%	5.1%	−	34.7%	−	3.4%	5.6%	0.9%	1.8%
Import	−9.3%	−0.2%	−6.6%	−5.2%	−0.6%	−1.7%	−2.3%	−2.9%	−5.2%	−2.7%	−0.5%

increase by 15.1% compared with the baseline in 2017/18, as a result of an increase in U.S. bioethanol production. U.S. corn consumption is predicted to increase by 5.4% in 2017/18 (Table 9). The ratio of bioethanol to total corn consumption in the U.S. is predicted to increase by 3.9 points (from 42.1% to 46.0%) in 2017/18. U.S. corn production is predicted to increase by 1.1% in 2017/18 (Table 9), and the changing rate of U.S. corn production is assumed to be lower than that of consumption (5.4%). U.S. corn exports are predicted to decrease by 20.5% in 2017/18 (Table 9). Although the U.S. is assumed to remain the world's biggest corn-producing and exporting country, the share of U.S. corn exports of total world exports is predicted to decrease by 7.4 points (from 60.3% to 52.9%) in 2017/18. The global share of corn exports from Brazil and Argentina is predicted to increase by 5.9 points (from 27.7% to 33.6%) in 2017/18. As a result, world corn prices are predicted to increase by 7.8% in 2017/18 (Table 10).

Table 10. Impacts on bioethanol, world corn and sugar prices (2017/18)

	Scenario 2/ Baseline
Brazilian hydrated bioethanol price	29.5%
Brazilian anhydrous bioethanol price (world price)	40.3%
U.S. bioethanol price	38.0%
Brazilian domesic sugar price	4.2%
World raw sugar price	2.3%
World white sugar price	2.1%
World corn price	7.8%

5. Conclusion

The production and utilization of biofuels is promoted in many countries and regions to deal with energy security and environmental problems as well as to increase farm income. Brazil and the U.S. have a long history of introducing biofuels as alternatives to fossil fuels. The two countries dominate 75.6% of global bioethanol production and lead the global biofuel markets. Both countries' markets have expanded in recent years, and it is estimated that their markets will continue to expand in the future. The expansion of FFV utilization can be the most crucial factor for Brazilian bioethanol markets. In the U.S. bioethanol market, the enforcement of new RFS, enacted by EISA, can be one of the most crucial factors not only for the U.S. and international biofuel markets but also for world agricultural markets.

In this study, we examined how the expansion of FFV utilization in Brazil would impact not only the domestic bioethanol and sugar markets but also the world sugar and corn markets. We also examined how the U.S. biofuel program amendment as a result of second-generation biofuel technological development would impact not only the domestic bioethanol markets but also the Brazilian bioethanol markets and the world sugar and corn markets.

As a result of expanded bioethanol consumption from the increasing use of FFV in Brazil, the Brazilian hydrated bioethanol price is predicted to increase dramatically, and world sugar and corn prices are predicted to increase to some extent. Brazilian bioethanol market structural changes are predicted to impact not only the Brazilian bioethanol and sugar markets but also the U. S. bioethanol and corn markets. As a result of expanded bioethanol imports from the U. S. program amendments from second-generation R&D, Brazilian bioethanol prices are predicted to increase greatly, with world sugar and corn prices predicted to increase to some extent. The U. S. biofuel policy amendment is predicted to impact not only the the domestic bioethanol and world corn markets but also the Brazilian bioethanol and world sugar markets. As a result of our econometric analysis, we concluded that both the expansion of Brazilian FFV utilization and U. S. biofuel policy amendments will impact not only the bioethanol market but also the world corn and sugar markets.

The Brazilian and U. S. biofuel and feedstock markets are affected and related to each other. Policymakers in both countries will have to conduct a biofuel program, taking into consideration the other country's biofuel programs and markets. Thus, biofuel policies in both countries are mutually affected and related.

It means that Brazilian biofuel policies and FFV utilization will impact on US energy policy and energy security. In addition to this, biofuel policies in both countries will impact on corn and sugar market for other countries and regions.

The future direction of this study is projections for the second-generation biofuel (cellulose-based bioethanol) market, and how the second-generation biofuel market will impact the world food and agricultural markets. We would like to go on to cover other biofuel markets (EU, China, India and others) using the world biofuel markets model. Evaluating the impact of these biofuel policy amendments on world livestock markets and FFV registered number in Brazil is the future direction for this study. Evaluating Brazilian drivers' preference between gasoline blended with anhydrous bioethanol and with hydrated bioethanol is also a future direction for this study.

1) For further information concerning Brazil's bioethanol program and the U. S. bioethanol program, please refer to Koizumi [10].

2) As for model structures, equations, parameters, and estimated equations of the world sugar market model, please refer to Koizumi and Yanagishima [11]. As for model structures, equations, parameters, and estimated equations of the world corn market model, please refer to Koizumi [10] and Koizumi and Ohga [11].

3) In this study, we focused on 11 major sugar countries.

4) In this study, we added Canada, EU27 and Mexico to our previous study (Koizumi and Ohga [11]). For added model structures, please refer to Koizumi [10].

5) F. O. Licht data covers the newest sugar markets situation all over the world, compared with other sugar marketing data, such as FAOSTAT.

6) The coefficient of calibration obtained to correct each market activity of the first projection year (2007/08) is equivalent to updated estimated data (2007/08) published by USDE [25] and Ministry of Mines and Energy in Brazil [16].

7) This model is a policy simulation model, reflecting time-series price changes. In building this model, we applied lagged variables. The main advantage of applying them is to prevent spurious regression, eliminating a trend.

8) Hydrated bioethanol contains between 92.6% and 99.3% alcohol. It is used for ethanol cars or FFV. Anhydrous bioethanol contains more than 99.3% alcohol. It is used for bioethanol blended gasoline (E20 or E25).

9) Light vehicle includes automobiles for passenger (*automoveis*) and commercial use (*comerciais leves*), excluding diesel cars. They represent transportation vehicles, which use bioethanol in Brazil. We estimated that the registered number of light vehicles is the total of the past 17 years' light vehicle production. This information is derived from Ministry of Mines and Energy in Brazil.

$$TOTALNUM_t = \Sigma VEHQP_{t-i,\, i=1,17}$$

where $TOTALNUM$ is the registered number of light vehicles and $VEHQP$ is the production of light vehicles.

10) The technological growth ratio is incorporated simply as a time trend.

11) Ethanol-running cars can run on 100% bioethanol. This car was sold in the late 1970s. As a result of a bioethanol shortage around 1990, the sales of ethanol cars have been decreasing.

12) Although anhydrous bioethanol is traded in

global areas, hydrated bioethanol is not traded in global areas and it is limited to use in Brazil.

13) Renewable Fuel Standard was applied from 2008. It was decided by EISA 2007.

14) Please refer to Appendix 1, Table 1-1.

15) It is very difficult to get transportation cost data for all sugar imports. We introduce internal and external price differences as a substitute for transportation cost and others. As for the internal and external price differences, Brazil is 1. 54, USA is 3. 17, EU27 is 3. 41, Australia is 1. 1, Mexico is 1. 87, Japan is 4. 73, India is 1. 36, China is 2. 66, Thailand is 1. 80 and Russia is 3. 03 in 2006. We assumed that the price differences will be stable during the projection period. The internal sugar price is the wholesale sugar price in Brazil, USA, Australia, Mexico, India and China derived from F. O. Licht [7]. The internal sugar price is the reference price in EU27 and the minimum stabilization price in Japan derived from OECD-FAO [17]. The external price is the world raw sugar price (No. 11-f. o. b.) in 2006.

16) It is very difficult to get transportation cost data for all corn imports. We introduce internal and external price differences as a substitute for transportation cost and others. As for the internal and external price differences, China is 1. 68, USA is 1. 01, Argentina is 1. 02, Brazil is 1. 78, Korea is 1. 22, Japan is 4. 05, South Africa is 1. 64, Canada is 1. 02, EU25 is 1. 86, Mexico is 1. 67 in 2006. We assumed that the price differences will be stable during the projection period. The internal corn price is the wholesale price in China, USA, Argentina, Brazil, Korea, South Africa and Germany (EU25) and is derived from FAS-USDA [24]. The internal corn price is the domestic mixed feed price in Japan. The external corn price is the world corn price (No. 2, Yellow, Chicago).

17) The WTI spot price dropped suddenly in September 2008, because of financial crisis and recession. It is difficult to get a world crude oil price projection which reflects the newest economic conditions. We use DOE's world crude oil price forecast data (Appendix 1, Table 1-1).

18) The GDP growth ratio is stagnating in 2008, because of financial problems and recession. It is difficult to get GDP growth ratio projection data which reflect the newest economic conditions. We use OECD and USDA economic forecasts (Appendix 1, Table 1-1).

19) EISA 2007 authorized the EPA administrator by his own motion, one or more states, or a refiner/blender to petition for a waiver of the renewable fuels mandate. The Administrator is authorized to waive the renewable fuels mandate if the administrator determines that implementing the requirement would severely harm the economy or the environment, or that there is inadequate domestic supply to meet the requirement (Sec. 202, EISA 2007).

20) Interview from the Ministry of Agriculture, Livestock, and Food Supply of Brazil, March and July 2008.

21) ANFAVEA [2] projected the Brazilian FFV vehicle registered number in 2008. It is predicted to increase from 2. 6 million vehicles in 2006 to 25. 4 million vehicles in 2015. ANFAVEA didn't publish model structures or parameters, so it is difficult to compare with the models from ANFAVEA and this model. When the two projection results are compared, there are no great differences in other results.

22) Interview from the USDA, USDE, EPA in July 2008.

23) RITE (Research Institute of Innovation Technology for the Earth) and Honda R&D Co., LTD. developed ***RITE strain***, which substantially reduces the harmful influence of fermentation inhibitors in 2006. This is evolutionary technology to produce cellulose-based bioethanol efficiently. However, this technology has no economic viability and DOE and US bio-refiners have not used this technology.

24) Please refer to Appendix 1, Table 1-3. U. S. BTL and BDF production and consumption are deducted from world bioethanol production and consumption.

25) Please refer to Appendix 1, Tables 1-4, 1-5, 1-6 and 1-7.

26) FAPRI [8] projected U. S. and World Agricultural Outlook. It covers the world sugar market. In FAPRI's baseline projection, world sugar production is predicted to increase by 1. 3 % and consumption is predicted to increase by 2. 0% per annum from 2007/08 to 2017/18 and world sugar trade is predicted to increase by 1. 5% per annum during this period. FAPRI didn't publish model structures or parameters, so it is difficult to compare the models from FAPRI and this model. When results for the two projections are compared, there are no great differences for other results.

27) Please refer to Appendix 1, Tables 1-8, 1-9, 1-10 and 1-11.

28) FAPRI [8] projected U. S. and World Agricultural Outlook. It covers the world corn market. In FAPRI's baseline projection, world corn production and consumption are predicted to increase by 1. 4% per annum and world corn trade is predicted to increase by 1. 7% per annum during this period. FAPRI didn't publish model structures or parameters, so it is difficult to compare the two models from FAPRI and this model. When the two projection results are

compared, there are no great differences with other results.

29) The price ratio is calculated as (domestic sugar price)/(domestic hydrated bioethanol price).

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Appendix 1. Baseline Projection

Table 1-1. Exogenous variables

	Unit	Source	2006/07	2017/18 (Projection)
Real GDP growth ratio, Brazil	%	OECD-FAO (2008)	2. 8	3. 5
Real GDP growth ratio, USA	%	ERS, USDA (2008)	2. 0	2. 9
Real GDP growth ratio, EU27	%	OECD-FAO (2008)	1. 6	1. 8
Real GDP growth ratio, Australia	%	OECD-FAO (2008)	3. 2	2. 8
Real GDP growth ratio, Argentina	%	OECD-FAO (2008)	4. 9	2. 8
Real GDP growth ratio, Mexico	%	OECD-FAO (2008)	2. 8	4. 0
Real GDP growth ratio, Japan	%	OECD-FAO (2008)	1. 7	1. 2
Real GDP growth ratio, Korea	%	OECD-FAO (2008)	4. 8	3. 9
Real GDP growth ratio, India	%	OECD-FAO (2008)	7. 7	5. 3
Real GDP growth ratio, China	%	OECD-FAO (2008)	10. 1	8. 2
Real GDP growth ratio, Thailand	%	ERS, USDA (2008)	5. 0	4. 9
Real GDP growth ratio, Russia	%	OECD-FAO (2008)	6. 5	5. 4
Real GDP growth ratio, South Africa	%	OECD-FAO (2008)	4. 4	5. 2
World crude oil price	Dollar/barrel	High Price, Imported low-sulfur, light crude oil, U.S. Department of Energy, Annual Energy Outlook 2008 (2008)	66. 0	102. 1
Natural gas price	Dollar/thousand cubic feet	Referenece case price, domestic natural gas at wellhead, U.S. Department of Energy, Annual Energy Outlook 2008 (2008)	6. 4	5. 7
Wet mill and dry mill rate	%	FAPRI (2008)	81. 5	85. 0
Corn gluten meal price	Dollar/t	FAPRI (2008)	336. 2	330. 5
Corn gluten feed price	Dollar/t	FAPRI (2008)	71. 1	92. 9
Corn oil price	Cents/pound	FAPRI (2008)	31. 8	66. 4
Dry mill ratio to total bioethanol facilities	%	FAPRI (2008)	77. 0	85. 0
Domestic sugar price, EU27	EUR/t	Reference price, white sugar, OECD (2008)	632. 0	405. 0
Domestic sugar price, Japan	JPY/kg	Minimum stablisation price, raw sugar, OECD (2008)	152. 0	152. 0
Total TRQ, USA	thousand metric tonnes	ERS, USDA (2008)	1, 624. 0	1, 402. 0
Re-export program import, USA	thousand metric tonnes	ERS, USDA (2008)	385. 5	385. 5
Other imports, USA	thousand metric tonnes	ERS, USDA (2008)	852. 0	1, 906. 0
Producer price of cereal, EU27	EUR/t	Cereal support price, OECD (2008)	101. 0	101. 0
Domestic soybeans price, USA	Dollar/Bushel	Soybean price, ERS, USDA (2008)	6. 4	9. 0
Domestic wheat price, USA	Dollar/Bushel	Farm price, ERS, USDA (2008)	4. 3	4. 7
Beef production, USA	Mil. ibs	ERS, USDA (2008)	26, 268. 0	27, 237. 0
Pork production, USA	Mil. ibs	ERS, USDA (2008)	21, 075. 0	23, 776. 0
Dairy production, USA	Mil. ibs	ERS, USDA (2008)	181. 8	207. 5
Wheat domestic price, China	2006/07=1	OECD (2008)	1. 0	0. 8
Pork production, China	ktcwe	OECD (2008)	49, 693. 0	61, 589. 0
Beef production, China	ktcwe	OECD (2008)	7, 486. 0	11, 660. 0
Domestic soybeans price, Argentina	2006/07=1	Export price, f. o. b. Argentine ports, OECD (2008)	1. 0	1. 3
Domestic wheat price, Argentina	ARS/t	Export price, f. o. b. Argentine ports, OECD (2008)	477. 4	652. 9
Beef production, Argentina	kt cwe	OECD (2008)	3, 099. 0	3, 458. 0
Dairy production, Argentina	mt pw	Butter, OECD (2008)	44. 0	44. 0
Beef production, Japan	kt cwe	OECD (2008)	507. 0	526. 0
Pork production, Japan	kt cwe	OECD (2008)	1, 249. 0	1, 003. 0
Poultry production, Japan	kt rtc	OECD (2008)	1, 320. 0	1, 337. 0
Domestic soybeans price, Brazil	2006/07=1	Producer price, OECD (2008)	1. 0	1. 2
Domestic wheat price, Brazil	2006/07=1	Producer price, OECD (2008)	1. 0	1. 6
Domestic rice price, Brazil	2006/07=1	Producer price, OECD (2008)	1. 0	1. 7
Beef production, Brazil	kt cwe	OECD (2008)	8, 967. 0	12, 400. 0
Poultry production, Brazil	kt rtc	OECD (2008)	9, 246. 0	11, 930. 0
Dairy production, Brazil	mt pw	OECD (2008)	493. 0	616. 0
Pork production, Korean Republic	kt cwe	OECD (2008)	1, 092. 0	1, 148. 0
Poultry production, Korean Republic	kt rtc	OECD (2008)	435. 0	560. 0
Domestic wheat price, South Africa	2006/07=1	Producer price, OECD (2004)	1. 0	1. 2
Domestic wheat price, Canada	2006/07=1	Producer price, OECD (2008)	1. 0	1. 1
Beef production, Canada	kt cwe	OECD (2008)	1, 694. 0	1, 414. 0
Pork production, Canada	kt cwe	OECD (2008)	2, 247. 0	2, 383. 0
Dairy production, Canada	kt pw	Butter, OECD (2008)	78. 0	87. 0
Domestic soybeans price, Mexico	2006/07=1	Producer price, OECD (2008)	1. 0	1. 6
Poultry production, Mexico	kt rtc	OECD (2008)	2, 485. 0	2, 711. 0
Dairy production, Mexico	kt pw	Cheese, OECD (2008)	15. 0	15. 0
Domestic wheat price, EU	2006/07=1	OECD (2008)	1. 0	1. 1
Pork production, EU	kt cwe	OECD (2008)	21, 883. 0	22, 791. 0
Dairy production, EU	kt pw	Cheese, OECD (2008)	8, 323. 0	9, 685. 0

Table 1-2. Projected bioethanol, sugar and corn prices

	Unit	Source	2006/07	2017/18 (Projection)
Domestic anhydrous bioethanol price (World bioethanol price)	R$/KL	USP/ESALQ/CEPEA (2008)	988. 1	939. 9
Domestic hydrated bioetahnol price, Brazil	R$/KL	USP/ESALQ/CEPEA (2008)	901. 7	789. 3
Domestic bioetahnol price, USA	Dollars/gallon	F. O. B, Omaha, Nebraska (2008)	2. 6	1. 8
World raw sugar price	Cents/lb	No. 11-f. o. b. stowed Caribbean port, including Brazil, bulk spot price, plus freight to Far East	12. 8	12. 0
World white sugar price	Cents/lb	No. 5, London daily price, for refined sugar, f. o. b. Europe, spot (2008)	15. 4	14. 5
Domestic sugar price, Brazil	Real 50 kg/bag	USP/ESALQ/CEPEA (2008)	46. 0	29. 5
World corn price	Dollars/bushel	Corn No. 2 Yellow, Chicago, ERS, USDA (2008)	3. 5	7. 7
Domestic corn price, USA	Dollars/bushel	Corn farm price, ERS, USDA (2008)	3. 0	6. 7
Domestic unleaded regular gasoline price	Dollars/gallon	U. S. Department of Energy, Annual Energy Outlook 2008 (2008)	1. 9	3. 0
Domestic corn price, China	CNY/t	Maize free market price, OECD (2008)	1, 320. 0	1, 874. 2
Domestic corn price, Argentina	ARS/t	Corn export price, f. o. b. Argentinean ports (2008)	357. 4	860. 3
Domestic corn price, Brazil	2006/07=1	Corn producer price, OECD (2008)	1. 0	1. 8
Domestic mixed feed price, Japan	JPY/t	Mixed feed price, all livestocks weighted average, MAFF, Japan (2008)	43, 285. 0	51, 569. 0
Domestic corn price, Korean Republic	2006/07=1	Corn import price, OECD (2008)	1. 0	2. 2
Domestic corn price, South Africa	Dollars/t	White corn price, ERS, USDA(2008)	193. 1	302. 7
Domestic corn price, Canada	CAN/t	Corn producer price, OECD (2008)	147. 6	287. 7
Domestic corn price, Mexico	MXN/t	Corn producer price, OECD (2008)	3. 0	4. 6

Table 1-3. World bioethanol market

(thousand KL)

	2004/05	2005/06	2006/07	2012/13	2017/18	Growth Rate 2006/07-2017/18
World Production	40, 711	44, 296	51, 322	80, 424	112, 738	6. 8%
Brazil	14, 648	16, 040	17, 764	26, 647	31, 312	4. 8%
USA	12, 888	14, 781	18, 381	38, 823	66, 808	11. 4%
World Consumption	40, 369	43, 711	50, 794	80, 317	112, 565	6. 8%
Brazil	13, 291	13, 989	13, 435	23, 781	26, 823	5. 9%
USA	13, 448	15, 365	20, 636	39, 192	67, 590	10. 4%
World Export	4, 957	5, 933	7, 814	7, 946	8, 692	0. 9%
Brazil	2, 800	2, 494	3, 460	3, 171	13, 950	12. 3%
USA	0	0	0	0	0	—
World Import	4, 616	5, 348	7, 285	7, 946	8, 692	1. 5%
Brazil	0	0	0	0	0	—
USA	563	514	2, 761	888	955	−8. 5%

Source: F. O. Licht [7] (2004/05, 2005/06, 2006/08), authors' projections (2012/13, 2017/18).
Note: Though, we projected annual projection from 2006/07-2017/18, we show mid-term and final terms' projection briefly in this study.

Table 1-4. World sugar production

(thousand metric tonnes)

	2000/01	2006/07	2012/13	2017/18	Growth rate (2006/07-2017/18)
World	132, 989	162, 443	176, 415	195, 606	1. 6%
Brazil	19, 070	32, 226	39, 635	48, 929	3. 5%
USA	7, 956	7, 344	7, 296	7, 642	0. 3%
EU27	21, 358	18, 554	17, 167	16, 082	−1. 2%
Australia	4, 469	4, 899	4, 800	4, 755	−0. 2%
Mexico	5, 236	5, 566	5, 630	6, 332	1. 1%
Japan	781	903	919	922	0. 2%
India	20, 121	28, 083	30, 486	30, 794	0. 8%
China, Mainland	6, 724	12, 198	12, 655	15, 069	1. 8%
Thailand	5, 439	6, 564	7, 550	8, 272	1. 9%
Russia	1, 718	3, 229	3, 481	3, 886	1. 6%

Source: F. O. Licht [8] (2000/01, 2006/07), authors' projections (2012/13, 2017/18).
Note: 1) Though, we projected annual projection from 2006/07-2017/18, we show mid-term and final terms' projection briefly in this study.
2) As for Table 1-5, 1-6, 1-7, sources and note are the same as this table.

Table 1-5. World sugar consumption

(thousand metric tonnes)

	2000/01	2006/07	2012/13	2017/18	Growth rate (2006/07-2017/18)
World	131, 278	150, 792	175, 676	194, 644	2. 0%
Brazil	9, 344	11, 481	13, 781	15, 304	2. 4%
USA	9, 190	9, 377	10, 412	10, 936	1. 3%
EU27	18, 244	18, 647	18, 866	18, 846	0. 1%
Australia	1, 004	1, 191	1, 341	1, 373	1. 2%
Mexico	4, 683	5, 536	5, 566	5, 420	−0. 2%
Japan	2, 303	2, 284	2, 286	2, 267	−0. 1%
India	17, 610	21, 176	26, 420	30, 326	3. 0%
China, Mainland	8, 469	13, 366	16, 607	19, 128	3. 0%
Thailand	1, 929	2, 420	2, 682	2, 859	1. 4%
Russia	6, 806	6, 350	6, 378	6, 201	−0. 2%

Table 1-6. World sugar export

(thousand metric tonnes)

	2000/01	2006/07	2012/13	2017/18	Growth rate (2006/07-2017/18)
World	45, 296	55, 136	63, 478	69, 730	1. 8%
Brazil	9, 972	19, 076	25, 792	33, 425	4. 8%
USA	111	269	210	186	−3. 0%
EU27	9, 749	7, 971	6, 103	5, 075	−3. 7%
Australia	3, 153	3, 577	3, 489	3, 432	−0. 3%
Mexico	120	450	368	1, 225	8. 7%
Japan	3	4	4	4	−0. 2%
India	1, 381	2, 092	3, 940	361	−13. 6%
China, Mainland	94	189	236	300	3. 9%
Thailand	3, 559	3, 891	4, 850	5, 410	2. 8%
Russia	123	238	235	240	0. 1%

Table 1-7. World sugar import

(thousand metric tonnes)

	2000/01	2006/07	2012/13	2017/18	Growth rate (2006/07-2017/18)
World	43, 889	51, 543	63, 478	69, 730	2. 1%
Brazil	—	—	—	—	—
USA	1, 443	2, 348	3, 475	3, 748	4. 0%
EU27	6, 303	8, 310	7, 705	7, 726	−0. 6%
Australia	5	7	7	7	0. 3%
Mexico	24	262	282	294	1. 0%
Japan	1, 552	1, 432	1, 371	1, 349	−0. 5%
India	49	13	14	14	1. 0%
China, Mainland	1, 028	1, 233	4, 245	4, 400	11. 2%
Thailand	—	—	—	—	—
Russia	5, 203	3, 287	3, 099	2, 520	−2. 2%

Table 1-8. World corn production

(thousand metric tonnes)

	2000/01	2006/07	2012/13	2017/18	Growth rate (2006/07-2017/18)
World	634, 520	733, 980	844, 910	943, 877	2. 1%
USA	251, 854	294, 000	338, 127	370, 941	2. 0%
China	106, 000	147, 598	161, 124	172, 605	1. 3%
Argentina	15, 400	19, 933	25, 301	32, 133	4. 1%
Japan	1	1	1	1	0. 0%
Brazil	41, 536	50, 233	52, 748	61, 213	1. 7%
Korea	64	74	96	118	4. 0%
South Africa	8, 040	8, 578	9, 906	10, 945	2. 1%
Canada	6, 827	10, 000	11, 570	12, 663	2. 0%
Mexico	17, 917	21, 450	24, 418	26, 712	1. 8%
EU27	44, 529	54, 757	55, 355	57, 725	0. 4%

Source: USDA-FAS[25] (2000/01, 2006/07), authors' projections (2012/13, 2017/18).

Note: 1) Though, we projected annual projection from 2006/07-2017/18, we show mid-term and final terms' projection briefly in this study.

2) As for Table 1-9, 1-10, 1-11, sources and note are the same as this table.

Table 1-9. World corn consumption

(thousand metric tonnes)

	2000/01	2006/07	2012/13	2017/18	Growth rate (2006/07-2017/18)
World	656, 374	735, 077	847, 322	944, 799	2. 1%
USA	198, 102	243, 272	293, 540	309, 929	2. 0%
China	120, 240	143, 667	162, 127	184, 906	2. 1%
Argentina	5, 600	6, 533	7, 273	8, 407	2. 1%
Japan	16, 200	16, 533	15, 713	16, 386	−0. 1%
Brazil	34, 500	41, 000	48, 623	57, 044	2. 8%
Korea	8, 616	8, 771	9, 802	10, 627	1. 6%
South Africa	8, 705	8, 433	8, 965	9, 548	1. 0%
Canada	10, 123	11, 858	14, 898	18, 977	4. 0%
Mexico	24, 000	30, 200	34, 392	38, 815	2. 1%
EU27	48, 158	61, 867	63, 414	64, 273	0. 3%

Table 1-10. World corn export

(thousand metric tonnes)

	2000/01	2006/07	2012/13	2017/18	Growth rate (2006/07-2017/18)
World	78, 184	90, 863	81, 664	102, 866	1. 1%
USA	49, 313	56, 801	46, 442	62, 044	0. 7%
China	7, 276	3, 165	1, 805	1, 106	−8. 4%
Argentina	9, 676	13, 258	18, 121	23, 694	5. 0%
Japan	0	3	0	0	—
Brazil	6, 261	8, 787	4, 999	4, 829	−4. 9%
Korea	0	0	0	0	—
South Africa	1, 281	1, 033	1, 577	1, 981	5. 6%
Canada	122	389	600	780	6. 0%
Mexico	17	175	198	215	1. 7%
EU27	1, 016	488	584	657	2. 5%

Table 1-11. World corn import

(thousand metric tonnes)

	2000/01	2006/07	2012/13	2017/18	Growth rate (2006/07-2017/18)
World	79, 428	88, 306	81, 664	102, 866	1. 1%
USA	173	303	265	238	−2. 0%
China	89	59	2, 424	13, 111	56. 8%
Argentina	23	25	16	12	−5. 6%
Japan	16, 340	16, 543	15, 711	16, 420	−0. 1%
Brazil	323	1, 099	765	584	−5. 1%
Korea	8, 743	8, 675	9, 699	10, 522	1. 6%
South Africa	395	760	659	617	−1. 7%
Canada	2, 746	2, 177	3, 959	7, 197	10. 5%
Mexico	5, 928	8, 477	10, 184	12, 321	3. 2%
EU27	3, 800	7, 563	8, 743	7, 313	−0. 3%

Appendix 2. Major Estimated Equations

Sugarcane allocated ratio for sugar production

$$\log(SUAL_t/SUAL_{t-1}) = \underset{(152.9891)}{3.7693} + \underset{(1.8941)}{0.2477}*\log(DSP_t/DSP_{t-1}) + \underset{(-0.7891)}{(-0.0978)}*\log(HEP_t/HEP_{t-1})$$

$$R^2 = 0.8037,\ \bar{R}^2 = 0.7382,\ n = 9 \text{ (from 1999 to 2007)},\ DW = 2.0358$$

Per capita hydrated bioethanol consumption in Brazil

$$\log(BRPQCEH_t/BRPQCEH_{t-1}) = \underset{(136.4686)}{6.0431} + \underset{(1.2158)}{0.2652}*\log(BRDPG_t/BRDPG_{t-1}) + \underset{(-2.6486)}{(-0.3614)}*\log(HEP_t/HEP_{t-1})$$

$$R^2 = 0.9284,\ \bar{R}^2 = 0.7853,\ n = 8 \text{ (from 1997 to 2004)},\ DW = 2.9768$$

Total light vehicle registered number in Brazil

$$\log(TOTALNUM_t/TOTALNUM_{t-1}) = \underset{(721.3730)}{9.2323} + \underset{(1.4611)}{0.3754}*\log(BRGDP_t/BRGDP_{t-1}) + \underset{(12.4032)}{0.0343}*\log(BRTECH_t/BRTECH_{t-1})$$

$$R^2 = 0.9906,\ \bar{R}^2 = 0.9889,\ n = 14 \text{ (from 1993 to 2006)},\ DW = 1.3329$$

Per capita consumption of gasoline in Brazil

$$\log(BRPQCG_t/BRPQCG_{t-1}) = \underset{(7.6999)}{0.4355} + \underset{(-1.6807)}{(-0.2696)}*\log(BRDPG_t/BRDPG_{t-1}) + \underset{(-1.6495)}{(-0.1522)}*\log(AEP_t/AEP_{t-1})$$

$$R^2 = 0.9277,\ \bar{R}^2 = 0.8842,\ n = 10 \text{ (from 1997 to 2006)},\ DW = 1.9812$$

Domestic gasoline price in Brazil

$$\log(BRDPG_t/BRDPG_{t-1}) = \underset{(4.4662)}{1.219} + \underset{(2.8001)}{0.8801}*\log(WOP_t/WOP_{t-1})$$

$$R^2 = 0.9924,\ \bar{R}^2 = 0.9885,\ n = 11 \text{ (from 1996 to 2006)},\ DW = 3.091$$

Ratio of bioethanol use to gasoline consumption in USA

$$\log(UETHAUSE_t/UETHAUSE_{t-1}) = \underset{(-7.0941)}{-0.8015} + \underset{(1.0759)}{0.3562}*\log(UGP_t/UGP_{t-1}) + \underset{(-0.5046)}{(-0.2894)}*\log(UDEP_t/UDEP_{t-1})$$

$R^2 = 0.893374$, $\bar{R}^2 = 0.8765$, $n = 23$ (from 1984 to 2006), $DW = 0.8245$

Gasoline consumption in USA

$$\log(UQCGAS_t/UQCGAS_{t-1}) = \underset{(50.9520)}{12.2675} + \underset{(-2.5459)}{(-0.1356)}*\log(UGP_t/UGP_{t-1}) + \underset{(1.5135)}{0.1560}*\log(UGDP_t/UGDP_{t-1}) + \underset{(0.3583)}{0.3771}*\log(UPOP_t/UPOP_{t-1})$$

$R^2 = 0.9880$, $\bar{R}^2 = 0.9761$, $n = 8$ (from 1999 to 2006), $DW = 1.6845$

Conventional bioethanol production in USA

$$\log(USQPEC_t/USQPEC_{t-1}) = \underset{(5.8266)}{5.9818} + \underset{(1.5482)}{0.6206}*\log(NETR_t/NETR_{t-1}) + \underset{(0.3858)}{0.1702}*\log(TEC_t/TEC_{t-1}) + \underset{(-0.4197)}{(-0.1744)}*\log(UGP_t/UGP_{t-1})$$

$R^2 = 0.9791$, $\bar{R}^2 = 0.9529$, $n = 11$ (from 1996 to 2006), $DW = 1.2376$

Domestic unleaded gasoline price in USA

$$\log(UPG_t/UPG_{t-1}) = \underset{(-3.4198)}{-0.7102} + \underset{(9.972)}{0.8798}*\log(WOP_t/WOP_{t-1})$$

$R^2 = 0.9924$, $\bar{R}^2 = 0.9885$, $n = 11$ (from 1996 to 2006), $DW = 3.091$

DDG price in USA

$$\log(DDGP_t/DDGP_{t-1}) = \underset{(61.3553)}{5.2487} + \underset{(1.1421)}{0.1294}*\log(DEP_t/DEP_{t-1}) + \underset{(5.5282)}{0.6864}*\log(DCP_t/DCP_{t-1}) + \underset{(0.2910)}{0.0449}*\log(SOYMP_t/SOYMP_{t-1})$$

$R^2 = 0.8749$, $\bar{R}^2 = 0.8437$, $n = 21$ (from 1986 to 2006), $DW = 2.1841$

Bioethanol ending stock in USA

$$\log(USSTE_t/USSTE_{t-1}) = \underset{(142.0135)}{12.4108} + \underset{(-1.8371)}{(-0.4369)}*\log(DEP_t/DEP_{t-1}) + \underset{(1.856)}{0.4012}*\log(QCE_t/QCE_{t-1})$$

$R^2 = 0.9462$, $\bar{R}^2 = 0.9315$, $n = 15$ (from 1992 to 2006), $DW = 2.004$

Note: The figure under each elasticity is a t-value.