ETHANOL POLICY, COMMODITY REVENUE, AND IMPORT QUANTITY DEMAND: THE UNITED STATES AND BRAZIL

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Title

Ethanol Policy, Commodity Revenue, and Import Quantity Demand: The United States and Brazil

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The Supervisory Committee certifies that this ***disquisition*** complies with North Dakota State University's regulations and meets the accepted standards for the degree of

MASTER OF SCIENCE

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ABSTRACT

Brazil and the United States have been major players in the ethanol industry for over a decade. Both countries have a strong policy backing to push the production and use of the renewable fuel while other parts of the world seem to fall short in comparison. These two nations can be used to determine how an ethanol policy affects ethanol producing commodities as well as the factors that drive import quantity demanded based on export statistics.

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DEDICATION

To my Great-Grandma Edith. You worked so hard to shape me into who I am today, so I dedicate my work to you.

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CHAPTER 1: INTRODUCTION

Ethanol has been used for several decades as a fuel. As early as 1826 ethanol was used by Nicolaus Otto, the inventor of the modern day four-cycle internal combustion engine, to power an engine. Nearly a century later, Henry Ford went on to design his Model T with the ability to operate using a fuel and ethanol mixture. Prior to Ford's use, ethanol was used periodically throughout the 1850s until a liquor tax was placed on it to help fund the Civil War. Once the tax was repealed, ethanol continued to be used for fuel and was first blended with gasoline in the early 1900's. Similar to the liquor tax ethanol once again faced the barrier of prohibition when ethanol was banned due to its classification as an alcoholic beverage. Once prohibition ended ethanol was back on the market as a fuel additive (EIA, 2018). From there it was used as an octane booster and it remained highly demanded throughout World War II due to fuel shortages (NDSU, 2018). Today, ethanol is used across the world to meet renewable fuel policy standards and reduce countries' dependence on crude.

Ethanol is a clear alcohol that is considered renewable due to its production from a variety of different biomasses. In particular, ethanol is typically made from three different types of biomass. The first is sugars. Sugars can include cane sugar, sugar beet, and sweet sorghum. Sugars are commonly used for ethanol in South America since sugarcane is a frequently grown crop. The second is starches. Starches can include grains (corn, wheat, and sorghum), tapioca, and cassava. Corn is the most commonly used crop for ethanol in North America as it is a crop that grows well in that climate. The final biomass type is cellulose. Examples of cellulose include wood, switch grass, and corn stover. Wood is a common biomass used across Europe (Bioenergy Australia, 2019).

Although ethanol has made for a productive fuel source for well over a century, it comes with its own set of problems. One of the largest problems relates to ethanol fueled engines starting in colder temperatures. Traditional gasoline fueled engines can start at temperatures as low as -40ºF. Ethanol engines however can only start at temperatures higher than 55ºF. Due to this temperature difference of over 100ºF, cold start systems have been implemented. These systems are very similar to those in older tractors that started on gasoline and ran on diesel. In the ethanol cold start system gasoline is injected during the could start and throughout the warming period. The vehicle then switches to the ethanol fuel it would normally operate on (Sales et al., 2012). While this is currently the necessary method for vehicles that run solely on ethanol, it is not an ideal situation. There are concerns with cold start emissions as well as a dependence on traditional gasoline. Many nations are trying to reduce their dependence on gasoline, so having to rely on gasoline so heavily is a problem for these nations.

One of the major differences between the ethanol produced in the United States and the ethanol produced in Brazil is the commodity it is made from. In the U.S., ethanol is made from corn, whereas in Brazil, the bulk of ethanol is produced from sugarcane. Although this may not seem like a major difference, previous studies, such as the one done by Debnath et al. (2017), have shown that the ethanol made in Brazil generates lower greenhouse gas emissions than the ethanol in the United States. This is an important thing to note as it could hint toward a major reason for two-way trade between Brazil and the United States.

The processes for creating ethanol from the two commodities differs slightly. The process to transform corn into ethanol looks more like a chain while the process to transform sugarcane mimics more of a tree shape. The differences will be discussed further below the figures that are shown below.

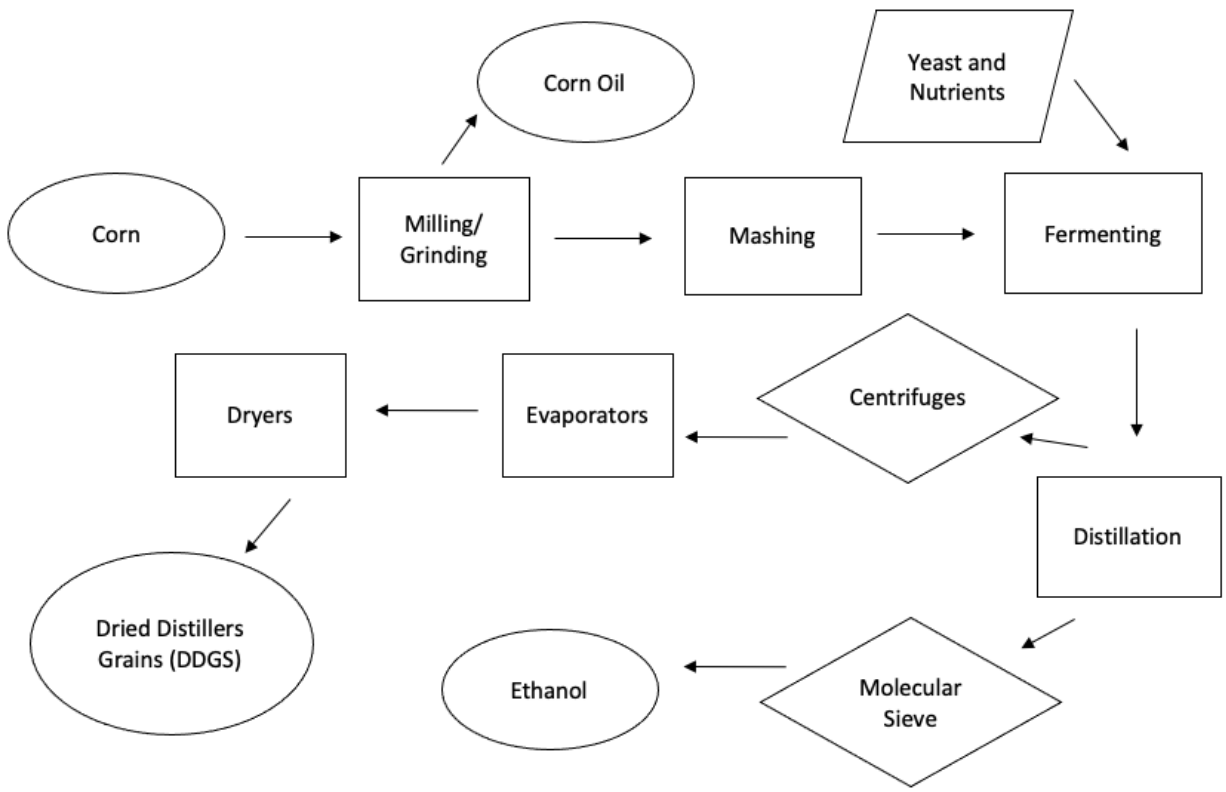

Figure 1.1: Conversion Process of Corn into Ethanol

The first step in creating ethanol from corn is to mill the corn into flour. Instead of referring to the milled corn as flour, it is typically referred to as meal. The next step for the meal is to add water to create what is referred to as mash. Different enzymes are added to the mash which converts the starch to a simple sugar known as dextrose. It is during the fermentation stage that yeast and other nutrients are added. The fermentation process typically takes around 40-50 hours. The next stage is the distillation stage. This phase is where the fermented liquid is separated from the solids. The liquid is either left in a concentrated 190-proof hydrous ethanol or is dehydrated in a molecular sieve system to create a 200-proof anhydrous ethanol.

One of the biggest differences between the processes of corn being converted to ethanol and sugar being converted to ethanol is the choice made when making ethanol from sugarcane. When sugarcane is used, a choice is made to either make sugar or ethanol. Typically, a choice is made to produce a certain ratio of both. This is shown in figure 1.3. We can see that the left side shows the process of producing sugar while the right shows the ethanol production process. The process is identical until the third stage where evaporation takes place in the sugar production and fermentation takes place in ethanol production. We can also see that at this stage, materials from sugar production are added to the ethanol process. Both molasses and syrup are used in ethanol's fermentation process. From the third step, both processes move to the drying stage. In sugar, crystallization is seen while in ethanol distillation is seen. The byproducts from sugar production are used in the production of ethanol which is also unique between the two figures.

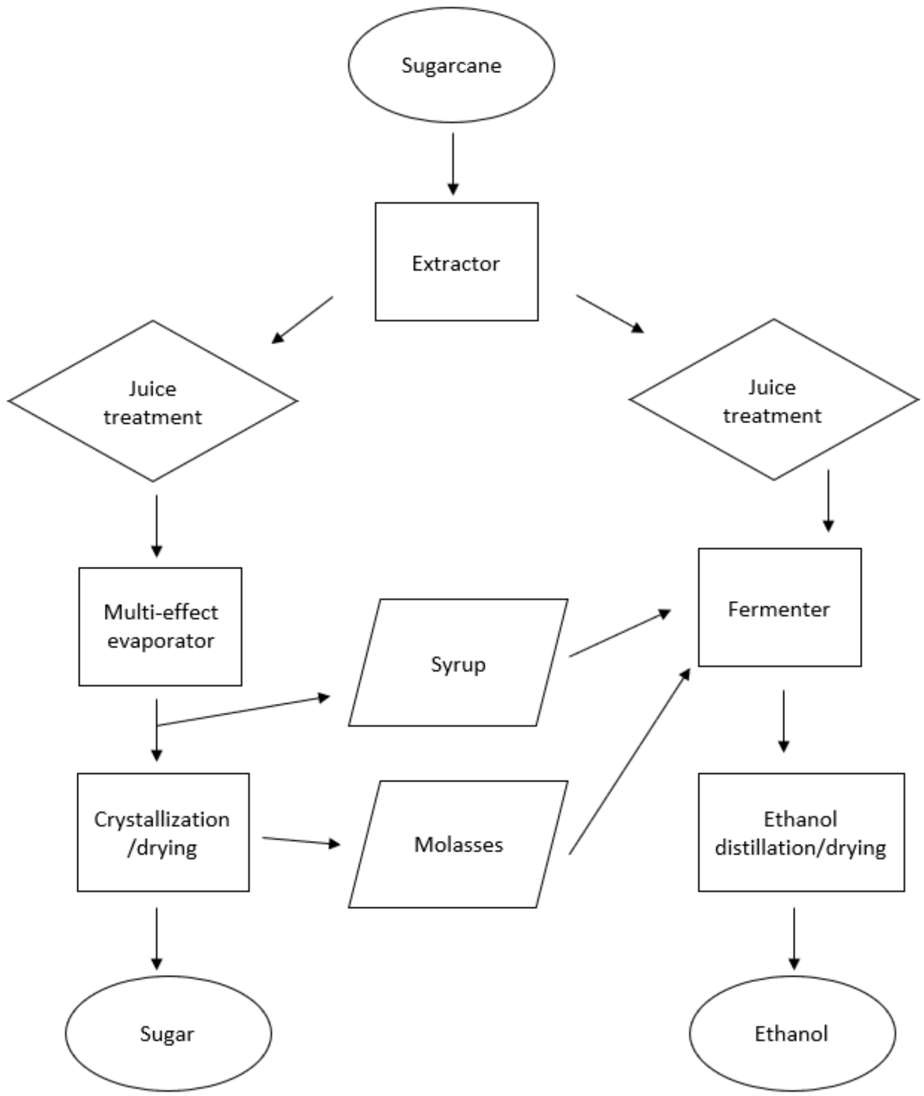

Figure 1.2: Conversion Process of Sugarcane into Ethanol

As was previously mentioned, it is important to note from the two processes is how the production chain looks. In the United States, it is a fairly linear production chain until the end when the fermented liquid is separated from the solids. In Brazil, the production chain more resembles a tree instead of a linear chain. In Brazil's process of producing ethanol, they have to make the choice of whether to allocate the sugarcane toward ethanol or sugar. There is only a certain amount of sugarcane, so there is a decision that must be made about which product to produce. This decision is mainly driven by the price that can be received for ethanol or sugarcane.

Although sugarcane is the main commodity used in Brazil to produce ethanol, Brazil has started using corn to produce ethanol as well due to their increased corn supply in states such as Mato Grosso and Parana in the center-west of the country. Currently, there are16 plants that use corn to produce ethanol. In Brazil, corn-based ethanol production is anticipated to hit 2.5 billion liters in 2020, but could hit 5.5 billion liters by 2022. In 2019, 96% of total ethanol produced was done so using sugarcane, however, this left about 1.5 billion liters that was produced using corn (Hughes, 2020).

Figure 1.3 shows how we reach the market clearing price in the United States. The process would be nearly identical for Brazil with the only difference being the fuel blends. E27 and E100 would replace E10, E15, and E85 in the Brazilian market. The importance of the market clearing price, is to show the equilibrium price of the ethanol market. Although it is mentioned how the United States and Brazil would use this model, it can be used as a base for other countries as well. In addition to the change of ethanol blends, other supply and demand factors may be added to the model. In summation, figure 1.3 is a strong base for any ethanol market clearing model.

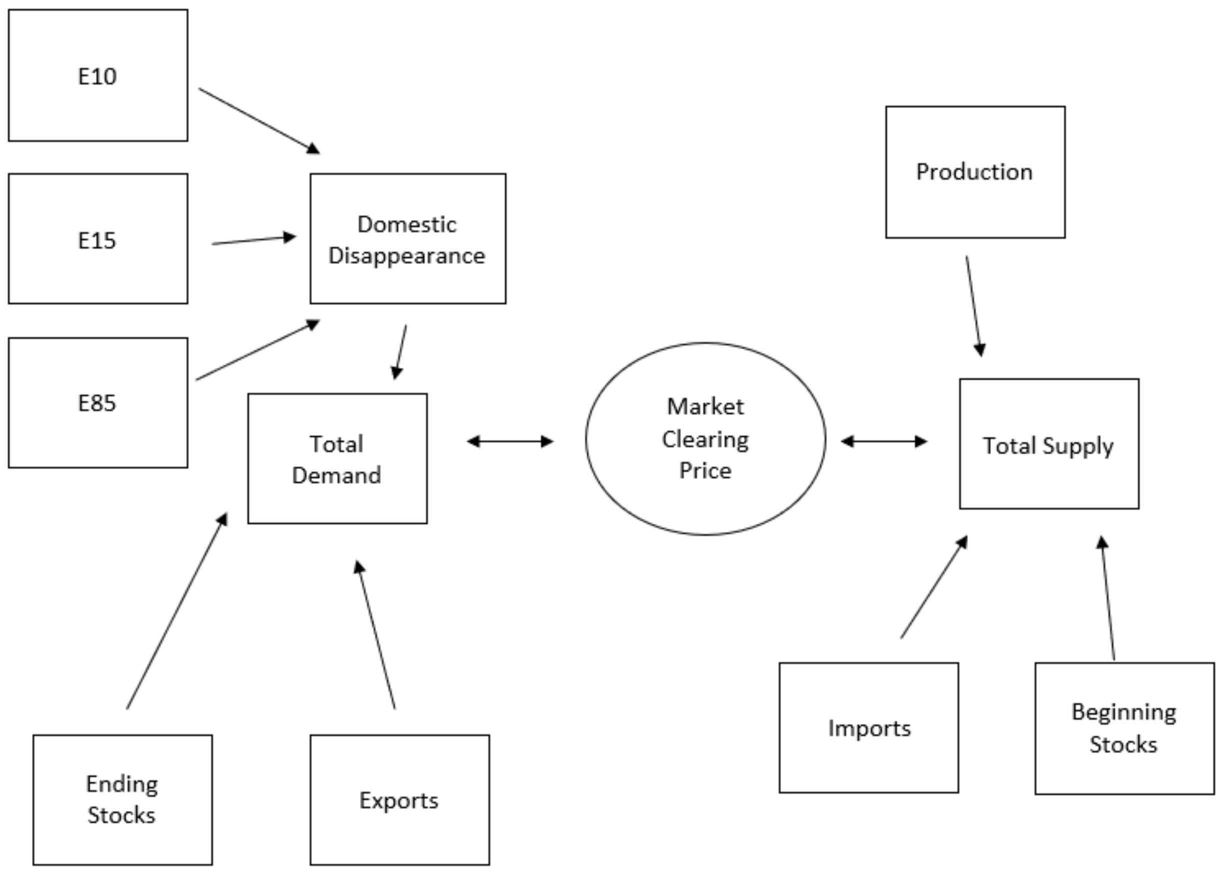

Figure 1.3: Market Clearing Price for the United States

1.1. Research Objectives

This thesis covers two research topics. The first study looks at how the implementation of ethanol policy affects the revenue that originates from the commodity used to produce ethanol while the second looks at what economic factors affect import quantity demand for a specific nation's ethanol. The first portion of this thesis is a Value at Risk (VaR) study of the Renewable Fuel Standard in the United States. This study uses VaR to determine how the Renewable Fuel Standard affected corn revenue as corn is the commodity most commonly used for ethanol production in the United States. This study also contains Stochastic Dominance with Respect to a Function (SDRF) which ranks outcomes based on their level of risk. The second study focuses on import quantity demand of Brazilian ethanol. The relation and usefulness of this study comes from the countries themselves. Both the United States and Brazil have a strong policy backing for ethanol which in turn incentives them to produce and trade ethanol. Since the United States and Brazil have been the top ethanol producers for over a decade, they were chosen to complete these studies.

CHAPTER 2: LITERATURE REVIEW

2.1. Introduction

The United States and Brazil both have five distinct geographical regions. As will be shown later in this chapter, a majority of both Brazilian and United States' ethanol production happens in specific regions of the countries. Discussed in this chapter are the reasons for the geographical placement of ethanol plants as well as a brief discussion as to where the most common ethanol commodity is grown.

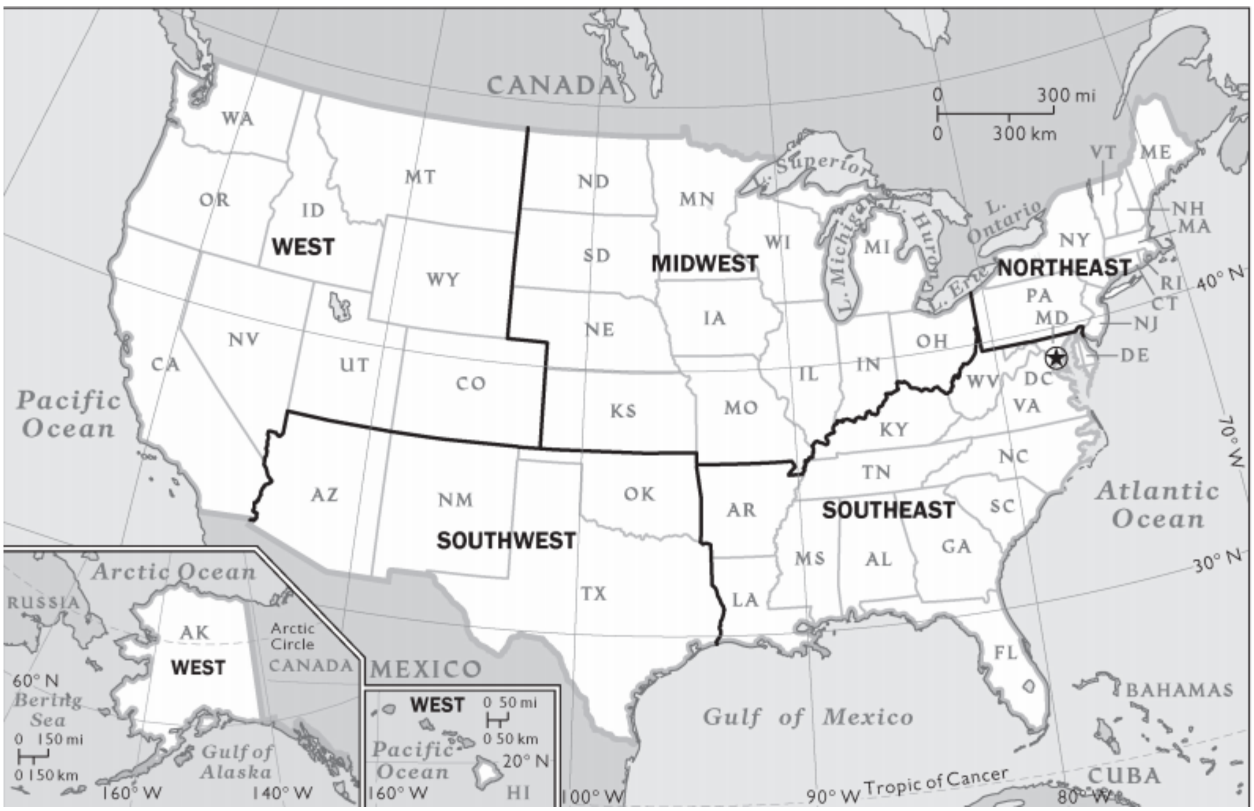

Figure 2.1: Map of Geographical Regions in the United States (National Geographic Society, 2012)

Figure 2.1 shows the five geographical regions in the United States. As will be discussed and shown later in this chapter, a majority of ethanol production happens in the Midwest region of the United States. This is due to the abundance of corn that is grown in that region. There are other commodities across the United States that are used for ethanol production. Many of the ethanol refinery locations that produce ethanol from commodities other than corn are located outside of the Midwest.

Figure 2.2: Map of Geographical Regions in Brazil (Barros, 2020)

Figure 2.2 shows the five geographical regions of Brazil. In Brazil, much of the ethanol production takes place in Southeast region of the country. There are other regions such as the Northeast that have significant production as well. As will be discussed further in this chapter, much of the ethanol plant concentration is centered around roadways and ports in Brazil.

When looking at ethanol trade, it is important to note what type of ethanol is being traded. Denatured ethanol is an ethanol that is most frequently used in fuel as it contains additives that make it toxic to humans. This ethanol is often blended with gasoline to create a renewable fuel. Undenatured ethanol is used for beverages and chemical production (Farinelli et. all, 2009). If ethanol is not denatured when traded, there is the possibility it is being used for products that are not fuel related. Depending on the research being done, this could provide skewed results.

One of the biggest reasons for Brazil's lower greenhouse gas emissions when using sugarcane comes from the byproduct bagasse. The bagasse reduces greenhouse gases by replacing the traditional fossil fuels that would be used for heating and electricity in mills and distilleries (Debnath et al., 2017). Having the ability to use the byproducts from ethanol not only helps lower greenhouse gas emissions by replacing alternatives, it also allows what would be just tossed aside to be reused and given a purpose. In the United States, the byproduct in ethanol production is dried distillers' grains (DDGS). These grains are used as nutrient rich feed ingredients. The United States often exports a lot of the DDGS produced to Mexico, Vietnam, South Korea, Indonesia, and Thailand (U.S. Grain Council, 2018).

Although the United States seems to currently have a good policy backing for the use of ethanol, there are other countries who seem to have an even stronger policy backing for the renewable fuel. The United States currently has its most common blend which is referred to as the E10 blend. This means that ethanol makes up 10% of the fuel. In addition to E10, E15 is also offered. Flex fuel is the blend with the highest quantity of ethanol at a blend rate of E85, or 85% ethanol. Although these are a start, other countries, such as Brazil have higher blend rates and even more ethanol in their flex fuels. Brazil for example, operates on flex fuel that is strictly hydrous ethanol. This means that it is E100. The use of flex fuel is also quite common in Brazil. Although Brazilian blend rates remain stronger than the United States', the United States has continuously increased their consumption mandate over the years. This means that instead of reevaluating the blend rate every year, the United States simply sets a billion-gallon consumption mandate.

There is an idea that United States biofuel mandates create incentives to import and export ethanol with Brazil. Brazil's ethanol made with sugarcane helps the United States to meet certain requirements that the RFS puts into place (Debnath et al., 2017). Since previous studies have suggested that the United States has long term goals to reduce greenhouse gas emissions and that sugarcane ethanol emits less greenhouse gases, this makes sense. If using Brazil's ethanol will assist the U.S. in meeting their goal, this is a huge incentive to continue trading ethanol with Brazil.

In addition to lower greenhouse gas emissions, Brazil also has an advantage in terms of cost and efficiency. Brazil is able to produce ethanol at a lower cost and they also have more efficient ways of production than the United States (Sauer, n.d.). There is the possibility that this is due to the different production methods between the two different ethanol types. As shown previously, the production chain is different between corn and sugarcane-based ethanol. Although it would be difficult to change the entire production chain, it may be a smart idea for the United States to begin to determine alternative, more cost-efficient options.

2.2. Ethanol Across the Nations

As previously discussed in chapter one, the production differs between the two nations in terms of both the commodity used as well as the decision making process (refer to figures 1.1 and 1.2). In terms of the decision on which commodity to use, it is most frequently determined by the ethanol crop most abundantly grown in the region. In Brazil's case, for many years this was sugarcane. In addition to the previously mentioned motivations, Brazil's production using sugarcane is also driven by the way ethanol is produced in Brazil. Since the decision to produce ethanol replaces the ability to produce sugar (as supplies are finite), the decision is often driven by which product would yield the highest price. While this has been the standard for several decades, production has been changing in Brazil's industry as a new commodity has flooded the market. In recent years, corn has been used to produce ethanol in Brazil due to the continued increase in bushels produced as well as its cost effective nature. While corn will not replace sugarcane in Brazil's ethanol industry, the introduction of corn into the ethanol industry will provide Brazil with more domestic independence as well as an additional trade opportunity (Barros and Woody, 2020).

Figure 2.3: Ethanol Plants in Brazil (Barros, 2020)

Figure 2.3 shows the locations of ethanol plants in Brazil. Of these, 16 plants produce ethanol from corn as of late 2020. Ethanol plants that have the ability to produce corn are located in Mato Grosso, Goias, and Mato Grosso do Sul. Four ethanol plants in the previously mentioned states only produce corn based ethanol (Barros and Woody, 2020). As is visually apparent, most ethanol plants reside in the Center-West and Southeast regions. There is however a heavy concentration of ethanol plants in the Northeast region near Natal, Cabedelo, Recife, Suape, and Maceio ports. These ports can be seen in figure 2.4 below. In Brazil, ethanol plants are located near either a major roadway or a port. While Brazil has a developed ethanol industry, their logistical system lags behind and tends to hold them back from their full production potential. Roadways in Brazil lack maintenance and distance between cities is quite extensive. In addition, Brazil has one of the highest fatality in the world from driving related accidents. This is due to Brazilian drivers' lack of regard for road rules (Meyer, 2010).

Figure 2.4: Brazilian Ports (Wanke, 2013)

In the United States the majority of ethanol is produced using corn. However, in several plants across the nation sorghum, waste sugars/alcohol, and cellulosic biomass are used to produce ethanol. Unlike Brazil, these plants that choose to produce from a different commodity are not specific to a geographic location. In fact, they are located throughout the continental US. While ethanol plants congregate mostly in the Midwest, several are found along the California coast and some even occupy the South as shown in figure 2.5.

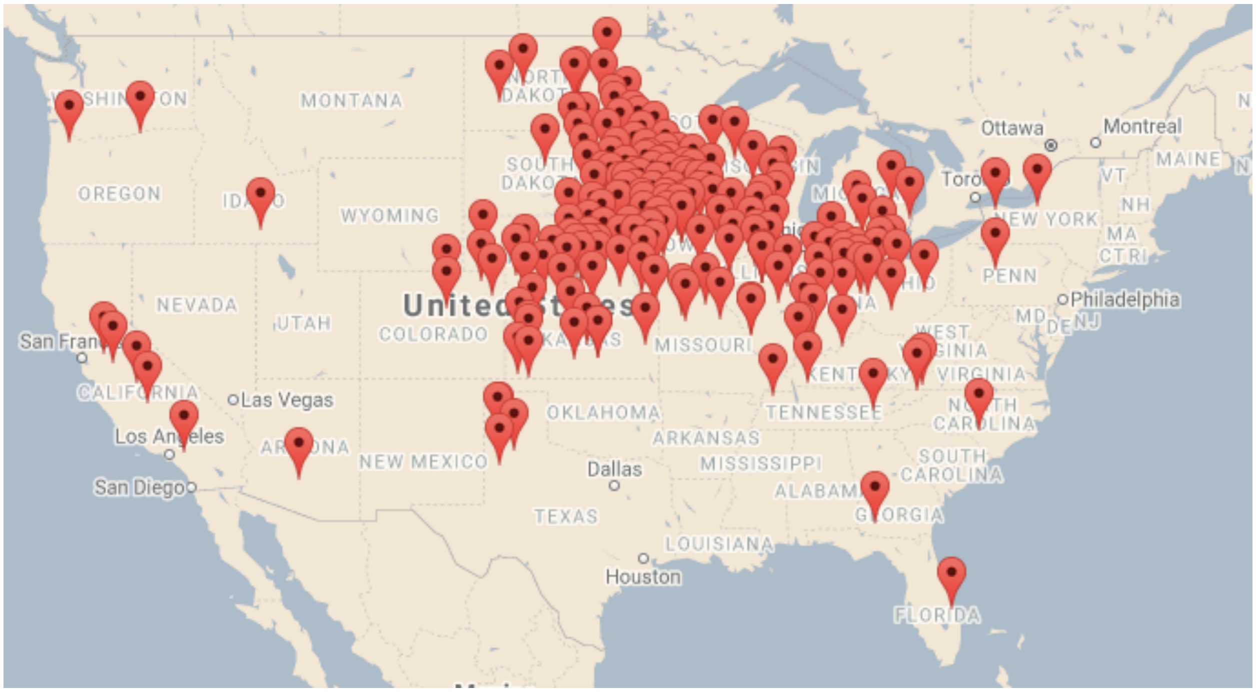

Figure 2.5: Ethanol Plants in the United States (Renewable Fuels Association, 2020)

2.3. Ethanol Production Byproducts

Since the main commodity ethanol is produced from in each nation differs, the byproduct differs as well. As was previously mentioned in this chapter there are three main byproducts between the United States and Brazil. The three main byproducts are DDGS, vinasse, and bagasse. Although a byproduct is typically thought of as a waste product, these two nations have developed beneficial uses for their byproducts.

The first byproduct comes from corn based ethanol in the United States. DDGs are the byproducts that come from the evaporation and drying stages of the corn based ethanol production process. DDGS are often used for livestock feed as they are quite nutrient rich. In addition to their nutrient rich nature, DDGS are also popular due to their use as a substitute to corn or soybean meal as feed. Studies have shown that, on average, 1.22 metric tons of corn and soybean meal feed can be replaced by a metric ton of DDGS (Hoffman & Baker, 2011).

The next two byproducts are from sugarcane based ethanol in Brazil. The first is vinasse. Vinasse is rich in potassium and is used frequently for sugarcane field fertigation (Lopes et al., 2016). Fertigation is a combination of fertilization and irrigation. Fertigation reduces the water input for plant growth, but can have negative effects on soil and ground waters long term (Reis et al., 2017). The next is bagasse. Bagasse is a dry pulp left over from the process of transforming sugarcane into ethanol. Unlike vinasse and DDGS, it is not used as nutrients but for fuel. Bagasse is often used as fuel to generate electricity for combined heat and power (CHP) systems (Dantas et al., 2013).

2.4. Alternative Renewable Fuel Sources

When looking at fuel, it is always important to look into the possibility of a potential substitute that may be entering the market or that has already begun to infiltrate the market. In terms of renewable fuel, it is important to continuously dig into substitute options that have the potential to emit less greenhouse gases. Some companies such as ExxonMobil have already begun to do just that. Scientists at ExxonMobil have been actively searching for alternatives and have found one in algae. The algae can use brackish or seawater instead of depleting freshwater sources the way ethanol does. Algae also consume CO_2 and have a lower emission profile than corn ethanol (ExxonMobil, 2018). Although this is not a current relevant threat to the ethanol industry, it could very easily become one in the coming years.

Another possible alternative renewable fuel source is butanol or biobutanol. Butanol is made from similar biomass sources as ethanol. However, butanol is less miscible with water and offers a higher energy content. This fuel source meets the Renewable Fuel Standard's specification of a 20% greenhouse gas emission reduction (Alternative Fuels Data Center, 2019). There are areas in the country where biobutanol is currently blended with gasoline, but this is not a common practice at most fueling stations. In the coming years, we could see more fueling stations with biobutanol as a source of renewable fuel.

An option that is not necessarily a substitute for renewable fuel, but is a threat to ethanol nonetheless is electric vehicles. Electric vehicles are an alternative to using fossil fuels. Although they do not use fossil fuels directly, they still need fossil fuels to operate however. In order to generate electricity, fossil fuels are typically used.

Although these options have not yet become a credible threat to ethanol, they very easily could in the coming years. As scientists continue to dig deeper into more sustainable or efficient options, ethanol could grow to be a thing of the past in terms of fuel use. Since ethanol is used in other products such as chemicals, I do not anticipate that ethanol will ever completely go away, however, domestic consumption could dramatically decrease.

2.5. Programs, Policies, Regulations, and Incentives

In the United States, regulatory bodies and programs are in place to encourage the use of biofuels. Arguably one of the most recognized programs in the United States is the Renewable Fuel Standard (RFS). This is a program by the United States Environmental Protection Agency (EPA), that regulates the amount of cellulosic biofuel, biomass-based diesel, advanced biofuel, and total renewable fuel volumes that are required to be used. A previous study done by Debnath, Whistance, and Thompson (2017), showed the importance of this program, since without it, their simulated scenario showed a significant ethanol consumption decrease which lead to nearly no ethanol consumption when ethanol is mixed with fuel. This study did not touch on ethanol used in other products that are not fuel related however.

The RFS, although a large program, is not the only program pushing the use of ethanol. Other policies put in place have encouraged the use of ethanol as well. Individual states such as

California have chosen to implement their own restrictions and requirements when it comes to greenhouse gas emissions as well as renewable fuel use. Their additional laws and regulations push their residents to take steps further than what the federal government already requires. One specific incentive offered by California's state government are the Alternative Fuel and Vehicle Incentives.

The Alternative Fuel and Vehicle Incentives provides financial incentives to numerous entities to develop alternative and renewable fuels. With the continuous incentivized research, individuals or organizations will continue to look for more efficient or effective renewable fuel sources. They may also continue to dig deeper to see how production could be changed in order to produce more efficiently or with less greenhouse gas emissions. With the government backing further research, there is much more likelihood for success in developing better technologies.

Brazil has fewer specific guidelines in terms of ethanol consumption. They simply require that 27% of the fuel consumed is renewable. This means that they use E27 fuel whereas in the United States there is typically an E10 blend. Flex fuel is an exception to both of these however as it is E85 in the United States and E100 in Brazil. As mentioned previously, flex-fuel can only be used in certain vehicles that have been made to use flex-fuel or traditional ethanol blends.

Table 2.1: Brazilian Ethanol Use Mandates (Barros, 2020)

Year	Month	Mandate
2006	January-February	E25
	March-October	E20
	November-December	E23
2007	January-May	E23
	June-December	E25
2008	January-December	E25
2009	January-December	E25
2010	January	E25
	February-April	E20
	May-December	E25
2011	January-September	E25
	October-December	E20
2012	January-December	E20
2013	January-April	E20
	May-December	E25
2014	January-December	E25
2015	January-March 15th	E25
	March 16th-December	E27
2016	January-Present	E27

Brazil's history with ethanol is quite extensive and goes back nearly a century. Brazil's ethanol history is often broken down into five distinct phases which range from 1934-present. These phases are the following:

- Ethanol as an additive to gasoline: 1934-1974
- Proalcool – Initial phase: 1975-1979
- Proalcool – Growth and maturity: 1979-1989
- The decline of proalcool and the deregulation of the ethanol industry: 1990-2002
- The resurgence of the ethanol industry: 2003-present

In the first phase hydrated ethanol was converted to anhydrous ethanol which was then blended with gasoline. The decision to blend the ethanol was not based on a need to replace gasoline, but as a reaction to fluctuations in the sugar market. Essentially, if the sugar price was high, less ethanol and more sugar was produced. The second phase was brought on by the oil shocks that occurred in the early 1970's. In an attempt to reduce Brazil's dependence on oil imports, the National Alcohol Program (Proalcool) was created to promote the addition of anhydrous ethanol to gasoline. Similar to the second phase, the third phase was brought on by yet another oil crisis. New goals were set for the already present Proalcool program which included using hydrated ethanol (E100) as fuel and expanding sugarcane fields and industrial capacity to make room for the new fuel. As oil prices recovered, the fourth phase began. When oil prices decreased, sugar prices also increased which led to a decreased incentive to produce ethanol and an increased incentive to switch production to sugar. In this time frame, Brazilian policy began to incentivize sugar production and exporting which led to uncertain ethanol supply at the pump. This lowered confidence in the good and led to a drastic decline in ethanol powered car sales. The fifth and current phase was brought on by private sector commitment to the renewable fuel. In this phase the flex-fuel vehicle was produced and marketed to allow consumers to freely choose between gasoline or E100. Brazilian gas stations are unique as they provide both E100 and gasoline (E27). When flex-fuel vehicles were released in 2003, new vehicle sales increased more than ninety percent by 2009 (Barros and Giles, 2010).

Brazil has a program known as the RenovaBio Program. In 2015 Brazil joined the 21st Conference of Parties where nations meet on climate change and how they can help to combat it. Brazil made six large commitments to be achieved by 2030 at this conference. The first was to increase their share of sustainable bioenergy to 18%. This means that they intend to increase biofuel consumption. Their pledge to increase ethanol consumption not only benefits the ethanol industry, but will also reduce greenhouse gas emissions. The second commitment was to achieve a 45% share of the renewable energy matrix. Doing this is a large undertaking, however, with

Brazil's recent trends, it seems as though they are already well on their way of meeting this goal. The third was to achieve at least a 66% share of hydropower generation. With Brazil's prime location near large water sources, this is a very feasible goal for them. The Amazon River alone can provide them with ample opportunities for energy generation. The fourth is to expand their use of renewable energy sources. There are many alternative energy sources out there, but not too many are the cheapest option, so they are not the most commonly used source of energy. However, with Brazil's commitment and push to use more of these alternative sources, other countries may follow their example in the future. The fifth is to expand the use of non-fossil fuel energy sources to at least 23%. This would include an increase in wind, biomass, and solar energy. This commitment would require Brazil to add more wind generators and solar panels, however, it is a fair investment in the fight against climate change. The final commitment from Brazil was a 10% efficiency gain in the energy sector. Most of their goals focused on a very specific form of energy while their last goal was broader, yet still important. If Brazil can fulfill these commitments, they will set a standard for other similar nations to follow.

Although the programs, policies, regulations, and incentives differ between the two nations, it is clear that both countries are working toward a common goal of lowering their ecological footprint. Studying trade patterns between the United States and Brazil is a large source of information when looking at their underlying goals. It is also important to look at when policies are enacted and compare them to changes in trade patterns or import and export data. In terms of policy and regulatory body changes, it is important to watch how greenhouse gas emissions change to determine whether the policy is serving its purpose, especially when the main goal is to lower such emissions.

2.6. Crude Oil

When looking at crude oil, one index of the density of a crude oil or refined products is the American Petroleum Institute (API) gravity. This is calculated from a hydrocarbon's specific gravity using the following formula:

API = (141.5/Specific Gravity) – 131.5 (Equation 2.1)

Typically, crude oils have an API between 15 and 45 degrees. The lower end represents a denser crude while the higher end represents a less dense crude. The lighter crudes are more valuable as they yield higher value products. The light crude range is typically around 35-45 API with medium crude around the 25-35 API range and heavy crude around the 15-25 API range. Anything above 45 API is considered an extra-light crude, which is valued lower than light crude as it contains more light ends such as propane and butane. In addition, anything below 15 is an extra-heavy crude (McKinsey, 2020).

2.7. Econometric Methods and Potential Issues

In previous research that looked at trade between Brazil and the United States such as that done by Debnath et al. (2017), a partial equilibrium model has been used. The purpose of the partial equilibrium model is to look at one market and equate supply and demand. While looking at the one market, everything else is held constant. When using a partial equilibrium model, three assumptions are made.

- In market 1, the price of good p_1 is to be determined. Further, it is assumed that every consumer and firm face the same price. This is known as the law of one price. In addition, all consumers and firms are price takers.
- Focusing on demand, there are J consumers who want the good in market 1. Each of these agents has an income that can be denoted by m^j and a utility that can be

denoted as $u^j(x1, \ldots, xn)$. The consumer spends their income on *N* outputs. These outputs have prices $\{p_1, p_2, \ldots, p_n\}$, where $\{p_2, \ldots, p_n\}$ are exogenous.

- Focusing on the supply side, there are K firms who want to sell the good in market 1. Each firm has the production technology $f^K(z_1, \ldots, z_m)$, where M input prices are shown exogenously by $\{r_1, \ldots, r_m\}$ (Board, 2008).

The previously mentioned study looked simply at the motivations behind two way trade between the nations such as policy and other import quantity demand motivations. For example these could be a desire to reduce greenhouse gas emissions, reduce dependence on fossil fuels, or meet use requirements. The study covered in this thesis however expands on the study done previously by using the original two countries to look at how policy can affect revenue from the most commonly used ethanol commodity and by looking at the difference of import quantity demand between Brazil's top four ethanol importers.

When running most traditional models, ordinary least squares (OLS) is used. When using OLS, there are four assumptions that must be met for a model to be unbiased and five assumptions that must be met for a model to be BLUE (best linear unbiased estimators). These assumptions are known as the Gauss-Markov Assumptions and they are necessary to show that estimators are unbiased. The six Gauss-Markov Assumptions are as follows:

- MLR.1 - Linear in Parameters
- MLR.2 - Random Sampling
- MLR.3 - No Perfect Collinearity
- MLR.4 - Zero Conditional Mean
- MLR.5 - Homoskedasticity
- MLR.6 - Normality

First we will look at MLR.1. linear in parameters means that a model is written as $\gamma = \beta + \beta_1 x_1 + \cdots + \beta_k x_k + u$ where $\beta, \beta_1, \ldots, \beta_k$ are constants of interest and u is an unobserved random error. The previously mentioned equation is specifically known as the population model, however, models that satisfy MLR.1 resemble the population model (Wooldridge, 2012).

MLR.2 random sampling means that we have a random sample of observations that follow the model from MLR.1. This would mean that no bias can be used when collecting data. For example, if you were looking at how fourth grade students did on state testing, you cannot choose the top five scoring students you must include a random group or all fourth grade students.

MLR.3 no perfect collinearity means that, in the model no independent variables are constant and there are no perfect linear relationships among those variables. This does not mean that there cannot be correlation between the independent variables. It simply indicates that they cannot be perfectly correlated.

MLR.4 zero conditional mean indicates that the error term u has an expected value of zero given any value of the independent variables. This can be shown by the following equation: $E(u|x_1, x_2, \ldots, x_k) = 0$. MLR.4 only fails if the functional relationship is not correct from MLR.1. This would happen if a quadratic term was forgotten or if a level of a variable is used instead of the log of the variable. With the inclusion of this assumption and the three previous, the model would be unbiased.

MLR.5 homoskedasticity means that the error term u has the same variance given any value of the explanatory variable. This can be shown by the following equation: $Var(u|x) = \sigma^2$. Although this assumption looks similar to assumption MLR.4, they differ in the fact that MLR.5

looks at the variance as opposed to the expected value. When MLR.5 is met while MLR.1-MLR.4 are also met, the model is BLUE.

MLR.6 normality means that the population error term u is independent of the independent variables $x_1, x_2, \dots, x_k$ and is normally distributed with a zero mean and variance. When we make assumption MLR.6, we have to also be assuming MLR.4 and MLR.5. MLR.1-MLR.6 are known as the classical linear model (CLM) assumptions. This means that the model holds all Gauss-Markov assumptions with the addition of the normally distributed error term.

While the above assumptions hold true for traditional OLS models, the import quantity demand model in this thesis uses time series data instead of cross-sectional data. Since the data is different, the assumptions differ as well. Although they are similar, the six time series assumptions are known as the Gauss-Markov assumptions TS.1-TS.6. They are still Gauss-Markov assumptions, they simply cover time series data as there are similar issues that can arise when running a time series regression. When TS.1-TS.5 are met the estimator $\hat{\sigma}^2$ is an unbiased estimator of σ^2 and the OLS estimators are the best linear unbiased estimators. When TS.1-TS.6 are met, the OLS estimators are normally distributed. The Gauss-Markov time series assumptions are as follows:

- TS.1 – Linear in Parameters
- TS.2 – No Perfect Collinearity
- TS.3 – Zero Conditional Mean
- TS.4 - Homoskedasticity
- TS.5 – No Serial Correlation
- TS.6 – Normality

As previously mentioned, TS.1-TS.6 are fairly similar. First we will look at TS.1 linear in parameters. This means that a stochastic process such as $\{(x_{t1}, x_{t2}, \ldots, x_{tn}, y_t): t = 1,2, \ldots, n\}$ follows a linear model such as $y_t = \beta_0 + \beta_1 x_{t1} + \cdots + \beta_n x_{tn} + u_t$, where $\{u_t: t = 1,2, \ldots, n\}$ is the sequence of errors.

TS.2 no perfect collinearity is the exact same as MLR.3 no perfect collinearity, so the previously stated rule holds true. TS.3 zero conditional mean is also similar to MLR.4 however it states that for each *t,* the expected error term u_t given the explanatory variables for all time periods, is zero. This would look like $E(u_t|X) = 0, t = 1,2, \ldots, n$.

TS.4 homoskedasticity means that conditional on X, the variance of u_t is the same for all *t*: $Var(u_t|X) = Var(u_t) = \sigma^2, t = 1,2, \ldots, n.$ Once again, TS.4 mimics MLR.5. TS.5 no serial correlation means that, conditional on X, the errors in different time periods are uncorrelated. Mathematically: $Corr(u_t, u_s|X) = 0$ for all $t \neq s$. When TS.1-TS.5 are met, the OLS estimators are the best linear unbiased estimators conditional on X. TS.6 normality also mimics MLR.6 in that all errors are independent of X and are independently and identically distributed as Normal(0,σ^2).With TS.1-TS.6 met this means that the classic linear model assumptions are met. This would mean that the OLS estimators are normally distributed conditional on X (Wooldridge, 2012).

2.8. Setbacks

In 2020 when the COVID-19 pandemic hit the United States, stay at home orders and social distancing was enforced. Gasoline consumption and consequently ethanol consumption was dramatically affected. Figure 2.4 shows how consumption differed in 2020 compared to nearly identical 2017, 2018, and 2019. Although we are currently still living through the effects of the pandemic, the current data we have has shown the difference the pandemic has already made (RFA, 2020).

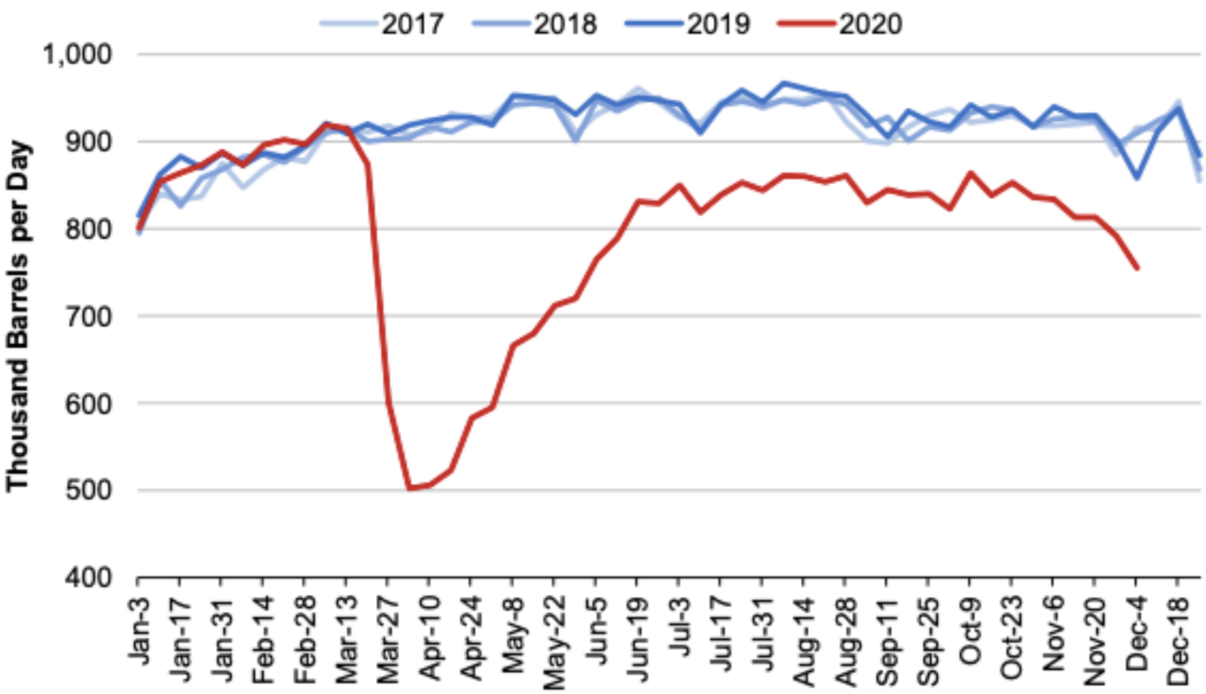

Figure 2.6: Monthly Ethanol Consumption from 2017-2020 (Renewable Fuel Association, 2020)

Due to the decrease in consumption, production has been stunted as well. When ethanol production was compared to 2017-2019, a substantial decrease can be seen. Figure 2.2 shows this decrease from the months of March through June. In addition to the decreased ethanol consumption and production, corn usage also decreased. The asterisks next to May and June indicate that those months' data is based on weekly data whereas the data for March and April is greater than implied weekly data due to EIA supply adjustment.

	Ethanol Production	Ethanol Consumption	Gasoline Product Supplied	Ethanol Blend Rate in Gasoline	Ethanol Stocks-to-Use Ratio	Corn Usage (Mil. Bu.)
March	-104	-223	-2,006	-0.2%	36%	-36
April	-566	-488	-4,325	-0.8%	79%	-195
May*	-452	-372	-2,918	-0.7%	29%	-156
June*	-231	-228	-1,907	-0.3%	10%	-80
Total	-1,354	-1,311	-11,155	-0.5%	39%	-467

Figure 2.7: Ethanol Consumption and Production Decrease (Renewable Fuel Association, 2020)

When gasoline and ethanol demand decreased, the price of ethanol suddenly decreased. For the first time in history, oil futures dipped into the negatives. This was caused by the sudden decrease in demanded quantity coupled with oil storage filled to capacity. Since capacity was met and no more oil could be stored, the purchases of it stopped buying (Hansen, 2020). As visualized by figure 2.6, ethanol revenues were negatively affected by the COVID-19 pandemic. Even revenues for distillers grains, a byproduct of corn ethanol production, were negatively affected.

Month	Ethanol Revenues	Distillers Grains Revenues	Total Revenues
March	-$581	-$24	-$605
April	-$925	-$59	-$984
May	-$672	-$56	-$728
June	-$335	-$37	-$372
July	-$224	$0	-$224
August	-$250	-$5	-$255
September	-$149	-$8	-$157
October	-$183	$0	-$183
November	-$299	$0	-$299
Total	-$3,619	-$189	-$3,808

Figure 2.8: Ethanol Price and Byproduct Price Decrease (Renewable Fuel Association, 2020)

Ultimately the full effects of the pandemic are not yet understood. As we continue to experience social distancing and remote work, we can expect to see a decreased trend in ethanol consumption and production. While COVID-19 is still prevalent in the United States, we will continue to see a decrease in gasoline and ethanol quantity demanded until some restrictions on travel and work are lifted.

CHAPTER 3: ETHANOL'S EFFECT ON COMMODITY REVENUE

3.1. Introduction

The first study in this thesis uses Value at Risk (VaR) and Stochastic Dominance with Respect to a Function (SDRF) to look at the effects of policy intervention on the commodity used to produce ethanol. An analysis was done to look at how the implementation of the RFS has impacted the United States' revenue from corn used for ethanol production. The hypothesis was that the implementation of the program has positively affected revenue, based on preliminary ran averages and previous literature. The results found in this paper are important to both farmers and policy makers. Theoretically, if revenue is increasing from corn used for ethanol production, farmers are receiving higher prices and/or more corn is being allocated to ethanol production. If more corn is being allocated, more ethanol must be demanded and therefore consumed thus the RFS is meeting its intended motive of increasing ethanol consumption and production.

3.2. Previous Research and Motivations

For many years, the United States has been a major producer, consumer, and exporter of ethanol. However, this has not always come naturally, so it has been pushed forward by use of policy intervention. In 2005, the U.S. Environmental Protection Agency (EPA) developed a national policy to increase the volume of renewable fuel blended into traditional fuels used for transportation. This policy, known as the Energy Policy Act of 2005, created the Renewable Fuel Standard (RFS) program. In 2007, The Energy Independence and Security Act of 2007 (EISA) both increased and expanded on the program (AFDC, 2018). With the inclusion of this program, previous studies have concluded that ethanol consumption has increased. With the increase in ethanol consumption, more corn has been demanded, thus impacting corn prices.

As previously mentioned, in the United States, regulatory bodies and programs are in place to encourage the use of biofuels. Arguably one of the most recognized previously mentioned programs in the United States is the Renewable Fuel Standard (RFS). This is a program by the United States Environmental Protection Agency (EPA), that regulates the amount of cellulosic biofuel, biomass-based diesel, advanced biofuel, and total renewable fuel volumes that are required to be used. A previous study done by Debnath, Whistance, and Thompson (2017), showed the importance of this program, since without it, their simulated scenario showed a significant ethanol consumption decrease which lead to nearly no ethanol consumption when ethanol is mixed with fuel. If this scenario were to become a reality, as has been brought up in legislature, the demand for corn, the commodity used in domestic ethanol production, would be negatively impacted. Changes on the Renewable Fuel Standard would not only affect the United States' corn market, but the global market as well (Worledge, 2018).

A study conducted by Carter et al. (n.d.) isolated all channels that generated a price increase from 2006 to 2011. When this was done, they found that with the mandate, corn prices were 30 percent higher. Another study also concluded that ethanol produced from corn has affected the corn commodity price. According to a paper by O'Malley and Searle (2021), crop farmers and ethanol producers realize the most benefit when it comes to the Renewable Fuel Standard. An estimated $14.1 billion dollars in profits had been returned to the agricultural sector.

Ethanol is the second largest user of corn in the United States. Many studies have pointed to ethanol as a corn price driver. However, not all corn growers receive the same price effects. If transportation costs are high, a new ethanol plant may open or there could be an increase in existing plant capacity. This will in turn increase demand which would increase the corn price.

As new plants open or current plants increase capacity nationwide, farmers may choose to sell more of their corn to ethanol plants as the price is higher. Since they are foregoing alternative uses of corn for things such as feed, they may need to get those nutrients for their livestock elsewhere. One alternative for them would be to use dried distillers grains (DDGs), which is a by-product of ethanol (Miller, 2015).

The ultimate problem that this paper strives to tackle is how the implementation of the RFS has impacted the United States' revenue from corn used for ethanol production. I predict that the implementation of the program has positively affected revenue, based on preliminary ran averages and previous literature. The results found in this paper will be important to both farmers and policy makers. Theoretically, if revenue is increasing from corn used for ethanol production, farmers are receiving higher prices and/or more corn is being allocated to ethanol production. If more corn is being allocated, more ethanol must be demanded and therefore consumed.

3.3. Methodology

To conduct this research, a percentage of corn used each year for ethanol as well as the price received by farmers for corn was considered. Using these two values, revenue generated by the corn used for ethanol was calculated. From there, data was separated into three different sections. The first section spanned from 2000-2005. This period represented before the RFS was active. In other words, the ethanol mandate was zero, so very little corn was being allocated to ethanol. The second section spanned from 2006-2011. This period represented large growth in corn allocated to ethanol. In the six-year period, the percentage of corn used for ethanol increased from 17% to 37%. The final section spans from 2012-2016. This period represents a plateau or even decrease in corn allocated to ethanol. Using these three periods, six separate distributions were fit, one on each section's corn used for ethanol and one on each section's price received. From there, output was added to each distribution and 1,000 data points were simulated for each. The simulated data was then taken and a batch fit was added between each section's corn and price data. This batch fit included correlations. The correlation matrices were then replaced with copulas. The data that had both a batch fit and copula was then used to look at copula value at risk. To do this, the revenue was calculated by multiplying the simulated corn usage by the simulated price. From there the three sections' revenues were combined in one spreadsheet so stochastic dominance could be ran to rank the three. The entire process was then repeated, but with 10,000 simulated observations.

3.4. Data

Data was collected from 2000-2016 from the USDA's Economic Research Service. The data collected includes corn supply, corn used for ethanol, and price received ($/bu). Total corn supply and corn used for ethanol data was used to calculate the percentage of corn used for ethanol. This showed how the percentage of corn used for ethanol changes over time. Ethanol mandate data for the United States was collected from a report by the USDA's Economic Research Service by Beckman and Getachew (2017). Figure 3.1 shows the data collected and the different sections that were mentioned in the methodology section.

Year	Total Corn Supply	Corn Used For Ethanol	% Corn for Ethanol	Price Received	Revenue	Ethanol Mandate
2000	11639.424	629.8272	5%	$ 1.85	$ 1,165.18	0
2001	11411.828	707.2384615	6%	$ 1.97	$ 1,393.26	0
2002	10577.659	995.503937	9%	$ 2.32	$ 2,309.57	0
2003	11188.041	1167.547727	10%	$ 2.42	$ 2,825.47	0
2004	12774.502	1323.212528	10%	$ 2.06	$ 2,725.82	0
2005	13234.965	1603.324444	12%	$ 2.00	$ 3,206.65	0
2006	12510.267	2119.493852	17%	$ 3.04	$ 6,443.26	4,000,000,000
2007	14361.543	3049.214074	21%	$ 4.20	$ 12,806.70	4,700,000,000
2008	13680.883	3708.88904	27%	$ 4.06	$ 15,058.09	9,000,000,000
2009	14748.81	4591.157	31%	$ 3.55	$ 16,298.61	10,500,000,000
2010	14160.786	5018.741	35%	$ 5.18	$ 25,997.08	12,000,000,000
2011	13470.974	5000.032	37%	$ 6.22	$ 31,100.20	12,600,000,000
2012	11904.084	4641.127	39%	$ 6.89	$ 31,977.37	13,200,000,000
2013	14687.683	5123.69	35%	$ 4.46	$ 22,851.66	13,800,000,000
2014	15480.842	5200.09	34%	$ 3.70	$ 19,240.33	13,600,000,000
2015	15400.693	5223.614	34%	$ 3.61	$ 18,857.25	14,100,000,000
2016	16942.164	5431.953	32%	$ 3.36	$ 18,251.36	14,500,000,000

Figure 3.1: Separation of Data Used

The data shown in figure 3.1 is the total corn supply, corn used for ethanol, price received, and the ethanol mandate. The percentage of corn used for ethanol and revenue data was manually calculated. The percentage of corn used for ethanol data was calculated to help separate the data into the different sections above. The revenue data is necessary for looking at the VaR and SDRF.

The separation of data in figure 3.1 differs from previous literature in that the data is split into nearly equal splits while also focusing on differences in the data. For instance, the “before” section represents before the mandate was present, so it covers the time period when the mandate was zero. The split between the “during” and “after” sections mostly came from the “% corn for ethanol” column. After a year of a slow increase, a split was made. In addition, after 2012, the values in the column began to decrease. Much of the previous literature such as that by Carter et al. (n.d.) focuses on just a couple of years prior to the mandate and a couple of years after. In the instance of the work done by Carter et al. (n.d.), projections were used to determine how revenue would be affected.

3.5. Results

Two different types of tests were used in this paper. The first is Value at Risk. According to a paper done by Nganje et al. (2006), the likelihood ratio determines if the desired coverage level corresponding to the given confidence level is equal to the number of observed violations and the Z test determines whether the model is biased in estimating VaR. The first set of results we will look at are the VaR results from the 1,000 simulations from the red, or before, section in figure 5.1. At the time that the VaR was calculated, the average was 2287.25 and the 5th percentile was 175.16. This means that the copula VaR was 2112.09. To test the model fitness, I used likelihood ratio and z tests. The likelihood ratio value was -1350.74. Since we were looking at a 5% significance level, the Chi-squared critical value was 3.841. This means that we reject the null hypothesis. The interpretation of this is that the actual revenue losses did exceed the predicted VaR estimates. The Z test value was 51.65. Since we are looking at a 5% significance level, the critical value is 1.96. This means that once again we will reject the null hypothesis. The interpretation of this is that VaR underestimates the actual downside risks. Overall, this VaR model was not a good fit.

	Average	2287.2489			
	5th percentile	175.16165			
	Copula VaR	2112.0872			
	Out of Sample Testing			**X**	406
LR(δ)	-1350.73916			**N**	1000
Zc	51.65391		**δ***	**X/N**	0.406
				N-X	594
LR(δ)	**Natural Log**				
4.9E-294	-675.3695805		The Chi-squared critical value is 3.841 for 5% level of significant.		
0	0		The critical Z value is 1.96 for 5% level of significant.		
	-675.3695805		Reject LR(δ)		
			Reject Zc		
Zc	356				
	47.5				
	6.892024376				
	51.65390901				

Figure 3.2: Results From 1,000 Simulations of the Red Section in Figure 5.1

The second set of results we will look at are the VaR results from the 1,000 simulations from the yellow, or during, section in figure 5.1. At the time that the VaR was calculated, the average was 14488.64 and the 5th percentile was 371.26. This means that the copula VaR was 14177.37. The likelihood ratio value was -1386.29. Since we were looking at a 5% significance level, the Chi-squared critical value was 3.841. This means that we reject the null hypothesis. The interpretation of this is that the actual revenue losses did exceed the predicted VaR estimates. The Z test value was 65.29. Since we are looking at a 5% significance level, the critical value is 1.96. This means that once again we will reject the null hypothesis. The interpretation of this is that VaR underestimates the actual downside risks. Overall, this VaR model was not a good fit.

	Average	14488.638			
	5th percentile	371.26447			
	Copula VaR	14117.373			
	Out of Sample Testing			X	500
LR(δ)	-1386.29436			N	1000
Zc	65.29286		δ*	X/N	0.5
				N-X	500
LR(δ)	Natural Log				
9.3E-302	-693.1471806		The Chi-squared critical value is 3.841 for 5% level of significant		
0	0		The critical Z value is 1.96 for 5% level of significant.		
	-693.1471806		Reject LR(δ)		
			Reject Zc		
Zc	450				
	47.5				
	6.892024376				
	65.29286251				

Figure 3.3: Results From 1,000 Simulations of the Yellow Section in Figure 5.1

The third set of results we will look at are the VaR results from the 1,000 simulations from the green, or after, section in figure 5.1. At the time that the VaR was calculated, the average was 22393 and the 5^{th} percentile was 11064.76. This means that the copula VaR was 11328.24. The likelihood ratio value was 0.989. Since we were looking at a 5% significance level, the Chi-squared critical value was 3.841. This means that we cannot reject the null hypothesis. The interpretation of this is that the actual revenue losses did not exceed the predicted VaR estimates. The Z test value was 1.02. Since we are looking at a 5% significance level, the critical value is 1.96. This means that we cannot reject the null hypothesis. The interpretation of this is that VaR overestimates the actual downside risks. Overall, this VaR model was a good fit.

	Average	22393			
	5th percentile	11064.762			
	Copula VaR	11328.238			
	Out of Sample Testing			**X**	57
LR(δ)	0.98893			**N**	1000
Zc	1.01567		**δ***	**X/N**	0.057
				N-X	943
LR(δ)	**Natural Log**				
1.12E-95	-218.6318522		The Chi-squared critical value is 3.841 for 5% level of significant.		
6.83E-96	-219.1263162		The critical Z value is 1.96 for 5% level of significant.		
	0.494464008		Fail to reject LR(δ)		
			Fail to reject Zc		
Zc	7				
	47.5				
	6.892024376				
	1.01566675				

Figure 3.4: Results From 1,000 Simulations of the Green Section in Figure 5.1

The fourth set of results we will look at are the VaR results from the 10,000 simulations from the red, or before, section in figure 5.1. At the time that the VaR was calculated, the average was 2253.06 and the 5th percentile was 204.298. This means that the copula VaR was 2048.76. The likelihood ratio value was 0. Since we were looking at a 5% significance level, the Chi-squared critical value was 3.841. This means that we cannot reject the null hypothesis. The interpretation of this is that the actual revenue losses did not exceed the predicted VaR estimates. The Z test value was 161.6. Since we are looking at a 5% significance level, the critical value is 1.96. This means that we reject the null hypothesis. The interpretation of this is that VaR underestimates the actual downside risks. Overall, this VaR model was a decent fit, but was not the best.

	Average	2253.0619			
	5th percentile	204.29804			
	Copula VaR	2048.7639			
	Out of Sample Testing			**X**	4022
LR(δ)	0.00000			**N**	10000
Zc	161.60044		**δ***	**X/N**	0.4022
				N-X	5978
LR(δ)	**Natural Log**				
0	0		The Chi-squared critical value is 3.841 for 5% level of significant.		
0	0		The critical Z value is 1.96 for 5% level of significant.		
	0		Fail to reject LR(δ)		
			Reject Zc		
Zc	3522				
	475				
	21.79449472				
	161.6004429				

Figure 3.5: Results From 10,000 Simulations of the Red Section in Figure 5.1

The fifth set of results we will look at are the VaR results from the 10,000 simulations from the yellow, or during, section in figure 5.1. At the time that the VaR was calculated, the average was 14598.31 and the 5th percentile was 789.68. This means that the copula VaR was 13808.63. The likelihood ratio value was 0. Since we were looking at a 5% significance level, the Chi-squared critical value was 3.841. This means that we cannot reject the null hypothesis. The interpretation of this is that the actual revenue losses did not exceed the predicted VaR estimates. The Z test value was 387.896. Since we are looking at a 5% significance level, the critical value is 1.96. This means that we reject the null hypothesis. The interpretation of this is that VaR underestimates the actual downside risks. Overall, this VaR model was a decent fit, but was not the best.

	Average	14598.311			
	5th percentile	789.68407			
	Copula VaR	13808.627			
	Out of Sample Testing			**X**	8954
LR(δ)	0.00000			**N**	10000
Zc	387.89612		**δ***	**X/N**	0.8954
				N-X	1046
LR(δ)	**Natural Log**				
0	0		The Chi-squared critical value is 3.841 for 5% level of significant.		
0	0		The critical Z value is 1.96 for 5% level of significant.		
	0		Fail to reject LR(δ)		
			Reject Zc		
Zc	8454				
	475				
	21.79449472				
	387.8961228				

Figure 3.6: Results From 10,000 Simulations of the Yellow Section in Figure 5.1

The final set of results we will look at are the VaR results from the 10,000 simulations from the green, or after, section in figure 1. At the time that the VaR was calculated, the average was 22476.08 and the 5th percentile was 11520.01. This means that the copula VaR was 10956.07. The likelihood ratio value was 0. Since we were looking at a 5% significance level, the Chi-squared critical value was 3.841. This means that we cannot reject the null hypothesis. The interpretation of this is that the actual revenue losses did not exceed the predicted VaR estimates. The Z test value was 81.901. Since we are looking at a 5% significance level, the critical value is 1.96. This means that we reject the null hypothesis. The interpretation of this is that VaR underestimates the actual downside risks. Overall, this VaR model was a decent fit, but was not the best.

	Average	22476.076			
	5th percentile	11520.008			
	Copula VaR	10956.068			
	Out of Sample Testing			**X**	2285
LR(δ)	0.00000			**N**	10000
Zc	81.90142		**δ***	**X/N**	0.2285
				N-X	7715
LR(δ)	**Natural Log**				
0	0		The Chi-squared critical value is 3.841 for 5% level of significant.		
0	0		The critical Z value is 1.96 for 5% level of significant.		
	0		Fail to reject LR(δ)		
			Reject Zc		
Zc	1785				
	475				
	21.79449472				
	81.90141699				

Figure 3.7: Results From 10,000 Simulations of the Green Section in Figure 5.1

The second testing method was stochastic dominance. Stochastic dominance was used to rank the three sections of simulated data where there was 1,000 data points and the three sections of simulated data where there was 10,000 data points. As previously mentioned, there were three different time periods. The time period from 2000-2005 was labeled “before”, the time period from 2006-2011 was labeled as “during”, and the time period from 2012-2016 was labeled “after”. When stochastic dominance was ran, the lower risk aversion coefficient (RAC) was set at 0 to represent a risk neutral individual while the upper RAC was set at 0.5 to represent a slightly risk averse individual. For both tested sections, the results were the same. In addition, for both a risk neutral and slightly risk averse individual the results were the same. These values are Constant Absolute Risk Aversion (CARA) coefficients (Chavas, 2004). For both individuals and sections, the rankings were after, during, and before respectively. This result made sense for both as the mean was highest in the after category yet it maintained a slightly lower standard deviation than the during section which was ranked second with a lower mean. Figure 8 shows the exact results from the stochastic dominance ran on the three sections of the simulated data where there was 1,000 data points. Figure 9 shows the exact results from the stochastic dominance ran on the three sections of the simulated data where there was 10,000 data points.

Efficient Set Based on SDRF at		
Lower RAC		0
	Name	Level of Preference
1	Revenue After	Most Preferred
2	Revenue During	2nd Most Preferred
3	Revenue Before	3rd Most Preferred

Efficient Set Based on SDRF at		
Upper RAC		0.5
	Name	Level of Preference
1	Revenue After	Most Preferred
2	Revenue Durin	2nd Most Preferred
3	Revenue Befor	3rd Most Preferred

*The efficient sets are the same for both RAC values. It is possible that the efficient set changes between the RACs. Use SERF analysis to evaluate possible efficient set changes between the RACs.

Summary Statistics

	Name	Mean	Std Dev	Coef Var	Skewness	Minimum
1	Revenue Before	2,251.85	823.87	36.59	-0.39	78.56
2	Revenue During	14,596.89	6,358.40	43.56	0.37	186.59
3	Revenue After	22,484.98	5,990.34	26.64	1.21	9,463.67

Figure 3.8: Results Using Stochastic Dominance with 1,000 Simulations

Efficient Set Based on SDRF at		
Lower RAC		0
	Name	Level of Preference
1	Revenue After	Most Preferred
2	Revenue During	2nd Most Preferred
3	Revenue Before	3rd Most Preferred

Efficient Set Based on SDRF at		
Upper RAC		0.5
	Name	Level of Preference
1	Revenue After	Most Preferred
2	Revenue Durin	2nd Most Preferred
3	Revenue Befor	3rd Most Preferred

*The efficient sets are the same for both RAC values. It is possible that the efficient set changes between the RACs. Use SERF analysis to evaluate possible efficient set changes between the RACs.

Summary Statistics

	Name	Mean	Std Dev	Coef Var	Skewness	Minimum
1	Revenue Before	2,251.41	833.14	37.01	-0.44	60.09
2	Revenue During	14,547.77	6,471.98	44.49	0.38	449.57
3	Revenue After	22,666.36	6,009.89	26.51	1.08	9,613.87

Figure 3.9: Results Using Stochastic Dominance with 10,000 Simulations

While previous results typically discuss the time period labeled in this paper as the "during" section, my results have expanded further to look at the time period labeled as the "after" section. This section shows that not only were average corn prices positively affected, but the revenue risk involved with corn used for ethanol production decreased. This can be seen through both the standard deviation and the minimum values in figure 8 and figure 9. While this sounds like a small research contribution, it is actually large as it shows a reduction in risk.

3.6. Conclusions

First looking at the VaR results, we can conclude that once the policy was in place and as it stabilized, the downside risk declined. This means that the RFS reduced uncertainty in the corn revenue and reduced the financial risk that is associated with losses. Since we see reduced losses, we will see greater revenues for corn used for ethanol production. Looking at the stochastic dominance results, they back up the VaR results by showing that both a risk neutral and a slightly risk averse individual prefer a time period where there is a stable policy in place. With both of these in mind, based on the VaR and stochastic dominance results, we can conclude that revenue from corn used for ethanol production did increase.

Although this study did serve its purpose, further research can be done. For instance, a study could be done that simulates an increase in the ethanol mandate which would theoretically increase the amount of corn allocated to ethanol. This simulated increase could then be compared with the three sections that were used in this paper to determine if the preferred option would be to increase the mandate or if it is better to leave it as is. Another study that could be done would be to use the same methodology, but look at a different country and/or policy.

CHAPTER 4: BRAZILIAN IMPORT QUANTITY DEMAND FOR ETHANOL

4.1. Introduction

The second study in this thesis looks at import quantity demand of Brazilian ethanol using four of Brazil's largest importers. The largest importers were decided based on how much ethanol they imported over the period from 2001-2020. Some qualifying countries were excluded due to a lack of data over the time period. The chosen countries were India, Japan, Nigeria, and the United States. Four additional countries were considered, but were left out due to a lack of workable data. The countries removed from the study were Jamaica, the Netherlands, South Korea, and the United Kingdom. While Jamaica had significant imports over the period, the data shows that their last import was taken in quarter two of 2013. The Netherlands and the United Kingdom were also major importers, however there was not tariff data available that covered the time period. Using the data available would have been a misrepresentation of the actual tariffs faced. South Korea had similar issues as the European Union countries. All three countries lacked the necessary tariff data, so they had to be removed from the study. While all four countries would have bettered the study, their lack of data left a lot up to interpretation and using them with their partial data would have been a misrepresentation of their ethanol economies.

Research similar to that done in this chapter was done by Farinelli et al. and published in 2009. In their research, they looked at the Caribbean region, Mexico, Japan, Nigeria, and the United States. They used these countries to look at the factors which drive Brazilian ethanol imports. This research uses most of the same variables although the data may differ slightly. The choice was made to update this paper due to the changes in the past decade in the ethanol market. For instance, many additional countries other than the United States and Brazil have implemented or improved their ethanol policies which have in turn changed the market for

Brazilian ethanol. The new countries used in this analysis represent Brazil's top ethanol importers. The research done by Farinelli et al. (2009) chose their countries based on potential majors exporters as well as global coverage of importers. In other words, the previous research aimed to gather data from around the world. Their research also only spanned from 1997-2007 while this research spans from 2001-2019.

4.2. Background

Brazil has utilized ethanol for over nearly a century. Brazil's ethanol history is often broken down into five distinct phases which range from 1934-present. These phases can be found in the bulleted points below. The following information was discussed in chapter 2, however, it will be discussed once again below to reiterate Brazil's ethanol economy.

- Ethanol as an additive to gasoline: 1934-1974
- Proalcool – Initial phase: 1975-1979
- Proalcool – Growth and maturity: 1979-1989
- The decline of proalcool and the deregulation of the ethanol industry: 1990-2002
- The resurgence of the ethanol industry: 2003-present

As previously mentioned, in the first phase hydrated ethanol was evaporated to create anhydrous ethanol which was then blended with gasoline. The decision to blend the ethanol was not based on a need to replace gasoline, but as a reaction to fluctuations in the sugar market. If we recall from chapter 2, a decision needs to be made to produce either ethanol or sugar. Essentially, if the sugar price was high, less ethanol and more sugar was produced. The second phase was brought on by the oil shocks that occurred in the early 1970's. In an attempt to reduce Brazil's dependence on oil imports, the National Alcohol Program (Proalcool) was created to promote the addition of anhydrous ethanol to gasoline. Similar to the second phase, the third phase was brought on by yet another oil crisis. New goals were set for the already present Proalcool program which included using hydrated ethanol (E100) as fuel and expanding sugarcane fields and industrial capacity to make room for the new fuel. As oil prices recovered, the fourth phase began. When oil prices decreased, sugar prices also increased which led to a decreased incentive to produce ethanol and an increased incentive to switch production to sugar. In this time frame, Brazilian policy began to incentivize sugar production and exporting which led to uncertain ethanol supply at the pump. This lowered confidence in the good and led to a drastic decline in ethanol powered car sales. The fifth and current phase was brought on by private sector commitment to the renewable fuel. In this phase the flex-fuel vehicle was produced and marketed to allow consumers to freely choose between gasoline or E100. Brazilian gas stations are unique as they provide both E100 and gasoline (E27). When flex-fuel vehicles were released in 2003, new vehicle sales increased more than ninety percent by 2009 (Barros and Giles, 2010).

Another previously mentioned program in chapter 2 is the RenovaBio Program. In 2015, Brazil joined the 21st Conference of Parties. This is a conference where nations meet on climate change and determine how they can help to combat it. At this conference, Brazil made six large commitments to be achieved by 2030 at this conference. These commitments can be reviewed in section 2.5. As a recap, most of their goals focused on a very specific form of energy while their last goal was broader, yet still important. If Brazil can fulfill these commitments, they will set a standard for other similar nations to follow.

Several nations across the globe have either implemented ethanol policies or have pushed to limit their independence on oil. Due to this, ethanol has become a hot commodity. Moving forward in this section we will cover different policies and motivations the countries in this study have to import ethanol. While this study focuses on just Brazilian ethanol, several factors discussed in this section could explain a motivation to import.

India has set a blend rate since 2003. India has always been a country that mandates the use but not the production of ethanol for fuel use. This means that the Indian government does not require a certain amount of ethanol be produced domestically (Aradhey et al., 2019). Since there is not a production mandate, India has the option to import the ethanol they need to meet use standards. A majority of India's ethanol imports are denatured ethanol. As previously mentioned, denatured ethanol is ethanol that is altered to not be used for human consumption. This type of ethanol is commonly used for fuel use or industrial and chemical uses. This is how India allocates much of their imported ethanol (Aradhey et al., 2019).

India has the blending goal for fuel ethanol of E10 by 2022. The purpose of updating their blend rate is to advance their energy security while creating new employment opportunities, and reduce greenhouse gas emissions. Although India has had ethanol policies in place for nearly two decades, the blend rate has remained the same for the policy entirety. Several attempts have been made to increase the mandatory blend rate, but consumption continuously falls short. Much of India's policy stagnancy comes from a lack of adequate price incentives (Aradhey et al., 2019).

Similar to India, Japan has an annual biofuel use target for their transport sector. Japan's blend rate is one of the lowest out of the countries that have an ethanol program. The current blend rate for Japan is 1.6% which it has been since 2017 and will be through 2022 (Sasatani et al., 2019). This blend rate requires very little ethanol be blended with gasoline. Since their blend rate is so low, their demand for ethanol is also fairly low. In addition to their low blend rate, their governmental support for ethanol is also poor.

Financial support for bioethanol projects ended at the end of 2014. Due to this, a majority of the Japanese ethanol plants closed. The one remaining facility produced 0.2 million liters in 2017 and is located in the Niigata prefecture which grows rice specifically for biofuel production. This facility is affiliated with three gas stations which supplies a blend of E3. As of October 2019, the facility only operated three months out of the year and was not self-sustaining (Sasatani et al., 2019). Since Japan does not produce much ethanol, the majority of their ethanol would have to be imported. Unfortunately however, Japan does not seem to have a strong governmental support for the biofuel.

Nigeria is one of the top 10 petroleum exporters in the world. Although it is a major player in the world energy sector, it faces several domestic energy issues. Nigerian cities face very frequent power outages and 49% of the population has no electricity whatsoever. Fossil fuel and wood use has caused environmental issues. In addition, the growing population and a growing economy has led to an abundance of waste in cities. The use of biofuels are thought to help alleviate some of these domestic energy issues.

The Nigerian climate allows for several commodities that can be used to produce ethanol to be grown. Sugarcane, cassava, and sweet sorghum can be used to produce ethanol. Each commodity comes with an issue in terms of ethanol production however. As was seen in figure 1.2, when ethanol is produced from sugarcane, the ability to produce sugar with the crop is given up. In Nigeria, the sugarcane sector has yet to have satisfied the domestic demand for sugar, so the use of sugarcane for ethanol would not be possible. Ethanol produced from cassava requires the input of energy and enzymes which are quite costly. This also limits the nation's ability to produce ethanol from cassava. The final crop, sweet sorghum, is relatively easy to produce in

Nigeria, however, production using this crop could be controversial due to the possibility of this encroaching on the food sector (Ishola et al., 2013).

Although the previously discussed information comes from a paper in 2013, the development of an ethanol sector would take a significant amount of time as has been displayed by other countries. With this in mind, Nigeria would need to import the ethanol they wish to use until they have the ability to meet the domestic demand they create. With their current energy situation, the demand for ethanol could be quite significant.

The United States has a fairly developed ethanol policy. Their most common national policy is known as the Renewable Fuel Standard (RFS). Similar to the other policies discussed in this section, the RFS is a policy that has a consumption mandate. Over time, the policy has been added onto requiring more ethanol to be consumed.

In 2005, the U.S. Environmental Protection Agency (EPA) developed a national policy to increase the volume of renewable fuel blended into traditional fuels used for transportation. This policy, known as the Energy Policy Act of 2005, created the Renewable Fuel Standard (RFS). The Energy Independence and Security Act of 2007 (EISA) both increased and expanded on the program (AFDC, 2018). These programs are known as RFS1 and RFS 2. RFS1 represents the policy initially created by the Energy Policy Act of 2005 while RFS2 represents the update to the policy created by The Energy Independence and Security Act of 2007.

As previously mentioned, in the United States, regulatory bodies and programs are in place to encourage the use of biofuels. While there are several biofuel policies across the United States, the most commonly known and recognized is the Renewable Fuel Standard. This is a program by the United States Environmental Protection Agency (EPA), that regulates the amount of cellulosic biofuel, biomass-based diesel, advanced biofuel, and total renewable fuel volumes that are required to be used. A previous study done by Debnath et al. (2017), showed the importance of this program, since without it, their simulated scenario showed a significant ethanol consumption decrease which lead to nearly no ethanol consumption when ethanol is mixed with fuel.

When policies are in place to encourage the use of ethanol, a nation's ethanol consumption is generally positively affected. However, as we have seen from Japan, once the government ceased incentives, production and use became stagnant. In nations such as the United States where policy is continuously advanced and supported, ethanol thrives and becomes a common good in that nation's economy.

All four of the previously discussed nations have a current demand for ethanol. In the case of this study, they are some of Brazil's top ethanol importers. Overtime, their imports may change dependent on how their policies develop or are removed. In terms of countries such as Japan where the government has removed incentives to produce ethanol, either more ethanol will be imported, or the country could stop using the fuel altogether. The latter does not seem likely however since, globally, there has been a push to reduce greenhouse gas emissions. In countries such as the United States who have a continuously evolving ethanol policy, it is likely that not only will more ethanol be produced domestically, but more ethanol will be imported to meet growing demand.

4.3. Methodology

As mentioned in the section 4.1, four countries are used in this study to represent Brazil's top importers over the 20-year period. These countries are India, Japan, Nigeria, and the United States. Looking at these countries, two have a fairly developed ethanol backing, so in addition to the uniform variables across the main model, an additional variable is added to both the India and the United States models to represent their policy backing for ethanol. This will be shown further in the next section.

In Farinelli et al., three import demand models were discussed. The first was a basic perfect substitutes model that shows that the quantity of imports (M_i) is a function of real domestic income (Y_i) and the price of the traded commodity (P_i). In our case, if this most basic model was used, we would be looking at the quantity of ethanol imported as a function of real income from ethanol and the price of ethanol. This equation can be seen below as equation 4.1.

$$M_i = f(Y_i, P_i) \qquad \text{(Equation 4.1)}$$

While equation 4.1 represents a base model, it can be altered to better fit a regression software. As Farinelli et al. continued they discussed the representation of equation 4.1 as a new equation that is a better representation of the ethanol model. In this equation, new parameters are added to represent responsiveness of the volume of the ethanol imports to the price and income changes of said ethanol imports. These additions are α_1 and α_2 which represent partial derivatives of M_i subject to P_i and M_i subject to Y_i respectively. In addition, an random error term, represented by ε_i, is added and assumed to be normally and independently distributed with a zero mean and constant variance. This equation can be seen below as equation 4.2.

$$M_i = \alpha_0 + \alpha_1 P_i + \alpha_2 Y_i + \varepsilon_i \qquad \text{(Equation 4.2)}$$

Farinelli et al. states that for a commodity such as ethanol, equation 4.2 can be used to derive ethanol elasticities. In addition, they also discussed the expected signs of α_1 and α_2. It was stated that α_1 is expected to have a negative sign since price and quantity should move in opposite directions. This is due to the fact that ethanol is considered a normal good. The sign for α_2 is expected to range from negative to positive. This is because, when real income increases, the demand for imported goods could increase, decrease or even remain the same. It would all depend on if the country sees ethanol and a normal or inferior good. If it is seen as an inferior good, the demand would increase. We would expect the opposite if it is a normal good however.

It has been previously stated that the most common functional forms are linear and log-linear. Previous research has been done as discussed in Farinelli et al. regarding which form is the better form. Previous research has not determined if one is better than the other, but it has been determined that the log-linear form is more convenient than the linear form. This is due to the fact that income elasticities can be derived from the regression coefficients. The log-linear form is expressed in equation 4.3.

$$logM_i = \alpha_0 + \alpha_1 logP_i + \alpha_2 logY_i + \omega_i \qquad \text{(Equation 4.3)}$$

Since there are not many variables in this equation, we may expect to see little statistical significance. This is due to the fact that there may be other factors that have a greater effect on the quantity imported than those used in equations 4.2 and 4.3. Other factors could be population changes, household income changes, policy implementation or changes, or even a change in vehicles on the road. Ultimately, while this looks at how price and income from ethanol affects quantity of ethanol imported, it does not have every necessary factor. This is where the model covered in the next section comes in.

4.4. Model and Data

The model in this section expands on those discussed in the previous section. In addition to the variables shown before, other explanatory and country specific variables were added to each model for the India, Japan, Nigeria, and United States models. These models were used to determine the effect of the price of ethanol, the price of crude oil, Gross Domestic Product, exchange rates, and tariffs on Brazilian ethanol imported. In addition, a trend variable was added to offset some potential problems that are associated with time series data. As was stated in Farinelli et al., time trend variables are often used as a proxy for an omitted variable that may have an effect on the dependent variable. Since quarterly data is being used in this analysis, a lagged variable is also used in the model in order to see if the quantity of ethanol imported is affected at all by the previous quarter's imports. The forementioned equation can be found below labeled as equation 4.4.

$$QMeth_{it} = \beta_1 + \beta_2 Peth_{it} + \beta_3 Poil_t + \beta_4 GDP_{it} + \beta_5 ExRt_{it} + \beta_6 Tariff_{it} + \beta_7 Trend + \beta_8 LagQMeth_{(t-1)i} + \varepsilon_{it} \quad \text{(Equation 4.4)}$$

Equation 4.4 represents the general model that is used for all countries. In addition to those used in this study, it can be used globally as it is a relatively basic ethanol import model. Additional variables can be added to equation 4.4 to make it more country specific. Particular variables used below in additional equations are blend rates and ethanol mandates required by the importing countries. Other country specific variables could also be added, or variables that better explain the importing country's motivation to import could be added as well. This equation as well as the subsequent equations and variables were gathered from Farinelli et al..

$$QMeth_{it} = \beta_1 + \beta_2 Peth_{it} + \beta_3 Poil_t + \beta_4 GDP_{it} + \beta_5 ExRt_{it} + \beta_6 Tariff_{it} + \beta_7 Trend + \beta_8 LagQMeth_{(t-1)i} + \beta_9 EtMan_{it} + \varepsilon_{it} \quad \text{(Equation 4.5)}$$

Equation 4.5 represents the United States' ethanol import model. The noticeable difference between equation 4.4 and 4.5 is the addition of the variable *EtMan*. This variable is used to represent the ethanol consumption mandate set into place by the Renewable Fuel Standard. While other countries have ethanol mandates, the United States' policy has been proven time and time again to have a positive effect on ethanol consumption. The Renewable Fuel Standard was proven to have a positive effect on corn, the primary commodity used in United States' ethanol consumption, revenue in this thesis.

$$QMeth_{it} = \beta_1 + \beta_2 Peth_{it} + \beta_3 Poil_t + \beta_4 GDP_{it} + \beta_5 ExRt_{it} + \beta_6 Tariff_{it} + \beta_7 Trend + \beta_8 LagQMeth_{(t-1)i} + \beta_9 BRt_{it} + \varepsilon_{it} \qquad \text{(Equation 4.6)}$$

Equation 4.6 represents India's ethanol import model. Similar to the difference in equation 4.5, equation 4.6 contains an additional variable to represent India's ethanol blend rate. Unlike the United States' ethanol mandate variable, India's blend rate is a percentage as opposed to a set consumption mandate. In addition, this value is constant throughout the time the blend rate was present which is unlike the mandate set by the United States.

Now that the general model structure is established, an explanation of variables can be discussed. The first up for discussion is the dependent variable *QMeth.* This variable represents the quantity of ethanol imported. It is in billions of liters and is specific to country *i* and in time *t.* This data was gathered from the Secretariat of Foreign Trade (SECEX). Next, we will move onto the discussion of the independent variables. An important note on these variables is that those representing a dollar value are not only in United States dollars, but are also in real 2015 dollars. The first is the variable *Peth.* This variable represents the import price of ethanol. This data was gathered from the Secretariat of Foreign Trade (SECEX). The variable *Poil* represents the import price of crude in dollars per barrel. The specific oil prices used are those for Brent Crude. This variable is standard across all countries as it is the world price. This data was gathered from the Energy Information Administration (EIA). The variable *GDP* represents real gross domestic product. This data was gathered from the United States Department of Agriculture Economic Research Service (USDA ERS). The next variable is *ExRt.* This variable represents the real exchange rate in local currency per dollar. This data was gathered from the USDA ERS as well. The next variable is *Tariff.* This variable represents the import tariff on the ethanol imported. This data was gathered from the World Trade Organization (WTO). The next variable is *Trend.*

This variable is a linear time trend variable where quarter one of 2001 is equal to t=1. The next variable is *LagQMeth*. This variable is the lagged quantity of ethanol imported in billion liters. The final variables are those that are added into equation 4.2 and 4.3. Variable *EtMan* represents the United States Renewable Fuel Standard mandate in billion gallons. This data was gathered from the United States Environmental Protection Agency (EPA) and an article published by the USDA ERS. Variable *BRt* represents the India blend rate which, although listed as a regular value, is a percentage. This data was gathered from the 2019 India Biofuels Annual Global Agricultural Information Network (GAIN) Report.

Equation 4.4 represents the base model for all four countries. Equations 4.5 and 4.6 refer to the United States and India respectively. The United States and India both have an additional variable in their equations due to their ethanol mandates need for representation. Ethanol mandates push the production and consumption of ethanol which, for some countries, means that they must import ethanol in order to acquire the ethanol they need to meet consumption requirements.

4.5. Results

Each model was ran for the respective previously mentioned countries. This means that the appropriate previously mentioned models were ran for India, Japan, Nigeria, and the United States. Unfortunately, there were not a lot of significant results in these models. Dickey-Fuller, Breusch-Godfrey, and Breusch-Pagan tests were ran to determine if non-stationarity, serial correlation, or heteroskedasticity was an issue in any of the models. In the models where any of the forementioned items were present, corrections were made.

The first results we will look at are pertain to India. Figure 4.1 shows the summary statistics for the Indian data. For each variable, there were 76 observations. None of the variables have negative values as it would not be logical for any to be negative. Three of the variables have minimum values of zero due to no imports in different time periods. The trend variable acts as a time variable so it ranges from 1 which indicates quarter 1 of 2001 while 76 would indicate quarter 4 of 2019. The four other variables have varying minimum and maximum values due to the nature of the variable itself.

```
. sum qmeth peth poil gdp exrt tariff trend lagqmeth

    Variable |        Obs        Mean    Std. Dev.       Min        Max
-------------+---------------------------------------------------------
       qmeth |         76    2.09e+07    5.44e+07          0   3.06e+08
        peth |         76    .1289179    .3210742          0          2
        poil |         76    66.32421    29.14334      19.35     118.49
         gdp |         76    403.7122    145.5584   209.7879   679.2021
        exrt |         76    72.42975    10.91309   60.46335   93.22168
-------------+---------------------------------------------------------
      tariff |         76    87.10526    12.55901       77.5      122.5
       trend |         76        38.5    22.08318          1         76
    lagqmeth |         76    2.09e+07    5.44e+07          0   3.06e+08
```

Figure 4.1: India Summary Statistics

Moving forward with the results from the India model, we can see that not all discussed variables are included in the regression results. As we can see, the variable *BRt* was not included. While India has implemented an ethanol policy, it has not changed in well over a decade. The India blend rate has been at 5% since 2003. While not all of the nation sits at the 5% blend rate, that is the standard blend across the nation (Aradhey, 2019). Since the blend rate has not been updated, it was removed since it is safe to assume it has not had a continued effect on the quantity of ethanol imported from Brazil. As we can see from figures 4.2 and 4.3, not many variables were statistically significant. The only statistically significant variables were *GDP* and *LagQMeth*. Both variables were statistically significant at the 1% level however. As we can see, the model only explains 23.63% of the variability of the response data around its mean. This would indicate that there are other factors not included in this model that have a significant effect on the quantity of Brazilian ethanol imported into India.

The two significant variables were *GDP* and *LagQMeth.* As we can see, the coefficient for the variable *GDP* is negative which indicates that as India's GDP increases, ethanol consumption decreases. This would mean that India sees Brazilian ethanol as an inferior good. The other statistically significant variable was *LagQMeth*. The coefficient for this variable was positive which means that the previous quarter has a positive effect on the current quarter's Brazilian ethanol imports.

```
. reg qmeth peth dpoil dgdp dexrt dtariff trend lagqmeth, r

Linear regression                               Number of obs     =         75
                                                F(7, 67)          =       2.76
                                                Prob > F          =     0.0139
                                                R-squared         =     0.2335
                                                Root MSE          =     5.0e+07
```

qmeth	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf.	Interval]
peth	1.23e+07	1.31e+07	0.94	0.349	-1.38e+07	3.85e+07
dpoil	413908.6	438869.5	0.94	0.349	-462078.6	1289896
dgdp	-521506.1	190886	-2.73	0.008	-902516.1	-140496
dexrt	1011108	965414.3	1.05	0.299	-915867.1	2938083
dtariff	491189.8	388405.2	1.26	0.210	-284070.3	1266450
trend	-341785.3	244345.8	-1.40	0.166	-829501.6	145931
lagqmeth	.3840686	.1171012	3.28	0.002	.1503337	.6178035
_cons	2.85e+07	1.48e+07	1.92	0.059	-1076251	5.80e+07

Figure 4.2: India Import Model

```
. estimates table, star(.1 .05 .01)
```

Variable	active
peth	12338229
dpoil	413908.58
dgdp	-521506.05***
dexrt	1011108
dtariff	491189.79
trend	-341785.28
lagqmeth	.38406862***
_cons	28466129*

legend: * p<.1; ** p<.05; *** p<.01

Figure 4.3: Statistic Significance of the India Import Model

A few different tests were ran on the India model. The first was the Dickey-Fuller test. The Dickey-Fuller test is a test for a unit root. The null hypothesis of this test is that $H_0: \theta = 0$ while the alternative is $H_1: \theta < 0$. When we fail to reject the null hypothesis we can say the data is stationary. When we reject the null hypothesis, we say the data is non-stationary. Four variables were corrected for non-stationarity. These variables were *Poil, GDP, ExRt,* and *Tariff*. The variables previously mentioned that were altered are apparent in figures 4.2 and 4.3 as they begin with the letter "d". In addition to the Dickey-Fuller test, the Breusch-Pagan test was ran. This is a test for heteroskedasticity. Heteroskedasticity was detected in the model at the 5% level, so it was ran with robust standard errors to correct for the heteroskedasticity. The final test that was ran was the Breusch-Godfrey test. This test determines if serial correlation is present in the model. The null hypothesis is that there is no serial correlation while the alternative hypothesis is that there is serial correlation. In this model, there is no serial correlation.

The next set of results we will cover are those pertaining to Japan. Figure 4.4 shows the summary statistics for the India data. For each variable, there were 76 observations. Once again, none of the variables have negative values as it would not be logical for any to be negative.

Three of the variables have minimum values of zero due to no imports in different time periods. The trend variable is the same as it is for India in that it acts as a time variable so it ranges from 1 which indicates quarter 1 of 2001 to 76 which would indicate quarter 4 of 2019. The four other variables have varying minimum and maximum values due to the nature of the variable itself.

```
. sum qmeth peth poil gdp exrt tariff trend lagqmeth
```

Variable	Obs	Mean	Std. Dev.	Min	Max
qmeth	76	4.19e+07	3.08e+07	0	1.23e+08
peth	76	.3507543	.257187	0	.7643707
poil	76	66.32421	29.14334	19.35	118.49
gdp	76	1059.299	46.49844	984.1262	1138.054
exrt	76	99.03648	12.47692	78.68037	121.04
tariff	76	16.69474	3.524009	14.3	27.2
trend	76	38.5	22.08318	1	76
lagqmeth	76	4.19e+07	3.08e+07	0	1.23e+08

Figure 4.4: Japan Summary Statistics

Moving forward with the Japan results, we can see that there are more significant variables when we use this dataset than there was with the India dataset. As we can see from figures 4.5 and 4.6, there were five statistically significant variables. Variable *Poil* was statistically significant at the 10% level. Variables *Peth* and *GDP* were both statistically significant at the 5% level. Both the constant and variable *LagQMeth* were statistically significant at the 1% level. As we can see, the model only explains 50.27% of the variability of the response data around its mean. This would indicate that there are other factors not included in this model that have a significant effect on the quantity of Brazilian ethanol imported into Japan. This is an improvement over the India model, however, it is still not ideal.

The four significant variables were *Peth, Poil, GDP, LagQMeth,* and the constant*.* The first statistically significant variable is *Peth.* The constant of this variable is negative which indicates that as the price of ethanol increases, the quantity of ethanol imported decreases. The variable *Poil* is also negative which indicates that as the price of oil increases, ethanol imported decreases. This could be a logical result if we think of the two goods as complementary. As we can see, the coefficient for the variable *GDP* is positive which indicates that as Japan's GDP increases, ethanol consumption increases. This would mean that India sees Brazilian ethanol as an normal good. The last statistically significant variable was *LagQMeth*. The coefficient for this variable was positive which means that the previous quarter has a positive effect on the current quarter's Brazilian ethanol imports. The constant is not necessarily a variable, but was statistically significant. The constant is known as the intercept of the model.

. reg qmeth peth dpoil dgdp dexrt dtariff trend lagqmeth

Source	SS	df	MS			
				Number of obs	=	75
				F(7, 67)	=	9.48
Model	3.4406e+16	7	4.9152e+15	Prob > F	=	0.0000
Residual	3.4748e+16	67	5.1863e+14	R-squared	=	0.4975
				Adj R-squared	=	0.4450
Total	6.9154e+16	74	9.3452e+14	Root MSE	=	2.3e+07

qmeth	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
peth	-2.58e+07	1.19e+07	-2.17	0.034	-4.95e+07	-2025999
dpoil	-438432.5	257179.3	-1.70	0.093	-951764.4	74899.46
dgdp	648409.6	290758.7	2.23	0.029	68052.84	1228766
dexrt	3707.582	749152.4	0.00	0.996	-1491607	1499022
dtariff	1463439	1741659	0.84	0.404	-2012928	4939805
trend	-110690.5	141911.7	-0.78	0.438	-393947.5	172566.5
lagqmeth	.6934043	.0984158	7.05	0.000	.4969655	.8898431
_cons	2.56e+07	7700963	3.32	0.001	1.02e+07	4.10e+07

Figure 4.5: Japan Import Model

```
. estimates table, star(.1 .05 .01)
```

Variable	active
peth	-25783929**
dpoil	-438432.49*
dgdp	648409.64**
dexrt	3707.5815
dtariff	1463438.7
trend	-110690.51
lagqmeth	.69340427***
_cons	25584881***

legend: * p<.1; ** p<.05; *** p<.01

Figure 4.6: Statistic Significance of the Japan Import Model

A few different tests were ran on the Japan model. The first was the Dickey-Fuller test. The Dickey-Fuller test is a test for a unit root. The null hypothesis of this test is that $H_0: \theta = 0$ while the alternative is $H_1: \theta < 0$. When we fail to reject the null hypothesis we can say the data is stationary. When we reject the null hypothesis, we say the data is non-stationary. Four variables were corrected for non-stationarity. These variables were *Poil, GDP, ExRt,* and *Tariff*. The variables previously mentioned that were altered are apparent in figures 4.5 and 4.6 as they begin with the letter "d". In addition to the Dickey-Fuller test, the Breusch Pagan test was ran. This is a test for heteroskedasticity. Heteroskedasticity was not detected at the 5% level in the model. The final test that was ran was the Breusch-Godfrey test. This test determines if serial correlation is present in the model. The null hypothesis is that there is no serial correlation while the alternative hypothesis is that there is serial correlation. In this model, there is no serial correlation.

Moving on, we will focus on the set of results from the Nigeria model. Figure 4.7 shows the summary statistics for the Nigeria data. For each variable, there were 76 observations. Once again, none of the variables have negative values as it would not be logical for any to be negative. Four of the variables have minimum values of zero due to no imports or no tariff in different time periods. The trend variable is the same as it is for India and Japan in that it acts as a time variable so it ranges from 1 which indicates quarter 1 of 2001 to 76 which would indicate quarter 4 of 2019. The four other variables have varying minimum and maximum values due to the nature of the variable itself.

```
. sum qmeth peth poil gdp exrt tariff trend lagqmeth
```

Variable	Obs	Mean	Std. Dev.	Min	Max
qmeth	76	1.57e+07	1.25e+07	0	5.04e+07
peth	76	.3991472	.2144498	0	.7379933
poil	76	66.32421	29.14334	19.35	118.49
gdp	76	93.55199	26.42052	47.72722	127.745
exrt	76	247.9151	61.78624	172.6323	375.412
tariff	76	14.88947	6.625357	0	30
trend	76	38.5	22.08318	1	76
lagqmeth	76	1.57e+07	1.25e+07	0	5.04e+07

Figure 4.7: Nigeria Summary Statistics

Looking further at the Nigeria results, we can see that there are a few highly significant variables. As we can see from figures 4.8 and 4.9, there were four statistically significant variables. Variables *Peth, Trend, LagQMeth,* and the constant were all statistically significant at the 1% level. As we can see, the model only explains 36.35% of the variability of the response data around its mean. This would indicate that there are other factors not included in this model that have a significant effect on the quantity of Brazilian ethanol imported into Nigeria. Ideally, the r squared value would be higher, but this is a definite indication that more variables are needed in further research.

The four significant variables were *Peth, Trend, LagQMeth,* and the constant. The first statistically significant variable is *Peth.* The constant of this variable is positive which indicates that as the price of ethanol increases, the quantity of ethanol imported increases. The variable

Trend is negative which indicates that as time goes on, ethanol imported decreases. This could be mean that Nigeria has developed its own domestic supply. If we remember, this was a possibility discussed previously. The last statistically significant variable was *LagQMeth*. The coefficient for this variable was positive which means that the previous quarter has a positive effect on the current quarter's Brazilian ethanol imports. The constant is not necessarily a variable, but was statistically significant. The constant is known as the intercept of the model.

```
. reg qmeth peth dpoil dgdp dexrt dtariff trend lagqmeth
```

Source	SS	df	MS			
				Number of obs	=	75
				F(7, 67)	=	5.41
Model	4.1758e+15	7	5.9655e+14	Prob > F	=	0.0001
Residual	7.3874e+15	67	1.1026e+14	R-squared	=	0.3611
				Adj R-squared	=	0.2944
Total	1.1563e+16	74	1.5626e+14	Root MSE	=	1.1e+07

qmeth	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
peth	2.03e+07	6083378	3.34	0.001	8147489	3.24e+07
dpoil	-35800.84	120081.7	-0.30	0.767	-275485	203883.3
dgdp	-388963.6	684395.4	-0.57	0.572	-1755023	977095.3
dexrt	-11464.92	150886.9	-0.08	0.940	-312636.4	289706.6
dtariff	217044.2	350647.3	0.62	0.538	-482850.8	916939.2
trend	-239127.6	64816.3	-3.69	0.000	-368501.5	-109753.7
lagqmeth	.2920262	.1065849	2.74	0.008	.0792818	.5047707
_cons	1.29e+07	3919585	3.29	0.002	5084553	2.07e+07

Figure 4.8: Nigeria Import Model

```
. estimates table, star(.1 .05 .01)
```

Variable	active
peth	20289963***
dpoil	-35800.836
dgdp	-388963.64
dexrt	-11464.923
dtariff	217044.23
trend	-239127.61***
lagqmeth	.29202624***
_cons	12908077***

legend: * p<.1; ** p<.05; *** p<.01

Figure 4.9: Statistic Significance of the Nigerian Import Model

A few different tests were ran on the Nigeria model. The first was the Dickey-Fuller test. The Dickey-Fuller test is a test for a unit root. The null hypothesis of this test is that $H_0: \theta = 0$ while the alternative is $H_1: \theta < 0$. When we fail to reject the null hypothesis we can say the data is stationary. When we reject the null hypothesis, we say the data is non-stationary. Four variables were corrected for non-stationarity. These variables were *Poil, GDP, ExRt,* and *Tariff*. The variables previously mentioned that were altered are apparent in figures 4.8 and 4.9 as they begin with the letter "d". In addition to the Dickey-Fuller test, the Breusch Pagan test was ran. This is a test for heteroskedasticity. Heteroskedasticity was not detected at the 5% level in the model. The final test that was ran was the Breusch-Godfrey test. This test determines if serial correlation is present in the model. The null hypothesis is that there is no serial correlation while the alternative hypothesis is that there is serial correlation. In this model, there is no serial correlation.

The final model results covered are those from the United States model. Figure 4.10 shows the summary statistics for the United States data. For each variable, there were 76 observations. Once again, none of the variables have negative values as it would not be logical for any to be negative. Three of the variables have minimum values of zero due to no imports or in different time periods. The trend variable is the same as it is for the previous three models in that it acts as a time variable so it ranges from 1 which indicates quarter 1 of 2001 to 76 which would indicate quarter 4 of 2019. Unlike the other models, the United States has two constant variables. The exchange rate and tariff variables for the United States are unchanging values that will be omitted from the actual regression due to collinearity issues.

```
. sum qmeth peth poil gdp exrt tariff trend lagqmeth etman
```

Variable	Obs	Mean	Std. Dev.	Min	Max
qmeth	76	2.01e+08	2.06e+08	0	9.38e+08
peth	76	.4734592	.2047681	0	.9312238
poil	76	66.32421	29.14334	19.35	118.49
gdp	76	4185.569	430.4457	3471.912	4992.966
exrt	76	1	0	1	1
tariff	76	2.2	0	2.2	2.2
trend	76	38.5	22.08318	1	76
lagqmeth	76	2.01e+08	2.06e+08	0	9.38e+08
etman	76	10.35053	7.594093	0	19.92

Figure 4.10: United States Summary Statistics

Looking at the United States model results, we can see that there is not much for significant variables in this regression. As we can see from figures 4.11 and 4.12, there were only two statistically significant variables. Variable *GDP* was significant at the 10% level and variable *LagQMeth* was significant at the 5% level. As we can see, the model only explains 30.96% of the variability of the response data around its mean. This would indicate that there are other factors not included in this model that have a significant effect on the quantity of Brazilian ethanol imported into the United States. Once again, the exchange rate and tariff variables were omitted due to collinearity issues.

Originally, it was expected that the variable *EtMan* would be significant. However, it does make sense that it is not. In the original research done by Farinelli et al. (2009), the variable representing the United States' ethanol mandate was statistically significant however, this research covered from 1997-2007. Since then, new ethanol policies have been enacted that possibly have a higher effect on the United States' Brazilian ethanol imports. Renewable Fuel Association reports have shown that a majority of Brazilian ethanol is imported into California. The state of California actually has their own ethanol policy known as the Low Carbon Fuel Standard (LCFS). This policy could potentially have a greater effect on the quantity of Brazilian ethanol imported as it has been speculated that ethanol produced in Brazil better satisfies the LCFS than United States' ethanol.

The two significant variables were *GDP* and *LagQMeth,*. As we can see, the coefficient for the variable *GDP* is negative which indicates that as the United States' GDP increases, ethanol consumption decreases. The second statistically significant variable was *LagQMeth*. The coefficient for this variable was positive which means that the previous quarter has a positive effect on the current quarter's Brazilian ethanol imports.

```
. reg qmeth peth dpoil dgdp trend lagqmeth detman, r

Linear regression                               Number of obs     =         75
                                                F(6, 68)          =       8.75
                                                Prob > F          =     0.0000
                                                R-squared         =     0.3109
                                                Root MSE          =    1.8e+08
```

qmeth	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf.	Interval]
peth	2.48e+08	1.71e+08	1.45	0.152	-9.37e+07	5.89e+08
dpoil	1138093	1709940	0.67	0.508	-2274039	4550226
dgdp	-550564.4	318212.3	-1.73	0.088	-1185547	84418.38
trend	618332.9	1117375	0.55	0.582	-1611355	2848021
lagqmeth	.3655323	.1427599	2.56	0.013	.0806594	.6504052
detman	-2.00e+07	2.10e+07	-0.95	0.345	-6.18e+07	2.19e+07
_cons	3842033	3.50e+07	0.11	0.913	-6.60e+07	7.37e+07

Figure 4.11: United States Import Model

```
. estimates table, star(.1 .05 .01)
```

Variable	active
peth	2.478e+08
dpoil	1138093.3
dgdp	-550564.4*
trend	618332.88
lagqmeth	.36553232**
detman	-19960628
_cons	3842032.6

legend: * p<.1; ** p<.05; *** p<.01

Figure 4.12: Statistic Significance of the United States Import Model

A few different tests were ran on the United States model. The first was the Dickey-Fuller test. The Dickey-Fuller test is a test for a unit root. The null hypothesis of this test is that $H_0\colon \theta = 0$ while the alternative is $H_1\colon \theta < 0$. When we fail to reject the null hypothesis we can say the data is stationary. When we reject the null hypothesis, we say the data is non-stationary. Two variables were corrected for non-stationarity. These variables were *Poil* and *GDP*. The variables previously mentioned that were altered are apparent in figures 4.11 and 4.12 as they begin with the letter “d”. In addition to the Dickey-Fuller test, the Breusch Pagan test was ran. This is a test for heteroskedasticity. Heteroskedasticity was detected at the 5% level in the model, so it was ran with robust standard errors to correct for the heteroskedasticity. The final test that was ran was the Breusch-Godfrey test. This test determines if serial correlation is present in the model. The null hypothesis is that there is no serial correlation while the alternative hypothesis is that there is serial correlation. In this model, there is no serial correlation.

4.6. Conclusions

While this study had benefits, it also had drawbacks and ways it could be improved. For example, a lack of available data significantly setback the study. For instance, several additional countries were chosen to represent Brazil’s ethanol importers initially, but due to a lack of data, had to be excluded. Although some countries had data available, the data often did not span the entire time period, thus not providing an accurate depiction of the ethanol markets. A common issue was the lack of tariff data. While the WTO had significant and accurate data for some countries, such as those used within this study, other countries had over a decade worth of missing data. This was the case for countries in the European Union and South Korea. Although some data could be found online, it often only went back to the early 2010’s.

Some other improvements to the models themselves, particularly to the models presented in equations 4.4-4.6, could be additional variables that may have an effect on the quantity imported. This study very much focused on just the basic structure of the ethanol import market and not as much on why a country would want to import a greater (or lesser) quantity. While equations 4.5 and 4.6 each have an additional variable for their respective country, more can be added to paint an even better picture of the intercountry models.

CHAPTER 5: CONCLUSIONS AND FURTHER RESEARCH

To recap, this thesis covered two research topics. The first study looked at how the implementation of policy affects the revenue that originates from the commodity used to produce ethanol while the second looked at import quantity demand for a specific nation's ethanol. The first portion of this thesis used VaR to study the Renewable Fuel Standard in the United States. Specifically, it VaR was used to determine how the Renewable Fuel Standard affected corn revenue as corn is the commodity most commonly used for ethanol production in the United States. This study also contained Stochastic Dominance with Respect to a Function (SDRF) which ranks outcomes based on their level of risk. The second study focused on import quantity demand of Brazilian ethanol. The relation and usefulness of this study comes from the countries themselves. Both the United States and Brazil have a strong policy backing for ethanol which in turn incentives them to produce and trade ethanol. The United States and Brazil were chosen for this thesis due to the previously mentioned reasons as well as their global production and consumption standings.

First, we will review the results from chapter 3. Of these results, we will focus first on the VaR results. A conclusion was made that once the ethanol policy was in place and as it stabilized, the downside risk declined. This means that the RFS reduced uncertainty in the corn revenue and reduced the financial risk that is associated with losses. Since we see reduced losses, we will see greater revenues for corn used for ethanol production. Looking at the stochastic dominance results, they back up the VaR results by showing that both a risk neutral and a slightly risk averse individual prefer a time period where there is a stable policy in place. With both of these in mind, based on the VaR and stochastic dominance results, we can conclude that revenue from corn used for ethanol production did increase.

Although this study did serve its purpose, further research can be done. For instance, a study could be done that simulates an increase in the ethanol mandate which would theoretically increase the amount of corn allocated to ethanol. This simulated increase could then be compared with the three sections that were used in this paper to determine if the preferred option would be to increase the mandate or if it is better to leave it as is. Another study that could be done would be to use the same methodology, but look at a different country and/or policy.

The second set of results we will review are those discussed in chapter 4. To recap, these results looked at which factors had a significant effect on the quantity of Brazilian ethanol imported. While several countries import Brazilian ethanol, four countries were chosen to represent Brazil's top 10 importers. These countries were India, Japan, Nigeria, and the United States. There was a desire to add more countries who fell within the criteria, but due to a lack of data, they had to be omitted. The most common variable that had an effect on Brazilian ethanol imports was *LagQMeth*. This variable indicated that a previous quarter's imports had an effect on the current quarter's imports.

For the most part, this study was able to show what variables have an effect on the countries' demand for ethanol. This study only focused on Brazil's exports, but could be altered to use any country's exports and top importers. In addition, based on the r squared values, additional variables could be added to the models in order to show other factors that affect the quantity of ethanol imported.

In conclusion, the first study looked at how the implementation of policy affected the revenue from corn, the main commodity used to produce ethanol in the United States. The second study looked at the factors that affected the quantity of Brazilian ethanol demanded through imports. Value at Risk (VaR), Stochastic Dominance with Respect to a Function

(SDRF), and time series regression was used in this thesis. This study showed that ethanol policy has a positive effect on revenue from the commodity used to produce ethanol. In addition, it showed that countries with varying ethanol policies and markets have different factors that affect their decision to import ethanol.

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APPENDIX. LIST OF VARIABLES

QMeth = quantity of ethanol imported, in billion liters, in country *i* and in time *t*

Peth = import price of ethanol, 2015 dollars per liter

Poil = import price of crude, 2015 U.S. dollars per barrel

GDP = real gross domestic product (GDP), 2015 billions of U.S. dollars

ExRt = real exchange rate, local currency per dollar, 2015 U.S. dollars

Tariff = MFN import tariff

Trend = linear time trend where quarter 1 of 2001 is t=1

LagQMeth = lagged quantity of ethanol imported, billion liters

EtMan = United States Renewable Fuel Standard mandate, billion gallons

BRt = India blend rate, percentage

t = time

i = country