INDIA'S ETHANOL IMPORT DEMAND: A STRUCTURAL MODEL APPROACH

A Thesis
Submitted to the Graduate Faculty
of the
North Dakota State University
of Agriculture and Applied Science

By

Michael Thomas Aaron

In Partial Fulfillment of the Requirements
for the degree of
MASTER OF SCIENCE

Major Department:
Agribusiness and Applied Economics

November 2020

Fargo, North Dakota

North Dakota State University
Graduate School

Title

INDIA'S ETHANOL IMPORT DEMAND: A STRUCTURAL MODEL APPROACH

By

Michael Thomas Aaron

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

SUPERVISORY COMMITTEE:

Thomas Wahl
Chair

David Ripplinger

Nurun Nahar

Approved:

11/25/2020
Date

William Nganje
Department Chair

ABSTRACT

In 2020 India is expected to be a net importer of ethanol for the 6th year in a row since 2012 (Aradhey, Amit, 2019). The drivers of net importation are government policy, strong economic growth, and weak domestic ethanol industry (Aradhey, Amit, 2019). Hence, the purpose of this thesis is three-fold. Firstly, investigating drivers of ethanol importation, providing an outlook for market viability. Second, to produce original research findings that meaningfully contribute to an understanding of India's ethanol market. Lastly, this research will be helpful to American firms seeking new export opportunities for their ethanol products.

ACKNOWLEDGMENTS

I would like to thank my advisor, Professor Thomas Wahl, for his dedication and hard work on this project. His knowledge and experience as a trade economist provided many insights that proved indispensable to my research process. I will always remember the hours we spent together developing the theories and analyzing the data that ultimately made all this possible.

I would also like to thank Professor David Ripplinger for providing advice regarding how to research India's ethanol industry. Professor Ripplinger's suggestions allowed me to form the theoretical framework that effectively analyzed the industry. His knowledge was essential to my research process, and I will always be grateful for his contributions to this project.

DEDICATION

I want to dedicate this thesis to the Department of Agribusiness & Applied Economics. The department presented me with the opportunity of researching India's ethanol market. In my eyes, it was an honor to trailblaze much of the original research that I present in this thesis. I realize my work could be useful for future research in this area because I applied myself to the best of my ability during my research process to ensure my work reflected well on the department as an organization dedicated to learning and free thought.

Moreover, I learned the importance of showing gratitude to others and emphasizing bestowing credit, where appropriate, because it is integral to effective academic research leadership. The proper credit bestowment in proportion to the relative research contribution aligns all involved in the process, which maximizes the likelihood of an outcome that is Pareto optimal. Education is the key to a better life, and the department's pedagogical philosophy treats every person, regardless of background, as deserving of an education. 'Education is the most powerful weapon which you can use to change the world.' ~ Nelson Mandela

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

$P_{s_{It}}$	Price of sugar per kilogram in India at time (t).
$MC_{s_{It}}$	Marginal cost of producing one-kilogram sugar in India at the time (t).
$P_{g_{It}}$	Price of Gur per kilogram in India at time (t).
$MC_{g_{It}}$	Marginal cost of producing one kilogram of Gur in India at time (t).
Ir_{It}	The average Interest rate in India at time (t).
ε_t	Error term for equation (1) at time (t).
$D_{s_{It}}$	Total demand for sugar in India at time (t).
$GDPPC_{It}$	India's Gross Domestic Product per capita (GDPPC) at time (t).
ϵ_t	Error term for equation (2) at time (t).
$S_{s_{It}}$	Total supply of sugar at time (t).
$B.S._{s_{It}}$	Beginning stock of sugar in India at time (t).
$E.S._{s_{It}}$	Ending stock of sugar in India at time (t).
$P_{s_{It}}P_{g_{It}}$	An interaction term between sugar and Gur prices in India at time (t).
ϑ_t	Error term for equation (4) at time (t).
$S_{g_{It}}$	Total supply of Gur at time (t).
Ω_t	Error term for equation (5) at time (t).
$D_{g_{It}}$	Total demand for Gur in India at time (t).
$Q_{sc_{se_{It}}}$	Quantity of sugarcane allocated for use as seed at time (t).
$S_{sc_{It}}$	Total supply of sugarcane in India at time (t).

$S_{sc_{se_{It}}}$	Supply of sugarcane allocated for use as seed in India at time (t).
$D_{sc_{It}}$	Total demand for sugarcane in India at time (t).
$S_{sc_{k_{It}}}$	Proportion of sugarcane allocated to khandasari in India at time (t).
η_{sc}^{s}	Conversion factor relating sugar output to sugarcane input.
η_{sc}^{g}	Conversion factor relating Gur output to sugarcane input.
ψ_t	Error term for equation (9) at time (t).
$Mc_{w_{It}}$	Marginal cost of producing wheat in India at time (t).
$P_{w_{It}}$	Price of wheat in India at time (t).
$AHTN_{It}$	The proportion of arable land used for multi-crop fields in India at time (t).
ς_t	Error term for equation (10) at time (t).
$Q_{M_{T_{It}}}$	Quantity of molasses produced as a byproduct of sugar production in India at time (t).
η_{M}^{sc}	Conversion factor relating molasses output to sugarcane input.
η_{e}^{M}	Conversion factor relating ethanol output to molasses input.
$Pr_{e_{T_{It}}}$	Total production of ethanol in India at time (t).
$D_{fe_{Tr_{It}}}$	Total demand for fuel ethanol in India at time (t).
$P_{Gas_{It}}$	Price of gasoline per liter in India at time (t).
$Mc_{A_{It}}$	Marginal cost of producing one liter of alcohol in India at time (t).
μ_t	Error term for equation (15) at time (t).

$B.R._{It}$	rate of ethanol blending in gasoline for India at time (t).
$G.C._{It}$	Total gasoline consumption in India at time (t).
$D_{e_{nf_{It}}}$	Total demand for non-fuel ethanol in India at time (t).
GDP_{It}	India's total Gross Domestic Product (GDP) at time (t).
$P_{sc_{It}}$	Price of one kilogram of sugarcane in India at time (t).
ω_t	Error term for equation (17) at time (t).
$D_{e_{T_{It}}}$	Total demand for ethanol in India at time (t).
$Q_{e_{Im_{It}}}$	Total quantity of ethanol imported by India at time (t).
Φ_t	Error term for equation (19) at time (t).
$E.S._{e_{It}}$	Total ending stock of ethanol in India at time (t).
$B.S._{e_{It}}$	Total beginning stock of ethanol in India at time (t).

CHAPTER ONE: BACKGROUND OF INDIA'S ETHANOL MARKET

1.1. The Ethanol Blending Program (EBP)

India's demand for fuel ethanol has risen steadily since the enactment of the Ethanol Blending Program (EBP) in 2007. This program's purpose was to set a phase-wise blending mandate for Oil Marketing Companies (OMCs), which stipulated that each liter of gasoline consumed for fuel must contain at least 5% ethanol (Ray et al., 2011). The passage of the EBP reflects the government's desire to reduce national reliance on foreign energy imports, thus, increasing India's energy security.

Since the EBP's adoption in 2007, the program's expansion has been slowed by other economic sectors' ethanol needs and weak domestic production. Consequently, ethanol-blended gasoline market penetration has hovered around 2% over the past decade (Aradhey, Amit., 2018). Figure 1.1 below illustrates the blending rate of ethanol in gasoline from 2000-2019.

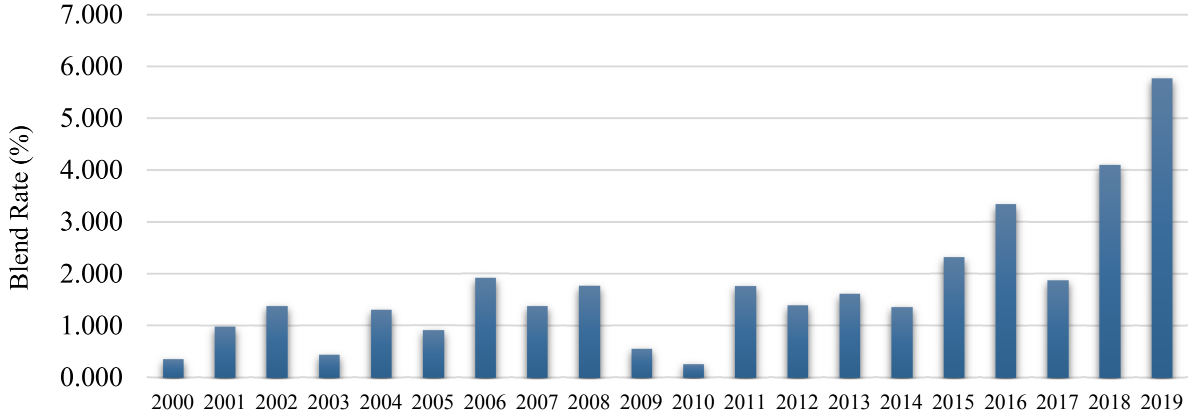

Figure 1.1: Market Penetration of Ethanol
Source: Aradhey, Amit. "India biofuels Annual" USDA Gain Report(s) # IN1058, IN1159, IN2081, IN3073, IN4045, IN5079, IN6088, IN7075, IN8085, & IN9069, 2010-2019.

Moreover, despite the difficulties associated with achieving the 5% blend target stipulated in the EBP, the legislation's impacts on fuel ethanol demand have still been substantial. In the decade since the GOI enacted the EBP, the transportation sector is now a significant end-user of ethanol, with consumption levels surpassing those from other more established industries (Aradhey, Amit., 2018). Figure 1.2 below shows the trend in the consumption of ethanol as motor fuel from 2000-2019.

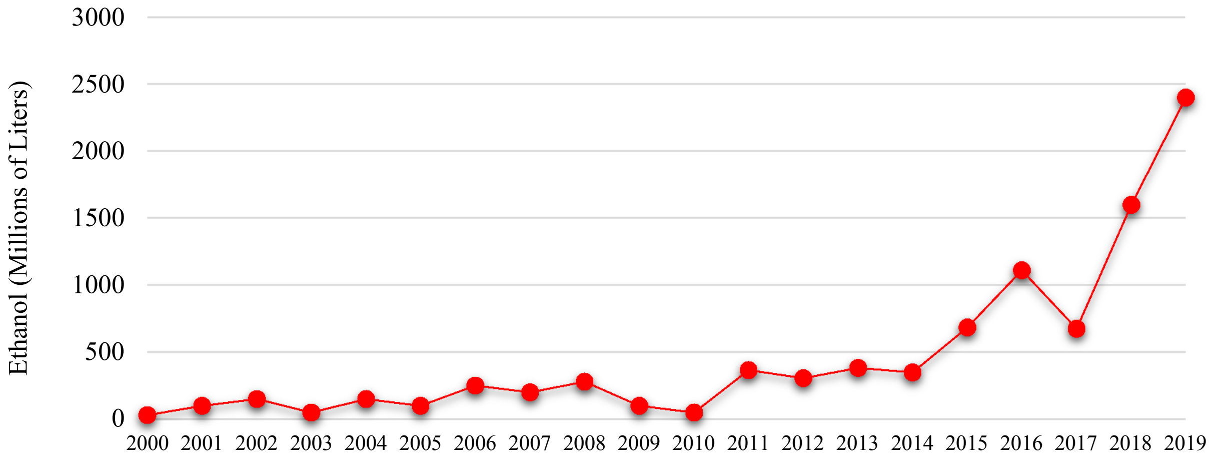

Figure 1.2: Ethanol Use as Motor Fuel Additive
Source: Aradhey, Amit. "India biofuels Annual" USDA Gain Report(s) # IN1058, IN1159, IN2081, IN3073, IN4045, IN5079, IN6088, IN7075, IN8085, & IN9069, 2010-2019.

The gradual expansion of the EBP over the past decade has not gone unnoticed by the Government of India (GOI), which revised its guidelines from the original in 2018 to help expedite the expansion of ethanol blending in India. Proponents of these amendments tailored each change to address problems, which hindered the first blending program's success. This (Aradhey, Amit., 2018). revised biofuel policy emphasizes the development of the country's domestic ethanol industry and promotes self-sufficiency. India's lack of capacity in ethanol production has primarily been responsible for its inability to achieve the target blend rates outlined in 2007 (Ray et al.,2011).

Thus, several of the revisions reflect steps toward self-reliance in ethanol utilization. For example, the EBP's revisions stipulate that ethanol made domestically is rationed for the transportation sector as a priority; thus, other industries' ability to procure ethanol from the domestic market as needed becomes hindered. Consequently, other areas of India's economy that use ethanol often face shortages, which offsets using imports from other countries (Aradhey, Amit., 2018).

In addition to these changes, the new legislation also calls for alterations to India's trade policy regarding ethanol's purchase from other countries. The revised policy stipulates a ban on the importation of ethanol for fuel blending purposes. Instead, imported ethanol is used explicitly for backfilling supply gaps in the industrial chemicals sector. Moreover, guidelines in the legislation that fixes ethanol's price for OMCs are responsible for blending gasoline with ethanol that meets or exceeds government standards (Aradhey, Amit., 2019).

1.2. Ethanol Demand in India

India's transportation sector is one of its fastest-growing industries and its largest ethanol end-user (Aradhey, Amit., 2019). The steady growth of India's economy and the government's blend requirements have increased demand for fuel ethanol at an exponential rate. In 2009, the transportation sector consumed 50 million ethanol liters (Aradhey, Amit., 2019). By 2019, fuel ethanol consumption reached 2.4 billion liters of ethanol, which with the average ethanol content of gasoline reaching a record high of 5.7%, making 2019 the first year that the market penetration of ethanol exceeded the EBP's 5% target (Aradhey, Amit., 2019). Furthermore, across the last decade, India's fuel ethanol requirements have increased nearly 50-fold. These demand trends will likely continue as the government continues its push to expand biofuels across the country.

Moreover, only two factors have slowed the growth in demand for fuel ethanol. The first has been the preparedness of India's automobile industry in meeting the requirements of the EBP, and the second is demand considerations from other sectors of the economy. (Ray et al., 2011).

In tests, researchers concluded that the majority of India's vehicular fleet was compatible with 5% ethanol-blended gasoline without the need for significant engine modifications (Ray et al., 2011).

However, blend rates above 15% will require changes to many of India's existing vehicles (Ray et al., 2011). This barrier has prompted the GOI to work more closely with the nation's leading automobile producers to make the modifications that will make the vehicular fleet compatible with the biofuels policy outlined in 2018 (Aradhey, Amit, 2019).

Despite the growing ethanol needs of the transportation sector, a significant portion of India's ethanol is used for unrelated purposes as a motor fuel additive. The use of ethanol in fuels is a recent development in India, and as few as three years ago, the demand for fuel ethanol was only the third-largest end-use of ethanol in India (Ray et al., 2011).

For decades, the alcoholic beverage sector was the largest ethanol consumer, followed by the industrial chemicals sector (Ray et al., 2011). The beverage sector distills sugarcane molasses into undenatured ethanol combined with different flavoring agents to produce alcoholic spirits. The undenatured ethanol produced by firms in this sector is intended for human consumption (Ray et al., 2011).

Conversely, the industrial chemical sector, like the transportation sector, makes use of denatured ethanol. This type of ethanol contains a denaturant like methanol, making it poisonous for consumption. Thus, denatured ethanol is used as a fuel additive in gasoline for motor vehicles and chemical bases to produce certain solvents and chemicals that require alcohol (Aradhey, Amit., 2018).

Moreover, a large share of India's ethanol demands each year remain attributable to both the beverage industry and the chemical industry. Though the transportation sector has surpassed these markets in terms of raw consumption over the past two years, both will remain significant ethanol users in absolute terms but will likely shrink in relative terms (Aradhey, Amit., 2019).

Consequently, the GOI's steady push to divert ethanol from the chemical industry for use as a motor fuel additive has seen the annual demand consistently outstrip production. The resulting shortfalls in supply are compensated for using imports from foreign countries. This practice has become a consistent theme over the past ten years, with India regularly being a net importer of ethanol because of regular shortages in at least one of these three industries (Aradhey, Amit., 2016). Figure 1.3 below illustrates the growth in ethanol demand over the past two decades.

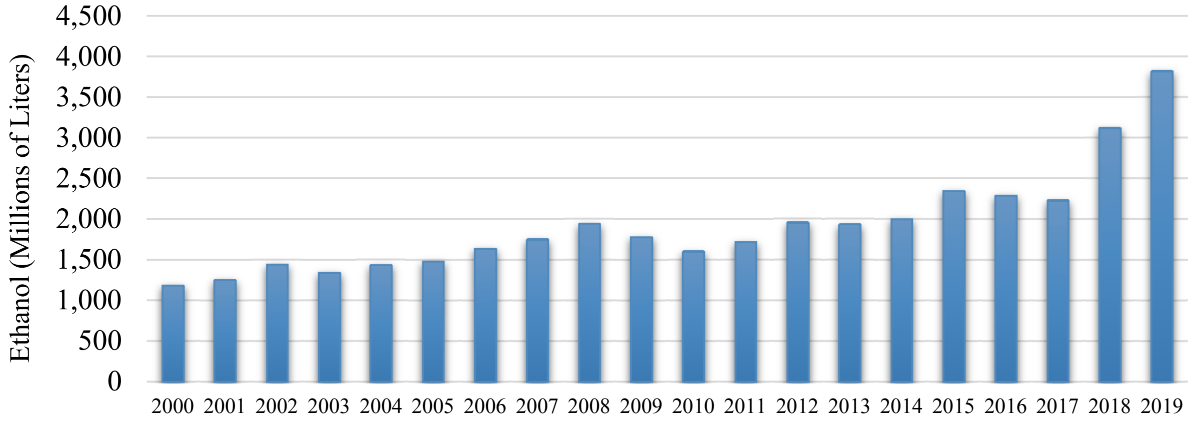

Figure 1.3: India's Annual Demand for Ethanol
Source: Aradhey, Amit. "India Biofuels Annual" USDA Gain Report(s) # IN1058, IN1159, IN2081, IN3073, IN4045, IN5079, IN6088, IN7075, IN8085, & IN9069, 2010-2019.

1.3. India's Domestic Ethanol Industry

Most of the ethanol India produces is made from sugarcane molasses, a byproduct of sugar production. Three main factors determine sugar production: the area under sugarcane cultivation in hectares, the output of sugarcane per hectare, and the proportion of sugarcane being crushed by sugar mills (Ray et al., 2011). The sugar production level corresponds directly to India's ethanol output. The molasses byproduct needed to produce ethanol is formed only when sugarcane is crushed into cane sugar by a mill (Ray et al., 2011).

Moreover, the cultivation of Sugarcane in India follows a cyclical pattern. This pattern is characterized by recurring trends, where sugarcane production is high for a 2 to 3-year period and then falls for two years (Ray et al., 2011). The proportion of land allocated for sugarcane cultivation by each farm tends to increase when farmers can sell their crops to sugar mills for higher profits when prices are high for the first few years of the cycle. Subsequently, this increases the supply of sugar, which eventually depresses its price. This fall in sugar price causes less cane to be grown in the final two years of each cycle, given the drop in profit associated with falling prices. Figure 1.4 below illustrates the sugar output trend over the past twenty years.

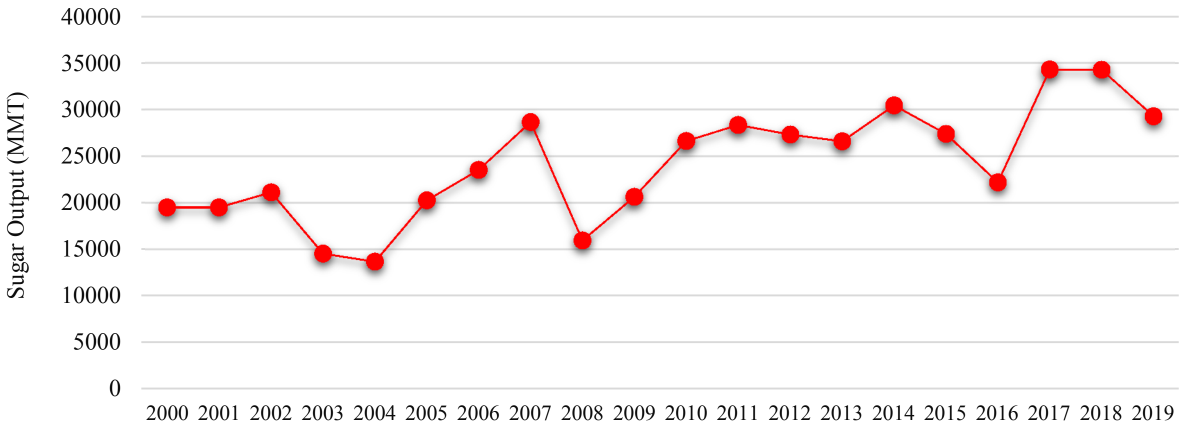

Figure 1.4: Annual Production of Cane Sugar in India
Source: Aradhey, Amit. "India Sugar Annual" USDA Gain Report(s) # IN1033, IN1137, IN2058, IN3040, IN4024, IN5059, IN6057, IN7045, IN8047, & IN9067, 2010-2019.

Moreover, in the years that follow this price decrease, Indian farmers will adjust the mix of crops that they plant because the fall in sugar prices causes a corresponding reduction in the profitability of farming Sugarcane (Ray et al., 2011). Consequently, the proportion of arable land being used to cultivate sugarcane decreases in favor of other profitable crops. This phenomenon indicates a mismatch in the incentive structure for Indian farmers, which culminates in recurring shortages (Ray et al., 2011). Figure 1.5 below shows the cyclical trend in sugarcane cultivation rates from 2000-2019.

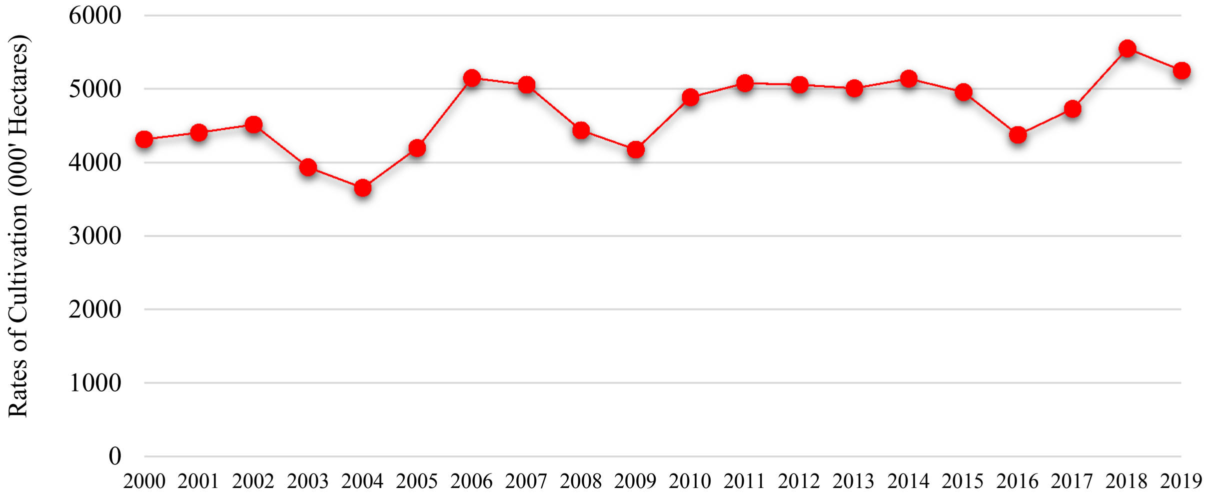

Figure 1.5: Sugarcane Cultivation in India
Source: Aradhey, Amit. "India Sugar Annual" USDA Gain Report(s) # IN1033, IN1137, IN2058, IN3040, IN4024, IN5059, IN6057, IN7045, IN8047, & IN9067, 2010-2019.

This mismatched incentive structure drives the cyclical patterns in sugarcane production that result in a structural problem for the domestic ethanol industry due to industry reliance on molasses, which is never consistent in its availability (Ray et al., 2011). In short, the bumper crop years of the cycle cause ethanol output to increase, which leads to a reduction of India's ethanol deficit and a subsequent decrease in the country's demand for ethanol imports. Conversely, during the sugarcane shortage that follows this initial glut in the cycle, ethanol output falls, causing a corresponding increase in the demand for imports (Ray et al., 2011).

Additionally, the government uses fair and remunerative prices to give farmers more certainty to receive 'fair' prices for their crops. To help farmers stabilize sugarcane farming's incentive structure by insulating farms against the business risk inherent to sugarcane farming (Alexander, Mino., 2010). However, using price controls may have done more harm than good. The remunerative cane price set by the government is difficult for sugar mills to afford.

Consequently, mills take on increasing amounts of debt each year to cover their sugarcane arrears to farmers. This debt burden on sugar mills incentives the purchase of less sugarcane from farmers (Ray et al., 2011).

Moreover, the demand for sugar also influences ethanol output. When the need for sugar is high, the proportion of sugar crushed in mills increases to meet the demand; this leads to a rise in the availability of byproducts like molasses and a corresponding increase in ethanol production (Aradhey, Amit., 2014). However, when the need for sugar is low, it decreases ethanol output because sugar mills reduce operational capacity, producing fewer molasses (Ray et al., 2011). In figure 1.6, the trend of sugarcane molasses production is shown from 2000-2019.

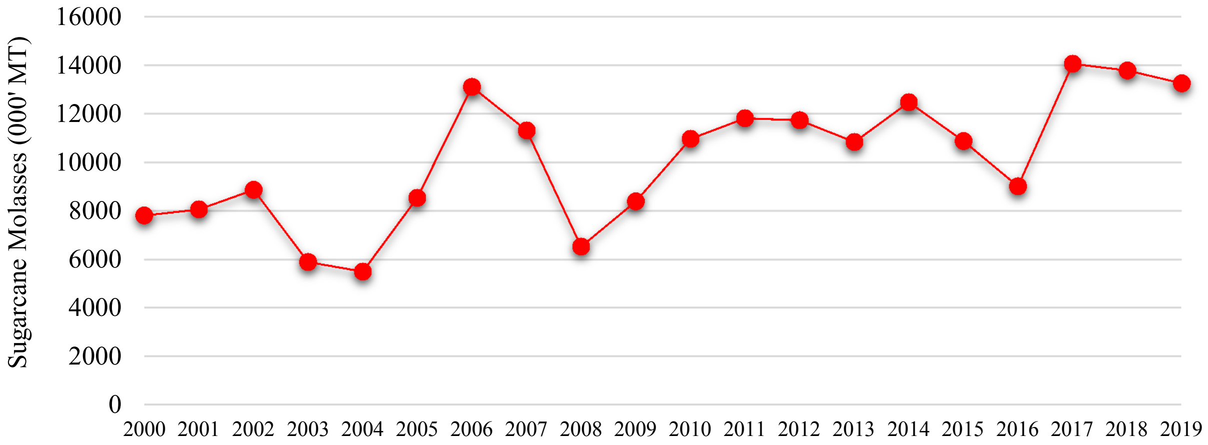

Figure 1.6: Annual Production of Molasses in India
Source: Aradhey, Amit. "India Biofuels Annual" USDA Gain Report(s) # IN1058, IN1159, IN2081, IN3073, IN4045, IN5079, IN6088, IN7075, IN8085, & IN9069, 2010-2019.

Beyond market factors and feedstock cultivation, the ethanol industry also faces a food or fuel problem. Realistically, India could produce all the ethanol it needs. However, it would have to augment its production of ethanol using sugarcane itself, food grains, and sugarcane juice in conjunction with the molasses already being utilized (Aradhey, Amit., 2018).

However, this approach forces a choice between using sugarcane and food grains for food or fuel, which describes a difficult trade-off the GOI is committed to avoiding. This sentiment is evidenced by legislative guidelines introduced in 2015, which prohibit raw sugarcane as a feedstock to produce ethanol. Hence, sugarcane molasses remains the primary feedstock for ethanol production in India. However, alternative feedstocks for ethanol are being explored but require further development before they can be considered genuinely viable alternatives to molasses (Aradhey, Amit., 2019).

However, the issues that pervade cane output have sparked interest in developing alternative feedstocks to supplement the nation's domestic ethanol production without using sugarcane or food grains as inputs (Ray et al., 2011). Hence, the GOI has created incentives that encourage the development of alternative feedstocks hoping they can be used more broadly in the future.

Moreover, resolving the structural problems that pervade India's ethanol market is of great interest to the government per its rhetoric; however, discovering a pragmatic solution remains elusive (Ray et al., 2011). Thus, ethanol production will remain inconsistent so long as sugarcane molasses remains the primary feedstock in its production (Ray et al., 2011).

In summary, the movements in sugar price and the corresponding shifts in the profitability of cultivating sugarcane relative to other crops causes the output of sugarcane, sugar, and molasses to follow nearly identical production patterns each year. Therefore, researchers can trace India's domestic ethanol production levels and the associated ebb and flow back to inconsistencies in sugarcane each year (Alexander, Mino., 2010). Figure 1.7 below demonstrates the recurring trends in India's production of ethanol from 2000-2019.

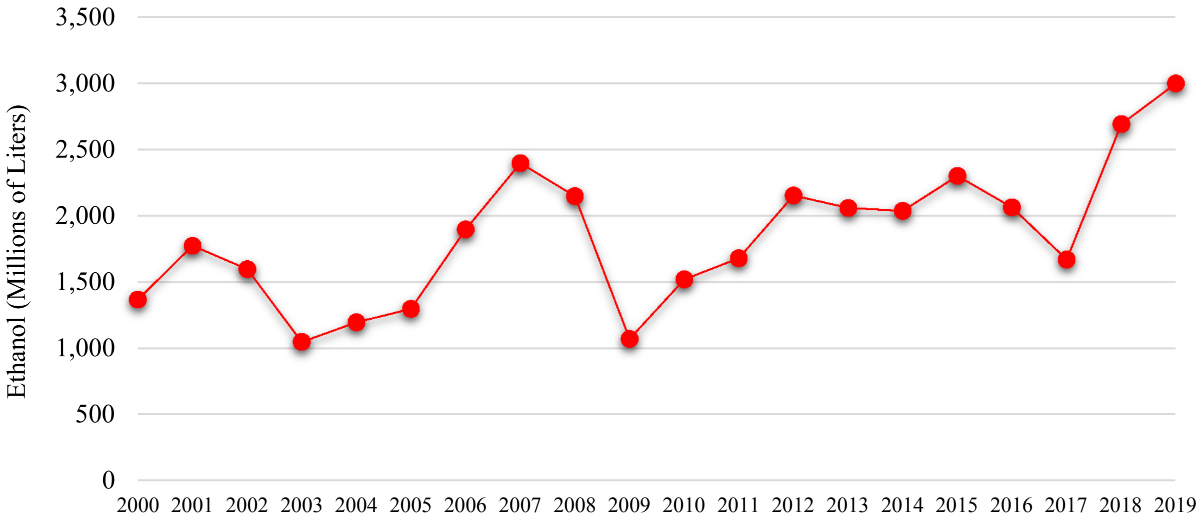

Figure 1.7: Annual Production of Ethanol in India
Source: Aradhey, Amit. "India Biofuels Annual" USDA Gain Report(s) # IN1058, IN1159, IN2081, IN3073, IN4045, IN5079, IN6088, IN7075, IN8085, & IN9069, 2010-2019.

1.4. Patterns in Trade: Ethanol Imports and Exports

The policy guidelines of India's EBP do not allow the importation of ethanol for fuel blending purposes. Moreover, the GOI has imposed a 150% import duty on all imports of undenatured ethanol coming into the country (Aradhey, Amit., 2018). Thus, a combination of import restrictions and trade barriers have led to nearly all the ethanol that India imports each year being denatured (Aradhey, Amit., 2019).

Furthermore, these imports of denatured ethanol are used to backfill any supply deficits for the chemical sector when ethanol rationing for use as motor fuel renders the domestic supply inadequate. Hence, when ethanol demand outstrips domestic production during a poor cane harvest, India's ethanol deficit grows. Conversely, when ethanol production is strong due to a sugarcane bumper harvest, the ethanol deficit shrinks (Aradhey, Amit., 2018). Figure 1.8 shows the trends in ethanol imports from 2000-2019.

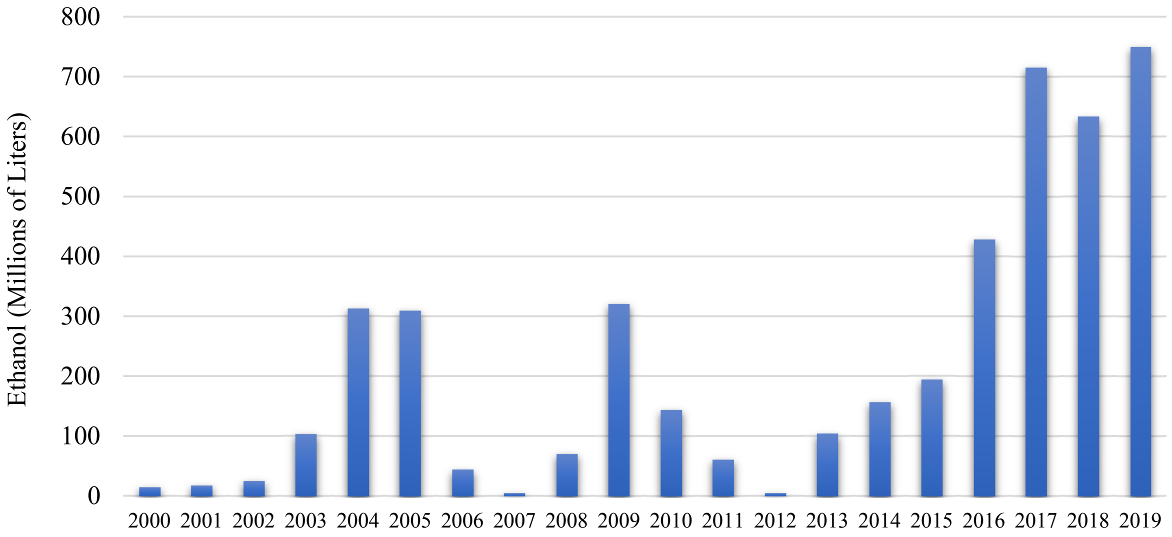

Figure 1.8: India's Annual Imports of Ethanol
Source: Aradhey, Amit. "India Biofuels Annual" USDA Gain Report(s) # IN1058, IN1159, IN2081, IN3073, IN4045, IN5079, IN6088, IN7075, IN8085, & IN9069, 2010-2019.

Moreover, the supply deficit for 2020 is expected to narrow, given steadier levels of domestic production. However, imports will continue being used to augment supply as needed. For instance, India's import demand of 716 million liters in 2017 was the highest year on record for import quantities (Aradhey, Amit., 2018). Thus, we can conclude that India's capacity to produce ethanol is improving. However, the volumes of ethanol Imported in the past three years indicate that self-sufficiency has yet to be achieved.

Furthermore, most of the ethanol that India imports come from the United States. In the past six years, the share of ethanol imports represented by the U.S. grew by nearly 22%, and by 2017 U.S. ethanol represented 96% of all ethanol imported by India. The remaining 4% was imported from China, Pakistan, South Korea, and Bhutan (Aradhey, Amit., 2018).

In contrast, patterns in export levels are not as straightforward in terms of intuition as those observed in imports. The trend of exportation seems puzzling at first glance, given regular annual shortages in the domestic market. However, the mystery of why export levels are often high when the country runs a domestic deficit unravels when a distinction between the two types of ethanol is considered. For instance, virtually all the ethanol that India exports each year is undenatured, while its imports consist exclusively of denatured ethanol (Aradhey, Amit., 2018). These exports are produced by distilleries using molasses from cane to make alcoholic spirits profitable enough to sell in global markets to warrant importing denatured ethanol from the U.S. to backfill the resulting supply gap in domestic markets (Ray et al., 2011).

A look at the numbers shows that export levels are related to existing domestic supply deficits, but the relationship is not always consistent. For example, exports peaked at 233 million liters in 2012 when production was robust. However, when production began tapering off, exports fell by an average of 15% before reaching a four-year low of 136 million liters in 2016. Moreover, in 2017, exports began to rebound, reaching 164 million liters in 2018. This rebound in exports was a result of more robust production. Thus, it can be shown that exports tend to rise when domestic output is strong and internal shortages are small (Aradhey, Amit., 2018). Figure 1.9 shows the trends in ethanol exports over the past two decades.

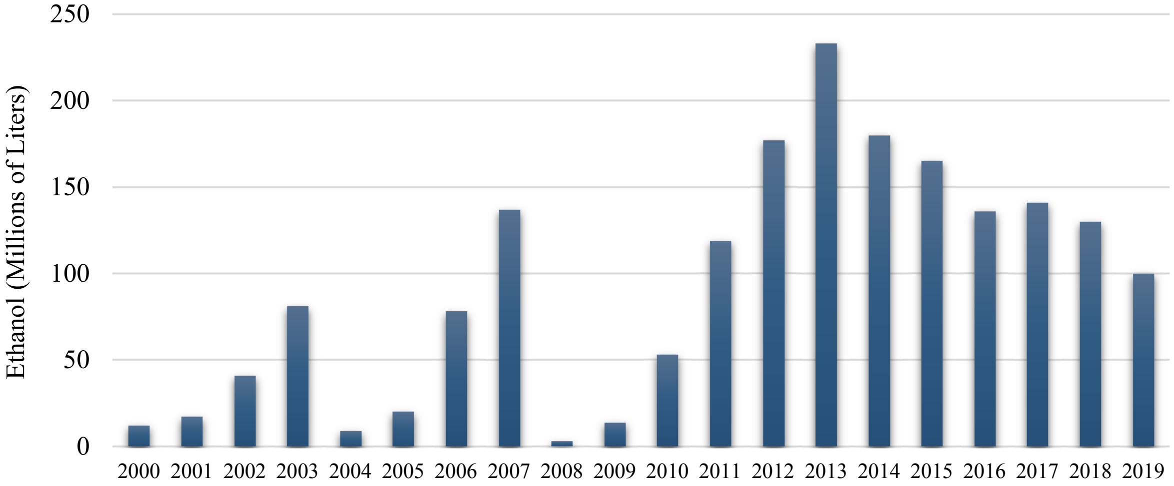

Figure 1.9: India's Annual Exports of Ethanol
Source: Aradhey, Amit. "India Biofuels Annual" USDA Gain Report(s) # IN1058, IN1159, IN2081, IN3073, IN4045, IN5079, IN6088, IN7075, IN8085, & IN9069, 2010-2019.

In summary, growth in ethanol demand continues to outstrip production growth. Moreover, trends can be observed in the country's trade balance, reflecting when ethanol production is reliable in some years and weak in others. For example, in 2012, ethanol production exceeded demand leading to only 5 million liters of imported ethanol, while 177 million liters were exported.

Conversely, in 2017, ethanol production fell substantially, resulting in 716 million liters of ethanol being imported, while 141 million liters were exports (Aradhey, Amit., 2018). Hence, this research concludes that India's import demand fluctuations are bound to shortfalls in domestic ethanol supply. This implies India will continue to import ethanol so long as foreign and domestic demand is secure and domestic production inconsistent. (Aradhey, Amit., 2018). Figure 1.10 shows the trends in ethanol production and consumption from 2000-2019.

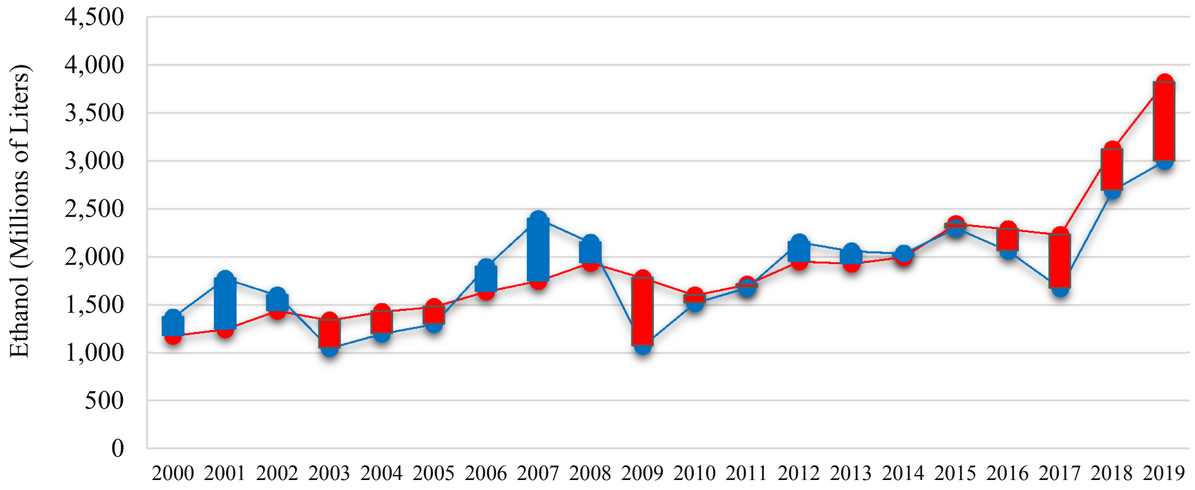

Figure 1.10: India's Annual Demand & Production of Ethanol
Source: Aradhey, Amit. "India Biofuels Annual" USDA Gain Report(s) # IN1058, IN1159, IN2081, IN3073, IN4045, IN5079, IN6088, IN7075, IN8085, & IN9069, 2010-2019.

1.5. Market Dynamics: The Sugar Cycle

The sugarcane cycle is believed to mirror the sugar cycle in price and quantities, with adjustments in the cane cycle lagging behind those in the sugar cycle by around one year on average (Alexander, Mino., 2010). This lag is attributed to the 16-month process of cultivating sugarcane, which delays cane price adjustments until output quantities are realized the year following (Ray et al., 2011).

Furthermore, the cane price is theorized to move opposite sugar prices because increased sugar production drives sugar prices down while simultaneously increasing the price mills are willing to pay for the cane to meet rising input demands. Conversely, decreased sugar production causes sugar prices to rise while driving cane prices down as input demand falls (Ray et al., 2011). The price of sugarcane reaches a minimum at the end of each cane cycle around a year after sugar prices reach a maximum at the end of the sugar cycle (Gulati, A., and T. Kelley, 1999).

This lag in the adjustment of cane quantity to those occurring in sugar quantity each year has some interesting ramifications for Indian farmers. This lag characterizes a structural problem in Indian agriculture. This problem's source is derived from the inability of sugarcane prices to adjust to those occurring in sugar at rates quickly enough to prevent inefficient outcomes (Ray et al., 2011). In other words, the cane price is unable to change rapidly enough to those occurring in sugar to clear the cane market each year fully.

Consequently, these slow adjustments in cane prices cause asymmetries in farmers' information as they decide what crops to cultivate presently. This lagged adjustment in cane prices makes cane growing a risky business for the farmers choosing to plant cane each year with each decision regarding how much to produce carrying risks that could bankrupt a farm if the wrong gamble is made (Gulati, A., and T. Kelley, 1999).

Therefore, farmers actively rely on cane prices to guide their decisions for what mix of crops to plant today, which is variable through time in response to previous sugar price movements. Hence, India's farmers are left with no choice but to sell their crops at unfavorable prices when movements in price are difficult to anticipate. (Ray et al., 2011). This dynamic indicates a lead-lag effect where farmers use rational expectations regarding future price trends in sugar to help them anticipate its movements to stay 'ahead of the curve' as cane price lags those occurring in sugar today (Alexander, Mino., 2010).

The cultivation of cane in India is not unlike the future market in American agriculture. The Indian farmers use speculative guesswork to anticipate what direction sugar and cane prices will move in, similar to speculation by U.S. farmers about any trends in U.S. commodity prices that may lend an edge as they vie to 'beat the market' (Ray et al., 2011). India's cane market departs its similarities from markets like those from the U.S. with the government's price floors on its commodity prices.

These price floors are known as fair and remunerative prices, which the government created to ensure farmers would always get 'fair' prices for their crops, which would help reduce future sugarcane shortages (Ray et al., 2011). This policy of using price controls may be harmful to farmers as the remunerative cane price is sometimes tricky for sugar mills to afford, forcing them to take on increasing amounts of debt to cover their sugarcane arrears owed to farmers each year (Ray et al., 2011).

Consequently, interest rates play an essential role in a mill's decisions about how much sugar should be produced in a year as the opportunity cost of borrowing the money needed to ensure its operation is paramount to its profitability. Moreover, the GOI also redistributes around ten percent of all sugar produced by sugar mills in the calendar year to needy families. This allocation is known as levy sugar, which the government forcibly procures from sugar mills at cost using a quota basis (Alexander, Mino., 2010).

Hence, these dynamics manifest themselves as the price movements behind each of the interrelated commodity markets, which make up a more significant sugar cycle. Moreover, the adjustment mechanisms observed for sugarcane prices are thought to be responsible for the structural flaws that have perpetuated the 'sugar cycles' apparent within India's agriculture system that has proven challenging to address pragmatically (Gulati, A., and T. Kelley, 1999). Figure 1.11 shows trends in sugar and sugarcane prices over the past twenty years.

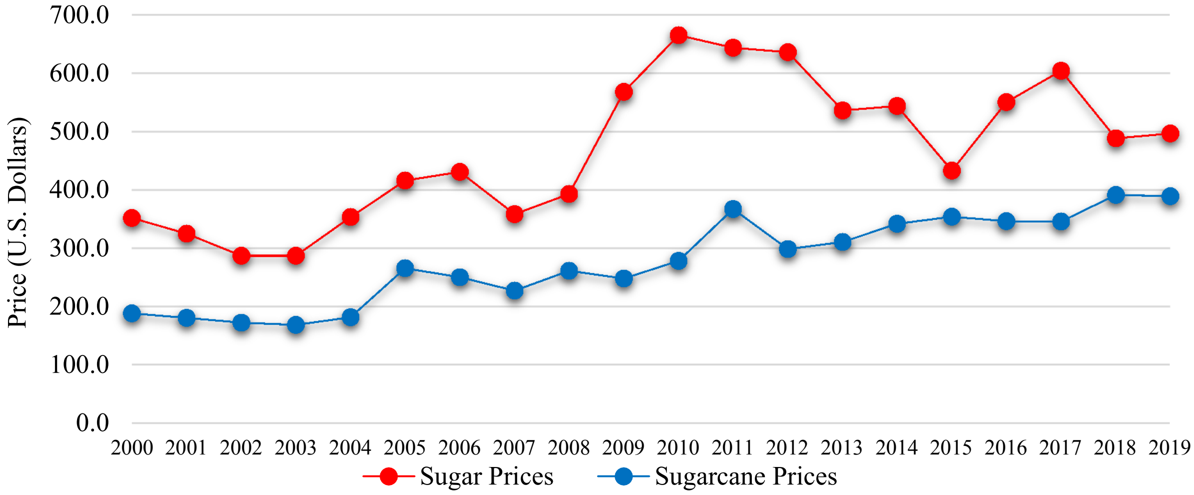

Figure 1.11: Sugar Prices & Remunerative Fair Cane Prices
Source: Aradhey, Amit. "India Sugar Annual" USDA Gain Report(s) # IN1033, IN1137, IN2058, IN3040, IN4024, IN5059, IN6057, IN7045, IN8047, & IN9067, 2010-2019.

Likewise, sugar price is mostly independent in determination; however, sugar prices trends are not without outside influence. Sugarcane can be used to produce many sweeteners, with each being imperfect substitutes. For example, a centrifugal sugar called Gur is, which is a sugar substitute. Thus, both the price and demand for sugar are inversely related to those of Gur. They are highly substitutable sweeteners used for similar purposes by households and industry (Aradhey, Amit., 2019).

Furthermore, both sugar and Gur are produced by crushing sugarcane with a near-identical production process that involves the same inputs, which in turn correspond to similar production costs. Also, Gur is effectively another form of sugar; thus, the extraction rate between sugar and Gur is the same.

Hence, Gur is an alternative to sugar, which mills can quickly produce in place of sugar, which occurs when profits from sugar production decrease relative to Gur. Furthermore, the substitutable nature of sugar and Gur in both consumption and production causes their respective prices to rise and fall in unison with any trends in Gur price having a significant bearing on sugar price and vice versa (Ray et al., 2011). Figure 1.12 shows trends in sugar and Gur prices from 2000-2019.

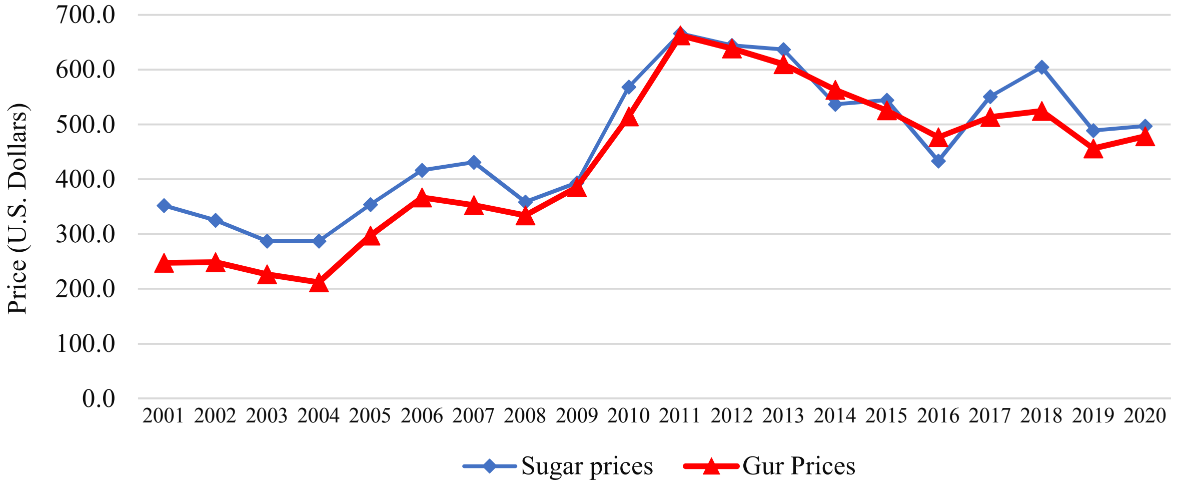

Figure 1.12: Sugar & Gur Prices
Source: Aradhey, Amit. "India Sugar Annual" USDA Gain Report(s) # IN1033, IN1137, IN2058, IN3040, IN4024, IN5059, IN6057, IN7045, IN8047, & IN9067, 2010-2019.

In summary, the cultivation of sugarcane faces a structural problem that renders the market inefficient. This inefficiency stems from the lagged response of sugarcane output to trends occurring in sugar prices. This lag causes cane farmers to make incorrect cultivation decisions that result in overproduction in some years and underproduction in others. This pattern lasts for 5-7 years on average and then repeats itself; hence, the name 'sugar cycle.' Furthermore, the output of molasses, the cultivation of sugarcane, and ethanol output are all closely tied to sugar production; thus, the best predictor of ethanol production is sugar price (Alexander, Mino., 2010).

1.6. Market Dynamics: Prices and Land Use

India's farmers use 2-3-year crop rotation systems based on nutrient considerations, cultivation times, and the relative price and marginal costs of cultivation associated with each crop. The farmer selects which crops to include in their rotation based on the relative profitability of crops which are substitutes in farming, meaning one cannot be grown consecutively after the other on the same land; they must be produced simultaneously in fields with heterogenous crop mixes or separately in areas used for cultivating one unique crop at a time (Gulati, A., and T. Kelley, 1999).

Furthermore, considerations are made for the relative profitability of complementary crops, meaning they should be grown in consecutive order on the same land because complementary crops provide some of the nutrients needed by each other when cultivated in a specific order on the same field. These fields are known as 'twice-sown,' meaning they are used to grow two or more crops in the same year (Gulati, A., and T. Kelley, 1999).

These 'twice-sown' fields are the lynchpin of the crop rotations that occur in India, with their cultivation involving a trade-off in the amount of arable land allocated to a given crop within some set of substitute crops. This trade-off assumes that substitute crops must either be jointly cultivated in the same crop rotation cycle or cultivated in an entirely different and unrelated crop rotation cycle (Gulati, A., and T. Kelley, 1999).

Therefore, the cultivation of any substitute crops within the same crop rotation sequence must be grown jointly on the fixed amount of arable land available for agriculture at that time. This produces the trade-off in land use mentioned earlier because the available land is mostly fixed through time. However, the number of ways this land can cultivate different crops is virtually unlimited (Gulati, A., and T. Kelley, 1999).

Moreover, this trade-off in allocating arable land between substitute crops being cultivated jointly can be conceptualized as a theoretical framework that treats crop rotation patterns as a response by farmers to changing economic conditions to optimize their profits. Moreover, crop rotation changes occur as farmers' respond' to dynamic changes occurring in the relative profitability of different crop varieties, hence, adjusting the mix of crops planted accordingly.

Furthermore, the substitution of varying crop varieties based on their profitability occurs within a subset of crops similar to their nutrient needs, cultivation length, and soil requirements. Moreover, each variety's relative profitability is gauged by the farmer using current market prices, price expectations for the future, and present cultivation costs (Gulati, A., and T. Kelley, 1999).

Subsequently, certain assumptions are imposed on this research's theoretical framework to explain patterns in crop rotation. These assumptions allow for variations in land use to occur in terms of adjustments to all crops' rotation within a variety based on the shifts in profitability occurring between varieties over time.

Hence, the theoretical framework assumes that each successive set of crops cultivated jointly during each cycle is considered strict substitutes in cultivation, starting from the initial set ending with the final set. Moreover, each subsequent group of substitute crops cultivated per the pattern specified for crop rotation is assumed by the model to complement each other in cultivation (Gulati, A., and T. Kelley, 1999).

In other words, the set of substitute crops to be grown jointly for each stage of crop rotation is based on spatial considerations because land availability is finite; thus, trade-offs in which crops to cultivate must be made. Moreover, the set of complementary crops are grown in separate periods based on temporal considerations for the overall length of each crop rotation cycle and the nutrient considerations of each crop that will be developed during the cycle, which affects the order of cultivation in complementary crops through time (Gulati, A., and T. Kelley, 1999).

Furthermore, these assumptions allow the theoretical model to ensure that the estimation of a crop rotation cycle conforms to proper crop rotation practices, e.g., an actual farmer would not plant substitute crops consecutively in the same 'twice-sown' field because it would reduce yields and by extension profits, hence, the importance of these assumptions (Gulati, A., and T. Kelley, 1999).

For example, cane cultivation requires 16-months to fully cultivate while rice takes around 8-months and wheat around 4-months. Moreover, rice and wheat are complements in farming to each other and substitutes in cultivation for Sugarcane (Gulati, A., and T. Kelley, 1999). Thus, a farmer can choose to set aside a plot of land to plant a homogenous field of sugarcane, which requires 16-months to cultivate fully, or this same plot of land can be used to plant a 'twice-sown' field containing both wheat and rice grown consecutively in a rotation that begins and ends with wheat with rice being cultivated in the middle of the cycle.

Therefore, the total length of time required by a farm to grow wheat and rice in the order above is around 16-months, and sugarcane itself takes 16-months to cultivate fully. Hence, the farmer faces a clear trade-off between growing Sugarcane or growing wheat and rice (Gulati, A., and T. Kelley, 1999). Thus, the ebb and flow like patterns in sugarcane output that occur each year across all of India are a function of profitability associated with cane cultivation relative to the profits of planting substitute crops for sugarcane, which are complementary in their agriculture, allowing them to be grown using crop rotation, e.g., rice and wheat (Alexander, Mino., 2010).

1.7. Forecasts: Predictions and Implications

The transportation sector is now the largest end-user of ethanol in India. This development took only ten years to occur after the GOI passed the EBP in 2007 (Ray et al., 2011). Therefore, a forecast of the transportation sector's ethanol demand in the coming years is insightful for understanding the broader industry and the aggregate ethanol demand. Moreover, these forecasts help demonstrate the intuition behind the mathematical identities used to isolate India's demand for fuel ethanol later.

Thus, table 1.1, which is specified in pg. Twenty-three gives predictions for ethanol demand in India over the next five years. The table presents historical data regarding the consumption of motor fuels in India from 1989-2018. Furthermore, the table gives basic predictions for India's motor fuel consumption for the years 2019-2024.

The predictions made in table one is calculated using an arithmetic average of historical rates of ethanol blending in gasoline to create a predictive value for blend rates in future years by assuming these blend rates will not vary from the average blend rates recorded in prior years. Moreover, the arithmetic average for India's change in gasoline consumption for the years 1989-2018 is calculated. This allows predictions for India's gasoline consumption for years 2019-2024 to be estimated using the recorded value from 2018 to calculate future values based on a constant increase of 7.5% for the years following, i.e., 2019-2024.

Moreover, table 1.2 is specified on pg. Twenty-four expands on the model illustrated in table one by incorporating 'what if' scenarios that are useful for demonstrating different outcomes for the quantity of ethanol demanded by India's transportation sector in the future. These scenarios are based on movements in the current blend rate. The first scenario predicts ethanol consumption based on a static 2.4% blend rate. The second and third scenarios predict ethanol demand levels using hypothetical blend rates of 5% and 10%, respectively. These hypotheticals reflect possible scenarios where ethanol blend rates rise to levels stipulated by the EBP. The inclusion of these hypotheticals is based on rhetoric from the EBP, reflecting the government's vision for future expansion of biofuels utilization.

Table 1.1: India's Ethanol Blended Gasoline Use per Year (millions of Liters)

Year	Ethanol Blended Gasoline	% Change in gasoline use	Gasoline with other Additives	Fuel Ethanol Requirement	Market Penetration (%)
1989	4,410.3	15.15 %	4,410.3	-	-
1990	4,816.5	9.21 %	4,816.5	-	-
1991	4,758.5	-1.20 %	4,758.5	-	-
1992	4,642.4	-2.44 %	4,642.4	-	-
1993	5,106.7	10.00 %	5,106.7	-	-
1994	5,164.7	1.14 %	5,164.7	-	-
1995	6,325.3	22.47 %	6,325.3	-	-
1996	6,731.5	6.42 %	6,731.5	-	-
1997	7,195.8	6.90 %	7,195.8	-	-
1998	7,485.9	4.03 %	7,485.9	-	-
1999	7,892.1	5.43 %	7,892.1	-	-
2000	8,762.6	11.03 %	8,762.6	-	-
2001	9,516.9	8.61 %	9,516.9	-	-
2002	10,271.4	7.93 %	10,271.4	-	-
2003	10,735.6	4.52 %	10,735.6	-	-
2004	11,141.8	3.78 %	11,141.8	-	-
2005	11,722.1	5.21 %	11,722.1	-	-
2006	12,012.3	2.48 %	12,012.3	-	-
2007	13,521.1	12.56 %	13,521.1	-	-
2008	14,913.8	10.30 %	14,913.8	-	-
2009	17,873.3	19.84 %	17,766.1	107.2	0.6
2010	18,511.7	3.57 %	18,456.2	55.5	0.3
2011	19,614.2	5.96 %	19,261.1	353.1	1.8
2012	21,355.1	8.88 %	21,056	299.1	1.4
2013	21,145.8	-0.09%	20,807.5	338.3	1.6
2014	23,013.1	8.83%	22,690.9	322.2	1.4
2015	25,632.8	11.38%	25,068.9	563.9	2.2
2016	29,322.2	14.52%	28,354.6	967.6	3.3
2017	31,908.6	8.74%	31,270.4	638.2	2.0
2018	33,935.4	6.31%	33,188.8	746.6	2.2
2019	36,409.8	7.5%	35,356	873.8	2.4[1]
2020	39,140.6	7.5%	38,201.2	939.4	2.4
2021	42,076.1	7.5%	41,066.3	1,009.8	2.4
2022	45,231.7	7.5%	44,146.1	1,085.6	2.4
2023	48,624.1	7.5%	47,457.1	1,167	2.4
2024	52,270.9	7.5%	51,016.4	1,254.5	2.4

Source: U.S. Energy Information Administration & the CEIC

---

[1] Estimates for India's consumption of ethanol-blended gasoline from (2019-2024) were calculated by averaging historic blend rates of ethanol in gasoline (2009-2018) and historical growth rates in gasoline demand (1989-2018).

Table 1.2: India's Projected Ethanol Blended Gasoline Use (millions of liters)

Year	Gasoline with other additives	Ethanol Blend Rates	Projected Ethanol use	Ethanol Blended Gasoline
2019	35,536	2.4%	873.8	36,409.8
		3%	1,066.9	36,602.9
		5%	1,776.8	37,312.8
2020	38,201.2	2.4%	939.4	39,140.6
		3%	1,146.1	39,347.2
		5%	1,910.1	40,111.3
2021	41,066.3	2.4%	1009.8	42,076.1
		3%	1,231.9	42,298.3
		5%	2,053.3	43,119.6
2022	44,146.1	2.4%	1,085.6	45,231.7
		3%	1,324.4	45,470.5
		5%	2,207.3	46,353.4
2023	47,457.1	2.4%	1,167	48,624.1
		3%	1,423.7	48,880.8
		5%	2,372.9	49,829.9
2024	51,016.4	2.4%	1,254.5	52,270.9
		3%	1,530.5	52,546.9
		5%	2,550.8	53,567.2

Source: U.S. Energy Information Administration & the CEIC

CHAPTER TWO: CONCEPTUAL MODEL

2.1. Developing the Framework: Simultaneous Equation Modeling

In this section, the use of Simultaneous Equation Modeling (SEM) is explored. The arithmetic average model discussed previously is useful for predictions but is limited by its simplicity. Moreover, the literature indicates that output quantities follow cycles based on prices that function as adjustment mechanisms.

These prices clear the market by adjusting to annual output changes from prior years to the present, which feedback through the market signaling to either scale production up or down (Gulati, A., and T. Kelley, 1999). The use of SEM allows these non-recursive aspects of the market to be modeled by recognizing the endogeneity of price and quantities. Moreover, SEM is expected to establish a partial equilibrium that produces robust results without accounting for the world market framework, beyond this research's scope.

The economic theory underlies the market dynamics identified by past analysis using simultaneous equations with each equation representing a piece of the overall market. These equations can be broken down into behavioral equations and identities. The behavioral equations represent portions of the model that describe economic agents' behaviors within the market based on market conditions.

These equations are functionally like single equation regression but with considerations for the endogeneity of independent variables. Behavioral equations contain intercept parameters, which can be considered the starting value for the dependent variable. Moreover, the error in estimation between fitted values and actual values is included.

The Identities involve fixed relationships, which usually reflect a production technology, a condition for market clearance, or an aggregation of related variables. For example, the amount of sugarcane available to produce molasses fluctuates because it is based on variable relationships changing through time. In contrast, the molasses extracted from these differential quantities of sugarcane will scale at a constant rate.

This example characterizes the distinction between identities and behavioral equations in SEM, with the former being used to represent relationships with fixed coefficients and the latter representing variable relationships. Moreover, some identities could be considered restrictive given the use of fixed coefficients to model production technologies that have been empirically shown to vary in output even when input is held constant but to a negligible degree.

Hence, table 2.1, pg. Twenty-seven gives Gur production breakdown from sugarcane, which forms the identities specified by equations 2.1-2.4. These equations represent the production technology used by sugar mills to produce Gur from sugarcane.

Moreover, table 2.2, on pg. Twenty-seven explains cane sugar production from sugarcane, which forms the identities specified in equations 2.5-2.10. These equations represent the production technology used by sugar mills to produce sugar from sugarcane.

Thus, an identity for sugar production can be derived from these equations and incorporated into the larger market model. Additionally, table 2.2 explains the extraction rate of molasses from the sugar production process and the rate at which molasses is fermented into ethanol. Hence, the derivation of identities specified by equations 2.7-2.10, which are included in the overall model. Lastly, Table 2.3 on pg. Twenty-eight explains the costs of producing cane sugar from sugarcane and fermenting ethanol from molasses, which form the identities specified in equations 2.11-2.13. These equations give a useful breakdown of relevant production costs but are not included in the overall model.

Table 2.1: Breakdown of Gur Production from Sugarcane

Sugarcane	High Quality	Low Quality
Juice per 100kg of crushed cane	50kg	40kg
sugar in juice (%)	22%	17%
Gur per 100kg of Cane	10kg	7kg

Source: Russell, Andrew., "Small and Medium Scale Sugar Processing Technology," Practical Action formerly ITDG, Bangladesh, 1998 last updated 2009, pp. 1-14.

Mass Balance[2]; $$\text{Weight of Gur}=\text{Weight of Cane}*\frac{\text{Weight of Juice}}{\text{Weight of Cane}}*\frac{\text{Sugar in Juice}}{\text{Sugar in Gur}} \tag{2.1}$$

$$\text{High quality};10\text{kg Gur}=100\text{kg of cane}*\frac{50\text{kg of Juice}}{100\text{kg of cane}}*\frac{21\%\text{ Sugar in Juice}}{95\%\text{ Sugar in Gur}} \tag{2.2}$$

$$\text{Low quality};7\text{kg Gur}=100\text{kg of cane}*\frac{50\text{kg of Juice}}{100\text{kg of cane}}*\frac{16.5\%\text{ Sugar in Juice}}{95\%\text{ Sugar in Gur}} \tag{2.3}$$

$$\text{High/Low Mix};8.5\text{kg Gur}=100\text{kg of Cane}*\frac{45\text{kg of Juice}}{100\text{kg of cane}}*\frac{18.5\%\text{ Sugar in Juice}}{95\%\text{ Sugar in Gur}} \tag{2.4}$$

Table 2.2: Conversion Ratios; Sugar from Cane, Molasses from Cane, Ethanol from Molasses

Conversion Ratios	Fixed Input/Output Production Ratios
Sugarcane to Crushed Cane (MT/MT)	0.5626 MT of Crushed Cane per M.T. of Sugarcane
Crushed Cane to Sugar (MT/MT)	0.1017 MT of Sugar per M.T. of Crushed Cane
Crushed Cane to Molasses (MT/MT)	0.044 MT of Molasses per M.T. Crushed Cane
Crushed Cane to Ethanol (MT/L)	70 Liters of Ethanol per M.T. of Cane
Molasses to Ethanol (MT/L)	225.225 Liters of Ethanol per M.T. of Molasses

Source: Sugarcane to Crushed Cane and Crushed Cane to Sugar: Handbook of Sugar Statistics, Indian Sugar Mills Association 2008. Crushed Cane to Ethanol: Report of the Commission on Development of Biofuels 2003. Molasses to ethanol/alcohol: Nguyen et al. 2008.

Sugar in kilograms (kg)[3]$$= \text{sugarcane}*\frac{\text{Crushed Cane}}{\text{Sugarcane}}*\frac{\text{Sugar}}{\text{Crushed Cane}} \tag{2.5}$$

$$117\text{kg of Sugar} = 1777.5\text{ kg sugarcane}*\frac{1000\text{kg Cru. Cane}}{1777.5\text{ kg Sugarcane.}}*\frac{117\text{kg Sugar}}{1000\text{kg Crushed Cane}} \tag{2.6}$$

Molasses in kilograms[4] $$= \left(\frac{\text{Cru.Cane}}{\text{Sugarcane.}}*\frac{\text{Sugar}}{\text{Cru.Cane}}\right)\xrightarrow{\text{Byproduct}}\frac{\text{Molasses}}{\text{Crushed Cane}} \tag{2.7}$$

$$44\text{kg Molasses} = \left(\frac{1000\text{kg Cru.Cane}}{1777.5\text{ kg Sugrcne.}}*\frac{117\text{kg Sugar}}{1000\text{kg Cru.Cane}}\right)\xrightarrow{\text{Byproduct}}\frac{44\text{kg Molasses}}{1000\text{kg Crushed Cane}} \tag{2.8}$$ [5]

---

[2] Equation (2.1) holds cane quantity constant while quality varies. The high/low-quality mix is 1:1 in equation four.

[3] Equation (2.5) assumes the extraction rate of sugar is based on static production technology.

[4] equation (2.7) assumes the molasses formed as a byproduct of sugar manufacture is static.

[5] Equation (2.8) assumes all molasses formed each year is used to produce ethanol at constant returns to scale.

$$\text{Ethanol in Liters (L)}^{5} = \text{sugarcane} * \frac{\text{Crushed Cane}}{\text{Sugarcane}} * \frac{\text{Molasses}}{\text{Crushed Cane}} * \frac{\text{Ethanol}}{\text{Molasses}} \tag{2.9}$$

$$\text{225L Ethanol} = \text{1777.5 kg Sugarcane.} * \frac{\text{1000kg Cru.Cane}}{\text{1777.5 kg Sugrcne.}} * \frac{\text{44kg Molasses.}}{\text{1000kg Cru.Cane}} * \frac{\text{225L Ethanol}}{\text{44kg Molasses.}} \tag{2.10}$$

Table 2.3: Production costs; Sugar from Cane, Molasses from Cane, Ethanol from Molasses

Cost Ratios	Fixed Costs of Production
Crushed Cane to Sugar (MT/MT)	4,168.6 INR per M.T. Sugar from 9.83 MT Crushed Cane
Crushed Cane to Ethanol (Rs/L)	11.32 INR per L Ethanol from 0.0142 MT Crushed Cane
Molasses to Ethanol (MT/L)	9.7 INR/L Ethanol from 0.0044 MT of Molasses
Molasses to Alcohol (MT/L)	9.7 INR/L Alcohol from 0.00467 MT Molasses

Source: Molasses to Ethanol cost: All India Distillers Association 2009. Crushed Cane to Ethanol cost: Kumar and Agrawal 2003. Molasses to Alcohol cost: The Viable Energy Substitute 2004.

$$\text{Total Costs}^{6}\text{; Cru. Cane kg to L Ethanol} = \frac{\text{Cru.Cane kg} * \frac{\text{Molasses kg}}{\text{Cru.Cane kg}} * \frac{\text{Ethanol L}}{\text{Molasses kg}}}{(\$0.17 * \text{kg}) + (\$0.22 * \text{L})} \tag{2.11}$$

$$\text{1777.5kg Cane to 225 L Ethanol} = \frac{\text{1777.5kg Cru.Ca.} * \frac{\text{44kg Molasses}}{\text{1777.5kg Cru.Cane}} * \frac{\text{225 L Ethanol}}{\text{44kg Molasses.}}}{(\$0.01 * 1777.5) + (\$0.22 * 225)} \tag{2.12}$$

$$\text{Total Costs} = \text{1777.5kg Cru. Cane} * \frac{\text{44kg Molasses}}{\text{1777.5kg Cru.Cane}} * \frac{\text{225 L Ethanol}}{\text{44kg Molasses.}} = \$67.27 \tag{2.13}$$

2.2. Applying the Theory: Specifying A System of Equations

A simultaneous equation model is used to estimate each commodity's output quantities that make up a broader sugar cycle component. This is done by treating commodity prices as endogenous, allowing the cane output pattern to be estimated based on developments in the sugar market, ultimately thought to drive the sugarcane market. Furthermore, the cycles in cane output lag behind those occurring in sugar due to its 16-month cultivation cycle delay price adjustments for sugar cane that move opposite those occurring in sugar (Gulati, A., and T. Kelley, 1999). Hence, cane farmers' cultivation choices are made each year using uncertain and incomplete information, which causes cane output to follow predictable patterns of contraction and expansion (Ray et al., 2011).

---

[6] Equation (2.11) assumes that costs are fixed, and that total costs scale linearly with total output.

Moreover, sugar production has a near-perfect one-to-one relationship with molasses output and ethanol production through its effect on cane cultivation rates. The quantity of cane is ultimately used to produce sugar by mills. The lag in cane cultivation causes the adjustment in cane prices to fall behind those occurring in sugar (Ray et al., 2011).

Thus, years that experience a cane shortage that slashes both ethanol and molasses production levels tend to happen when a lag in cane price from the previous year signaled farmers to scale production down when production should have been increased.

Conversely, some years see an opposite effect where the lag in the adjustment of cane price sends the wrong signal to farmers that output should be increased in the current year when it should be scaled back, causing an oversaturation of the cane market the following year, which tends to increase the supply of ethanol and molasses (Alexander, Mino., 2010).

Furthermore, the sugar production trend affects both ethanol and molasses output but in real-time because any expansion or contraction in sugar manufacture impacts the proportion of cane being crushed into sugar by mills. This is significant because the molasses feedstock needed by India's domestic ethanol industry to produce its product is formed only when sugarcane is crushed into sugar-producing the needed molasses as a byproduct (Ray et al., 2011).

Hence, the supply and demand functions for each commodity; sugar, sugarcane, and Gur, are estimated using behavioral equations that attempt to account for these non-recursive features of the sugar cycle as peaks and troughs in ethanol production can be traced back to the cyclical patterns occurring annually in sugar production (Alexander, Mino., 2010).

Furthermore, a behavioral equation is used to estimate India's ethanol consumption for fuel blending purposes: ethanol is used as a motor fuel additive in gasoline consumed by the nation's transportation sector. Moreover, a behavioral equation Is also used to estimate ethanol used for non-fuel purposes, e.g., ethanol consumed by India's economy's potable and chemical industries. The ethanol consumption for both fuel and non-fuel uses is aggregated using an identity that derives the nation's total demand for ethanol across all its economic sectors each year.

Furthermore, India's domestic supply of ethanol is then differenced from domestic demand levels to determine if supply shortages or surpluses are evident each year. The internal balance can predict the country's demand for imported ethanol with an expectation that import quantities will rise in years of ethanol shortage in the local market. Conversely, ethanol export levels are predicted to shrink with shortages and grow with surpluses. However, export quantities are treated as exogenous for simplicity.

Lastly, a trade identity is specified, constraining the entire system to ensure the full ethanol availability and the aggregate ethanol demand in each year (t) are equivalent. This ties the model together by serving as the market-clearing identity that relates the otherwise independent sub-systems to each other using the ending stocks as the left-hand side variable because it is known with the least certainty.

2.3. The Theoretical Model

$$\hat{P}_{s_{It}}{}^{7} = \beta_0 + \beta_1 GDPPC_{It} - \beta_2 Ir_{It} + \beta_3 P_{g_{It}} + \varepsilon_t \tag{2.14}$$

[Estimation of the price of sugar in year (t) as a function of Gur prices & consumer incomes]

$$\mathrm{D}_{\mathrm{s}_{\mathrm{It}}} = \alpha_0 - \alpha_1 \widehat{\mathrm{P}}_{\mathrm{s}_{\mathrm{It}}} + \alpha_2 \mathrm{P}_{\mathrm{g}_{\mathrm{It}}} + \alpha_3 \mathrm{GDPPC}_{\mathrm{It}} + \epsilon_{\mathrm{t}} \tag{2.15}$$

---

[7] A variable specification is provided in the list of symbols on pg. ix-xi , which details the nomenclature used to denote variables in this theoretical model.

[Total consumer demand for sugar in year (t) as a function of sugar prices, gur prices, & income.]

$$\mathrm{D}_{\mathrm{s}_{\mathrm{It}}} + \mathrm{E.S.}_{\mathrm{s}_{\mathrm{It}}} = \mathrm{S}_{\mathrm{s}_{\mathrm{It}}} + \mathrm{B.S.}_{\mathrm{s}_{\mathrm{I}}}{}^{8} \tag{2.16}$$

[Market clearance identity for sugar in year (t) with factors for beginning & ending stock levels]

$$\mathrm{S}_{\mathrm{sc}_{\mathrm{se}_{\mathrm{It}}}} = (\mathrm{S}_{\mathrm{sc}_{\mathrm{It}}} * \mathrm{Q}_{\mathrm{sc}_{\mathrm{se}_{\mathrm{It}}}}{}^{9}) \tag{2.17}$$

[Allocation of sugarcane for use as seed and feed for India in year (t).]

$$\mathrm{D}_{\mathrm{sc}_{\mathrm{It}}} = \left(\mathrm{S}_{\mathrm{s}_{\mathrm{It}}} * \eta^{\mathrm{s}}_{\mathrm{sc}}\right) + \mathrm{S}_{\mathrm{sc}_{\mathrm{se}_{\mathrm{It}}}} + \mathrm{S}_{\mathrm{sc}_{\mathrm{g}_{\mathrm{It}}}} + \mathrm{S}_{\mathrm{sc}_{\mathrm{k}_{\mathrm{It}}}} \tag{2.18}$$

[Total demand for sugarcane in year (t) as an aggregation of all its uses, e.g., sugar, seed, & Gur, etc.]

$$\widehat{\mathrm{P}}_{\mathrm{sc}_{\mathrm{I(t-1)}}} = \pi_0 + \pi_1 \mathrm{Mc}_{\mathrm{sc}_{\mathrm{I(t-1)}}} + \pi_2 \mathrm{P}_{\mathrm{s}_{\mathrm{I(t-1)}}} - \pi_3 \mathrm{P}_{\mathrm{s}_{\mathrm{I(t-2)}}} + \psi_{\mathrm{t}} \tag{2.19}$$

[Estimating sugarcane price in year $(\mathrm{t}-1)$ as a function of sugar price & cane cultivation cost.]

$$\mathrm{S}_{\mathrm{sc}_{\mathrm{It}}}{}^{10} = \sigma_0 - \sigma_1 \widehat{\mathrm{P}}_{\mathrm{sc}_{\mathrm{I(t-1)}}} - \sigma_2 \mathrm{P}_{\mathrm{s}_{\mathrm{I(t-1)}}} + \sigma_3 \mathrm{P}_{\mathrm{s}_{\mathrm{I(t-2)}}} + \varsigma_{\mathrm{t}} \tag{2.20}$$

[Supply of Sugarcane in year (t) as a function of sugarcane prices & sugar prices from prior years.]

$$\mathrm{S}_{\mathrm{sc}_{\mathrm{It}}} = \mathrm{D}_{\mathrm{sc}_{\mathrm{It}}} \tag{2.21}$$

---

[8] Equations (2.16) & (2.21) represent identities that ensure the availability of a commodity is equivalent to its disappearance. This ensures each respective market can fully clear.

[9] Equation (2.17) uses a fixed coefficient of around 0.12, i.e., 12%, and the total supply of sugarcane produced to determine the amount of sugarcane that is allocated for use as seed and feed on average in year (t).

[10] the 16-month cultivation time required for sugarcane implies that the cane's output that will be realized from cultivation each year will not be realized till the following year. Hence, lagged price and cost variables are used to describe the output of sugarcane in equation (2.20).

[Market clearance identity for sugarcane in year (t).]

$$S_{sc_{s_{It}}} = S_{sc_{It}} - [(S_{g_{It}} * \eta^{g}_{sc}) + S_{sc_{k_{It}}} + S_{sc_{se_{It}}}] \tag{2.22}$$

[Sugarcane allocation to produce sugar in year (t), i.e., total sugarcane supply minus all other uses for sugarcane besides cane sugar production.]

$$Q_{M_{T_{It}}} = S_{sc_{s_{It}}} * \eta^{sc}_{M}. \tag{2.23}$$

[Molasses formed as a byproduct of sugar production from sugarcane with η^{sc}_{m} representing the ratio of molasses formed per ton of cane crushed into sugar on average.]

$$Pr_{e_{T_{It}}} = Q_{M_{T_{It}}} * \eta^{M}_{e} \tag{2.24}$$

[Ethanol production in year (t) as a function of molasses availability multiplied by the ratio η^{M}_{e}, which denotes the total yield of ethanol per metric ton of fermented molasses.]

$$D_{fe_{Tr_{It}}} = \theta_0 + \theta_1 GDP_{It} - \theta_2 P_{s_{It}} - \theta_3 P_{Gas_{It}} + \theta_4 Mc_{A_{It}} + \mu_t \tag{2.25}$$

[Behavioral equation describing India's demand for fuel ethanol in year (t) as a function of India's GDP, sugar prices, gas prices, & marginal costs of alcohol production.]

$$B.R._{It}{}^{11} = \frac{D_{fe_{Tr_{It}}}}{G.C._{It}}, 0 \leq B.R._{It} \leq 0.10 \tag{2.26}$$

[Average rate of ethanol blending in gasoline in year (t), i.e., fuel ethanol consumption divided by total gasoline consumption yields the blend rate for a given year.]

$$D_{e_{nf_{It}}} = \phi_0 + \phi_1 GDP_{It} - \phi_2 P_{sc_{It}} + \phi_3 P_{gas_{It}} + \omega_t \tag{2.27}$$

---

[11] equation (2.26) is an identity that calculates the average blend rate of ethanol blended gasoline in India as the quantity of ethanol in liters consumed as motor fuel in year (t) divided by the quantity of gasoline consumed in year (t).

[Ethanol demand in year (t) for all non-fuel uses as a function of India's GDP, sugarcane prices, & gas prices.]

$$\mathrm{D}_{\mathrm{e}_{\mathrm{T}_{\mathrm{It}}}}{}^{12} = \mathrm{D}_{\mathrm{fe}_{\mathrm{Tr}_{\mathrm{It}}}} + \mathrm{D}_{\mathrm{e}_{\mathrm{nf}_{\mathrm{It}}}} \tag{2.28}$$

[Total demand for ethanol (Both fuel and non-fuel) in year (t).]

$$\mathrm{Q}_{\mathrm{e}_{\mathrm{Im}_{\mathrm{It}}}} = \delta_0 + \delta_1(\mathrm{D}_{\mathrm{e}_{\mathrm{T}_{\mathrm{It}}}} - \mathrm{Pr}_{\mathrm{e}_{\mathrm{T}_{\mathrm{It}}}}) - \delta_2\mathrm{Ir}_{\mathrm{It}} - \delta_3\mathrm{P}_{\mathrm{gas}_{\mathrm{It}}} + \delta_4\mathrm{GDP}_{\mathrm{It}} + \Phi_{\mathrm{t}} \tag{2.29}$$

[Behavioral equation estimating India's ethanol import demand in year (t) as a function of India's deficit in domestic ethanol supply, interest rates, gas prices, and India's GDP.]

$$19.\,\mathrm{E.S.}_{\mathrm{e}_{\mathrm{I(t-1)}}} = \mathrm{B.S.}_{\mathrm{e}_{\mathrm{It}}} \tag{2.30}$$

[Identity stating that India's ending stock of ethanol from year $(\mathrm{t}-1)$ must be equivalent to its beginning stock in the following year (t).]

$$ES_{e_{It}} = \left(Pr_{e_{T_{It}}} + BS_{e_{It}} + Q_{e_{Im_{It}}}\right) - (D_{e_{T_{It}}} + Q_{e_{ex_{It}}}) \tag{2.31}$$

[This equilibrium trade identity clears the model by defining India's ending stock of ethanol in a year (t) as a function of the quantities of ethanol the nation consumes, produces, exports, & holds as stock in that years' time.]

---

[12] Equation (2.28) aggregates India's use of ethanol for both fuel and non-fuel purposes to obtain a measure of the nation's aggregate demand for ethanol for each year (t).

CHAPTER THREE: RESULTS

3.1. Introduction

The first five equations from the theoretical model were specified as two-stage models. These regressions were estimated using the Generalized Method of Moments to account for the potential endogeneity of prices and mitigate heteroskedastic sampling distributions. Hence, the first stage for each of these regressions was specified to instrument prices into structural second-stage regressions that describe demand quantities.

Additionally, heteroskedasticity-robust standard errors are reported to ensure statistical significance tests are not invalidated by any heteroskedasticity issues that may still arise. Moreover, the R-squared, F-statistics, T-statistics, and Root Mean Squared Error for each first-stage regression is reported after estimation. These statistics help determine the relevance of the variables used to instrument prices for each structural model.

Likewise, the R-squared, Chi-Squared statistics, Z-statistics, and Root Mean Squared Error for each second-stage regression are reported post-estimation. These statistics are included to provide measures that establish both robustness and goodness of fit for each model (or lack thereof). Similarly, the orthogonality conditions [13] of each two-stage regression are tested against the null hypothesis. ' $\mathrm{H_0}$: $\mathrm{Variables\ are\ Exogenous}$ 'implying that each explanatory variable within each model is independent of the error term from their respective structural (second-stage models).

Therefore, low values for the C-statistic and high p-values are desirable as failure to reject the null allows the conclusion to be drawn that each variable from each model is indeed

---

[13] Loosely stated, the adherence of an estimator to the conditions of orthogonality indicate all possible values for the estimator are orthogonal to the error vector of the optimal estimator. Therefore, the orthogonality conditions are a necessary and sufficient condition for the optimality of a Bayesian estimator like the GMM estimator. Hence, the orthogonality conditions can be used to find the minimum mean square error estimator.

exogenous in determination. Hence, the values of the C-statistic and corresponding p-values are reported after each estimation.

The last three equations from the theoretical model are estimated using Ordinary Least Squares (OLS). OLS's use is justified in the case of these regressions because each independent variable was found to be exogenous in a determination based on violations of the over-identifying restrictions that were identified after each regression was tested post-estimation using Hansen's J-statistic.

Furthermore, The J-statistic follows a chi-squared distribution and tests the model against the null that. ' H_0: Instruments are Exogenous. 'This indicated that OLS estimates and GMM estimates were near-identical for these three models; hence, the use of instrumental variables was unnecessary.

Also, heteroskedasticity-robust standard errors are reported to ensure that any heteroskedasticity issues do not invalidate statistical significance tests. Furthermore, the R-squared, F-statistics, T-statistics, and Root Mean Squared Error for each OLS regression are reported post-estimation. These statistics are included as they provide measures to establish the robustness and goodness of each OLS model's fit.

Moreover, Variance Inflation Factors (VIF) is calculated after each OLS regression to detect multicollinearity. Furthermore, convention dictates that a VIF of more than ten is indictive of multicollinearity. Thus, the Mean VIF of each regression is reported after each estimation. The Durbin-Watson (D.W.) test is conducted after each regression to detect autocorrelation of the model residuals. Moreover, convention determines that values of the D.W. d-statistic that fall between the range of 1.5-3 in value are considered 'normal,' indicating minor problems with autocorrelation

3.2. Results

3.2.1. Sugar Prices

The adjusted R-squared for the Sugar Prices Model is 94.41%. The constant for this model is 278.35.

Table 3.1: Sugar Prices Model

Variables	Coefficients	T-Stat	P-Value
Gur Prices	0.997	11.43	0.000
GDPPC	0.043	1.46	0.169
Interest Rates	-22.49	-2.65	0.020

3.2.2. Sugar Demand

The adjusted R-squared for the Sugar Demand Model is 94.38%. The constant for this model is 17,838.08.

Table 3.2: Sugar Demand Model

Variables	Coefficients	T-Stat	P-Value
Sugar Pries	-38.53	-2.92	0.004
Gur Prices	40.33	3.59	0.000
GDPPC	5.05	13.23	0.000

3.2.3. Sugarcane Prices

The adjusted R-squared for the Sugarcane Prices Model is 53.36%. The constant for this model is 10.43.

Table 3.3: Sugarcane Price Model

Variables	Coefficients	T-Stat	P-Value
Sugarcane Cultivation Costs	0.654	4.77	0.000

3.2.4. Sugarcane Supply

The adjusted R-squared for the Sugarcane Supply Model is 47.08%. The constant for this model is 260.3.

Table 3.4: Sugarcane Supply Model

Variables	Coefficients	T-Stat	P-Value
Lagged Sugarcane Prices	169.7	3.77	0.002
Lagged Sugar Prices	-81.6	-1.73	0.102

3.2.5. Demand for Fuel Ethanol

The adjusted R-squared for the Fuel Ethanol Demand Model is 79.52%. The constant for this model is 359.63.

Table 3.5: Demand for Fuel Ethanol Model

Variables	Coefficients	T-Stat	P-Value
Sugar Prices	-2.006	-3.30	0.005
GDPPC	0.89	2.41	0.029
Gas Prices	-638.8	-1.57	0.138
Alcohol Prod. Costs	-0.24	-1.41	0.179

3.2.6. Demand for Non-Fuel Ethanol

The adjusted R-squared for the Non-Fuel Ethanol Demand Model is 52.17%. The constant for this model is 1,163.36.

Table 3.6: Demand for Non-Fuel Ethanol Model

Variables	Coefficients	T-Stat	P-Value
Sugarcane Prices	-25.29	-1.88	0.079
GDPPC	-0.314	-2.04	0.058
Gas Prices	631.38	2.68	0.016

3.2.7. Quantity of Ethanol Imports

The adjusted R-squared for the Quantity of Ethanol Imports Model is 90.36%. The constant for this model is 1,057.19.

Table 3.7: Quantity of Ethanol Imports Model

Variables	Coefficients	T-Stat	P-Value
GDPPC	0.554	5.76	0.000
Gas Prices	-459.39	-3.97	0.001
Ethanol Balance	0.172	2.48	0.026
Interest Rates	83.88	-2.75	0.015

3.3. Recommendations for Future Trade Agreements with India

The outlook for ethanol producers seeking to sell their products in the Indian market is convoluted to some degree. This lack of clarity can be attributed to the apparent lack of predictability concerning India's government's future direction regarding biofuels legislation, which diminishes an otherwise very bright outlook to at least some degree.

For example, the ban on the importation of ethanol for fuel was an unexpected move by the GOI that was accompanied by several other revisions made to the EBP in 2018 that give an unmistakable indication of the government's desire to push for self-sufficiency in ethanol utilization (Aradhey, Amit., 2019).

Therefore, it can easily be argued that the government's ambition to strive towards self-sufficiency in ethanol use does not bode well for India's future potential as an export market for countries like the U.S. or Brazil. However, the government's direction should be considered a cause for concern but not for alarm because lofty ambitions like those of the government take time and resources to implement. Furthermore, conventional wisdom dictates that even well-intentioned government policies sometimes fall short of expectations.

For instance, the first attempt at a statewide blending mandate by India's government in 2007 expressed desires for self-sufficiency in ethanol production, just like those expressed a decade later in 2018. Despite the legislation's enthusiastic rhetoric, its translation into a statewide blending program proved challenging to implement from a logistical standpoint in practice (Ray et al., 2011).

The evidence supporting this assertion can be inferred from the original blending mandate's lackluster performance, which stipulated the achievement of a 5% blend rate that was not met in till 2019, nearly a decade behind schedule. Moreover, the 5% blend rate was only the first target outlined in the original three-tiered plan that also called for an even more ambitious target blend rate of 20% that was intended to be reached by no later than 2017 (Ray et al., 2011).

Moreover, because of these government policy changes towards ethanol importation, the chemical sector is now the primary source of demand for imported ethanol in India. Fortunately for ethanol exporting countries like the United States, this shift in market dynamics have not diminished the overall need for ethanol imports that are needed to supplement an unreliable domestic supply (Aradhey, Amit., 2018).

On the contrary, the nation's demand for imports appears to be growing faster than in the past. This trend is driven by growth in the ethanol needs of economic sectors like the budding transportation industry, which regularly achieves double-digit growth rates in ethanol demand each year. Meanwhile, firms from both the chemical and beverage sectors continue to increase their ethanol acquisitions with each new year as both sectors consistently experience growth rates on par with those of the broader Indian economy (Aradhey, Amit., 2018).

Moreover, the government's current policy of rationing domestically produced ethanol for gasoline blending poses a significant problem for India's chemical industry. This is because the policy is structured to divert domestically produced ethanol away from the country's chemical companies, which rely on it to create the organic chemicals that make up a large part of their daily operations (Aradhey, Amit., 2018).

Subsequently, the purchase of ethanol from foreign sources like Brazil and the U.S. has become a lifeline for India's chemical companies. They become pressed to seek out and secure reliable business partners abroad (Ray et al., 2011). Consequently, U.S. ethanol exports have represented most of those being imported into India over the past four years. These exports have generally been used to supplement the availability of denatured ethanol to Indian chemical companies, which ensured continued operations when the domestic supply proved incapable of reliably providing for the industry's needs (Aradhey, Amit., 2018).

The lack of reliability is attributed to both the inconsistency in annual production and the siphoning of denatured ethanol away from the chemical sector for fuel when ethanol is rationed to the transportation sector because the government gives it a priority. Therefore, exports provide a reliable avenue that Indian chemical companies often need to procure the ethanol required to backfill supply gaps when the domestic output falls short (Ray et al., 2011).

Besides the healthy outlook for ethanol demand, India's domestic ethanol industry continues to be weighed down by the structural problems inherent to Indian sugarcane cultivation with the availability of the molasses feedstock following recurrent cycles that mirror patterns occurring in sugar production with a lag (Ray et al., 2011).

Subsequently, the domestic industry will remain unable to reliably fulfill the nation's ethanol requirements each year in till such time that a reliable method of procuring the feedstock needed to maintain stable production levels is found (Aradhey, Amit., 2019).

Therefore, the one factor that may shrink India's import demand and, thereby, diminish the current market outlook for ethanol exporting countries like the U.S. in the Indian market is the further development of the nation's domestic ethanol industry (Ray et al., 2011). If India's ethanol production capacity catches up with the consumption growth, it will lead to lower import demand and fewer export opportunities.

Moreover, there is substantial evidence this will happen with the GOI already exploring the use of alternative feedstocks to sugarcane molasses in ethanol production, which in time could augment the production capacity of the nation's domestic industry (Ray et al., 2011).

However, the development and implementation of these alternative feedstocks in ethanol manufacture are costly and time-consuming to implement on the scale needed to make India self-sufficient in its market for ethanol (Alexander, Mino., 2010). Hence, the outlook on the Indian market for global ethanol exporters is currently robust, and this is evidenced by the quantities of ethanol that India has imported in recent years, with these volumes being some of the highest on record for three consecutive years now (Aradhey, Amit., 2019).

Hence, the current lack of reliable ethanol production that has hindered the nation's domestic industry for the past decade gives even more weight to the assertion that India is almost undoubtedly a country that global ethanol firms will have their eyes on shortly. The significant growth in ethanol demand by the Indian economy and the lack of reliable domestic output make India one of the most promising emerging markets for the sale of ethanol in the world today (Aradhey, Amit., 2019).

Beyond the new blending program's policy guidelines from 2018, the ethanol market outlook has been diminished slightly by recent developments in the country's biofuels sector. In 2019, India's union minister of roads and transport unveiled the M15 blending program (Panday, Amit 2019). This new program calls for methanol produced with high ash coal as a blending agent for gasoline. Moreover, this program's implementation requires a production facility to be built where coal can be converted into methanol. This project will result in a multibillion-dollar expense for India and will take several years to construct, so the M15 program will not move forward shortly (Panday, Amit 2019).

However, the implication remains that India may turn to methanol for its fuel blending needs instead of ethanol in the coming years (Panday, Amit 2019). This development has some of India's trading partners in the U.S. and abroad slightly uneasy because it could spell trouble for future trade agreements related to ethanol.

This is because methanol is a substitute for ethanol as a fuel additive in its energy content and its desirable properties as an anti-knocking agent when blended with conventional gasoline. Therefore, if India passes the M15 program, it would be detrimental to any firms currently selling ethanol to India, which cast doubt on the market's long-term potential to ethanol exporters worldwide (Panday, Amit 2019).

However, it is worth questioning whether methanol produced with coal is a feasible alternative to ethanol for India's biofuel needs. In 2016, India signed the Paris Climate Agreement, which seeks to limit greenhouse gas pollution. This alone casts doubt on the M15 program because producing methanol with coal leads to greenhouse gas creation (Panday, Amit 2019).

Beyond the climate agreement itself, the GOI is keen to limit greenhouse gas emissions because India's pollution problems already must contend within the present. Consequently, the M15 program may not be as feasible in practice as it seems on the drawing board, which may give discerning spectators a glimmer of hope that the M15 program will lose steam, leaving the very bright market outlook intact for coming years (Panday, Amit 2019). Thus, at this point, it should be reiterated that the rhetoric of India's government regarding biofuels legislation is cause for concern but not alarm. The developments occurring within India's domestic ethanol industry should be monitored by ethanol exporters that are either already doing business in India or are interested in exploring its potential as a new market.

This is because developments in the domestic market that bring India closer to being self-sufficient have a strategic value that ethanol exporters cannot ignore. After all, the market outlook is currently stable, but this may change with time. The importance of being able to 'read the signs' as they occur cannot be understated in terms of strategic value as the timely recognition of trends in any market represent opportunities to stay 'ahead of the curve' by adapting to any trends before they occur which in no uncertain terms will either make or break any business venture and selling ethanol in India is no exception to this principle.

In summary, the recommendation for ethanol exporters is to tap into the Indian market today as the market has a stable outlook in terms of growth potential that also presents an attractive alternative to the Chinese market in Asian that American exporters are well-positioned to capitalize on if they have not already done so. Moreover, the evidence for this recommendation is two-fold.

Firstly, the steady rise in ethanol demand occurring in India, coupled with its unreliable and underdeveloped domestic ethanol industry, indicates strong growth in the nation's import demand that shows no signs of changing over the next few years. The nation's import demand seems more likely to continue growing even more rapidly than ever rather than tapering off over the coming years.

Secondly, continued operations in the Chinese market entail a strategic risk for U.S. ethanol exporters associated with the possibility of future trade disputes between the U.S. and China that threaten to provoke the Chinese government into imposing yet another wave of tariffs on U.S. commodity exports.

The recent trade war between the U.S. and China has shaken U.S. firms' confidence in the Chinese market. Many American companies were caught off guard by the sudden decline in relations that left many without access to markets that they had become reliant on after years of business as usual.

This casts doubt on the continued viability of the Chinese market that cannot be ignored from a strategic standpoint because it cannot be said with certainty whether tensions between the U.S and China will flare up again. Therefore, India represents an attractive alternative to China with comparable market potential to China without the uncertainty of a possible trade war.

3.4. Recommendations for Future Research

This research provides a theoretical foundation for understanding India's ethanol industry but lacks a practical translation from conceptual framework to empirical model. The theoretical foundation developed for India's ethanol market lends itself to Structural Equation Modeling (SEM). This assertion is based on the non-recursive aspects of India's commodity markets identified by past research. These Non-recursive features in sugarcane farming characterize interrelations theorized to 'feedback' through a greater system of interrelated markets sugarcane at the center.

Moreover, each of these markets is inferred in the literature to have varying endogeneity degrees between their prices and output quantities with some degree of endogeneity between the prices and output quantities of different commodities (Alexander, Mino., 2010). Hence, SEM seems an ideal approach to translating this theoretical framework to an empirical model that is suited to account for the non-recursive relationships between prices and quantities indicated (Cook et al., 2015).

Generally, the system of equations specified by the theoretical model discussed in this research would be estimated simultaneously using techniques like Three-Stage Least Squares (3SLS) or Seemingly Unrelated Regressions (SUR). However, the lack of available data precluded using these techniques; thus, 2SLS and OLS were used to estimate each equation on an individual basis instead.

Thus, I propose Generalized Maximum Entropy (GME) to estimate parameters in future research specific to describing and forecasting ethanol import demand in India. The use of GME may provide means to circumvent the lack of data available on India's ethanol market, which is currently limited to annual observations across the past twenty years.

The lack of available data limited this work's scope because of concerns that micro-numerosity would render traditional estimators like 3SLS inefficient because of their susceptibility to random sampling error when few observations are available. Also, 3SLS, when applied to models with limited data, may fall apart because there is not enough information to create asymptotically justified distributions to derive robust model parameters (Cook et al., 2015). Thus, the GME technique appears uniquely suited to this research, given the small sample size limitations.

The GME estimator's usefulness is based on its ability to produce robust parameter estimates even when data availability is problematic by constraining estimator distributions by imposing support points (Cook et al., 2015). Thus, the GME technique may circumvent small sample size issues more effectively than traditional SUR and 3SLS. Hence, GME estimation would allow the entire system of equations to be estimated concurrently instead of on an individual basis and less likely to experience econometric problems associated with limited data like traditional estimators used for structural equation modeling (Cook et al., 2015).

The GME estimator has been shown to outperform 3SLS in small samples when the technique is applied correctly (Cook et al., 2015). However, in large samples, both the 3SLS and GME estimator are equivalent when the GME technique is used appropriately. Thus, it can be inferred that the GME estimator should only be used to substitute the 3SLS estimator when micro numerosity is an issue because even in large samples, the GME estimator can be biased if the relevant support points are not chosen wisely (Cook et al., 2015).

Similarly, the use of GME to empirically model problems with limited data availability is attractive as data availability is a common problem in applied research. However, an important caveat tied to the GME estimative technique is that the model parameters will only be valid if the correct model support points are chosen, which is often much easier said than done (Cook et al., 2015).

Generally, the process of estimating structural equations using GME is straightforward in terms of intuition. Support points are imposed on the model, constraining model parameters' estimates to be reasonable in their distributions. Thus, valid parameter estimates for the linear SEM can be obtained without the need for medium to large samples (Cook et al., 2015).

These support points help to predetermine certain features of the actual model, which gives the estimative algorithm an idea of how specific model mechanics ought to function before any estimation has taken place. This allows some predictions to be discounted while others are brought to greater prominence based on prespecified information (Cook et al., 2015).

This, in turn, reduces the sensitivity of the GME estimator to outliers and random sampling error. The process of selecting which support points to use is subjective. Generally, this process is based on the use of Monte-Carlo experiments, findings from past research, and any intuitive insights derived from the underlying economic theory of the model in question (Cook et al., 2015)

Moreover, my final recommendation is to consider using the elasticities estimated by the OLS and 2SLS regressions used in this research for purpose as support points in an empirical estimation of India's ethanol market in the future. The GME technique can use these support points to circumvent the small sample issues that limited this research while also providing initial values that can assist the optimizing algorithm in its approximation of the relevant estimator distributions needed to produce a robust linear SEM model in future research (Cook et al., 2015). The applications of such a model to India's ethanol market would be of significant worth to many agricultural companies that both produce and export ethanol abroad.

REFERENCES

Aradhey, Amit. 2019. "India Biofuels Annual" United States Department of Agriculture Foreign Agriculture Service, Global Information Network Report # IN9069, 1-25.

Aradhey, Amit. 2018. "India Biofuels Annual" United States Department of Agriculture Foreign Agriculture Service, Global Information Network Report # IN8085, 1-26.

Aradhey, Amit. 2017. "India Biofuels Annual" United States Department of Agriculture Foreign Agriculture Service, Global Information Network Report # IN7075, 1-30.

Aradhey, Amit. 2016. "India Biofuels Annual" United States Department of Agriculture Foreign Agriculture Service, Global Information Network Report # IN6088, 1-29.

Aradhey, Amit. 2015. "India Biofuels Annual" United States Department of Agriculture Foreign Agriculture Service, Global Information Network Report # IN5079, 1-23.

Aradhey, Amit. 2014. "India Biofuels Annual" United States Department of Agriculture Foreign Agriculture Service, Global Information Network Report # IN4055, 1-21.

Aradhey, Amit. 2013. "India Biofuels Annual" United States Department of Agriculture Foreign Agriculture Service, Global Information Network Report # IN3073, 1-18.

Aradhey, Amit. 2012. "India Biofuels Annual" United States Department of Agriculture Foreign Agriculture Service, Global Information Network Report # IN2081, 1-16.

Aradhey, Amit. 2011. "India Biofuels Annual" United States Department of Agriculture Foreign Agriculture Service, Global Information Network Report # IN1159, 1-14.

Aradhey, Amit. 2010. "India Biofuels Annual" United States Department of Agriculture Foreign Agriculture Service, Global Information Network Report # IN1058, 1-11.

Aradhey, Amit. 2019. "India Sugar Annual" United States Department of Agriculture Foreign Agriculture Service, Global Information Network Report # IN9067, 1-12.

Aradhey, Amit. 2018. "India Sugar Annual" United States Department of Agriculture Foreign Agriculture Service, Global Information Network Report # IN8047,1-12.

Aradhey, Amit. 2017. "India Sugar Annual" United States Department of Agriculture Foreign Agriculture Service, Global Information Network Report # IN7045, 1-12.

Aradhey, Amit. 2016. "India Sugar Annual" United States Department of Agriculture Foreign Agriculture Service, Global Information Network Report # IN6057, 1-12.

Aradhey, Amit. 2015. "India Sugar Annual" United States Department of Agriculture Foreign Agriculture Service, Global Information Network Report # IN5050, 1-12.

Aradhey, Amit. 2014. "India Sugar Annual" United States Department of Agriculture Foreign Agriculture Service, Global Information Network Report # IN4029, 1-13.

Aradhey, Amit. 2013. "India Sugar Annual" United States Department of Agriculture Foreign Agriculture Service, Global Information Network Report # IN3040, 1-13.

Aradhey, Amit. 2012. "India Sugar Annual" United States Department of Agriculture Foreign Agriculture Service, Global Information Network Report # IN2058, 1-12.

Aradhey, Amit. 2011. "India Sugar Annual" United States Department of Agriculture Foreign Agriculture Service, Global Information Network Report # IN1137, 1-12.

Aradhey, Amit. 2010. "India Sugar Annual" United States Department of Agriculture Foreign Agriculture Service, Global Information Network Report # IN1033, 1-11.

Cook, Larry., Philip Harslet. 2015. "An Introduction to Entropy Estimation of Parameters in Economic Models" 18th Annual Conference on Global Economic Analysis, Melbourne, 1-46.

Gulati, A., and T. Kelley. 1999. Trade Liberalization and Indian Agriculture" Oxford University Press, New Delhi, 722-734.

Mino, Alexander. 2010. "Ethanol Production from Sugarcane in India: Viability, Constrains, And Implications" the University of Illinois at Urbana – Champaign, Master's Thesis, 1-142.

Russell, Andrew. 1998. "Small and Medium Scale Sugar Processing Technology," Practical Action formerly ITDG, Bangladesh, 1-14.

Ray, Saon., Smita Miglani, Amrita Goldar. 2011. "Ethanol Blending Policy in India: Demand and Supply Issues" ICRIER Policy Series, no. 9, 1-31.

Ray, Saon., Smita Miglani, Amrita Goldar. 2011." Issues Related to Pricing," ICRIER Policy Series, no. 10, 1-34.

Zsohar, Peter. 2012. "Short Introduction to The Generalized Method of Moments" Hungarian Statistical Review, Special Number 16, 1-21.